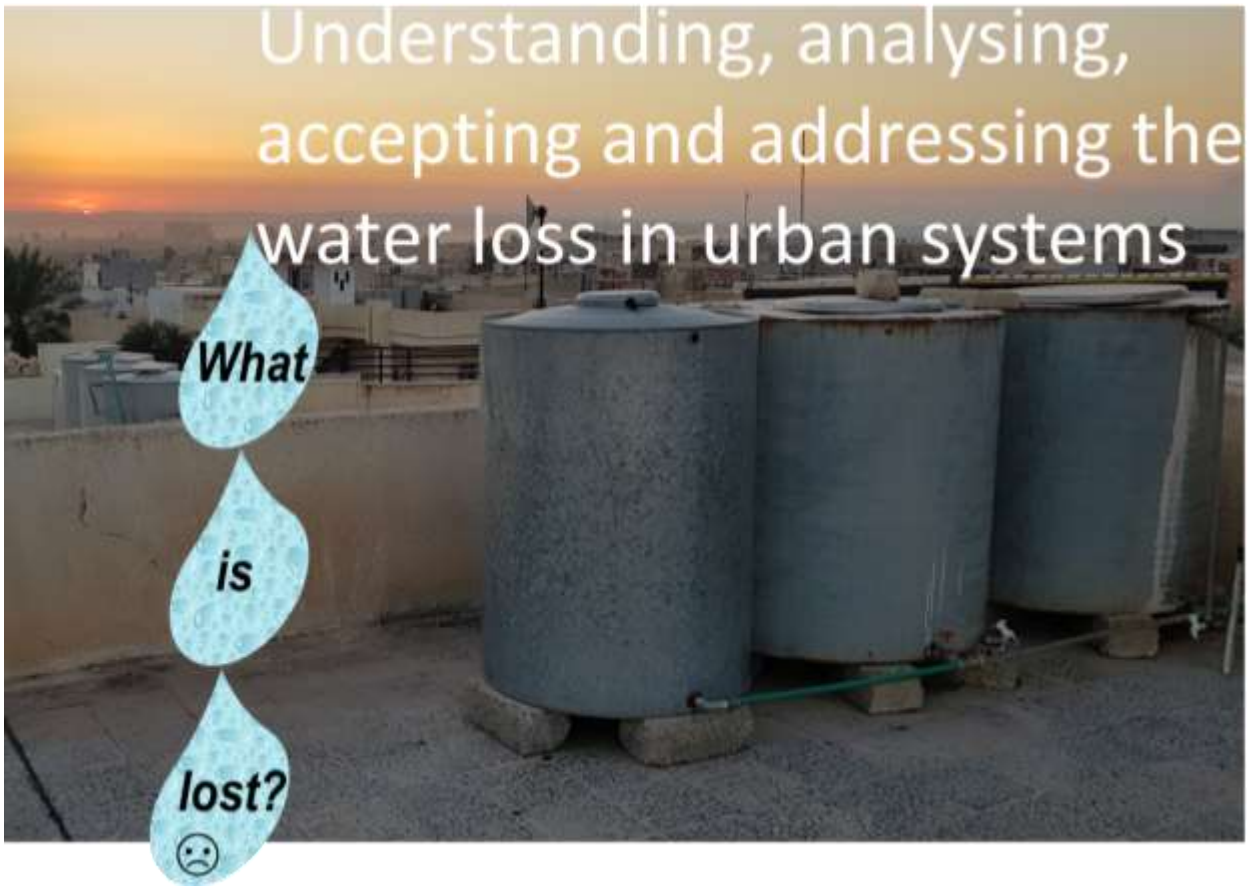

GIZ training Series: Training of trainer's guidance literature for municipal water supply engineers and managers

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Executive summary

What is lost in an urban water system? The answer is obvious when you look at what flows in and out of these urban water networks, it is water. Some might say money and some might say energy. Yes, this is true but is not the whole truth. This training is about finding out what is lost from an urban water system by looking beyond water and looking in the urban systems to track the lost water and the other elements that are being lost. The training touches upon the three prime movers of the urban water utility, namely engineering, management and strategic planning. Place, proportion and play of these trinity in an urban water utility can be ascertained only by a thorough understanding of the urban system that is served by the water utility. This can shed light on what are actually gained and lost through urban water systems.

We the engineers and managers of urban water utility are trained to ascertain the problem, quantify the impact, find out why it happened and devise ways to minimise or eliminate the problem. Quantification has always been the guiding principle, the means and the end in this endeavour. The water balance methods in their original or modified form used all over the world follow this logic and has proved to be a success in estimating the quantity of non-revenue water and formulating actions to reduce the losses in terms of water and revenue. The training starts by introducing the conventional water loss assessment methods to the urban water engineers and managers; the various elements of a water distribution system comprising physical, conceptual and design aspects; and, water loss management measures. Understanding and analysing these engineering aspects of the water supply system would create a comfort zone from where the engineer can start the process of identifying and minimising losses.

Managing the water losses and reducing the risks in the urban system are the outcomes of water system understanding. Understanding the systems leads to identification of various risks based on impacts and probability of failure. The participants will learn the basics of risk management, resulting in prioritisation of assets that subsequently leads to asset management of urban water system and water loss reduction. Certain losses are inevitable from an urban water system and has to be accepted. This acceptance can only happen when the interplay of elements in the urban systems is understood through social, political and economic perspectives and by looking at the urban water systems from various urban water stakeholders' point of view.

An urban water strategist understands and embraces the socio-political turbulence that is omnipresent in the urban system and makes use of it to manage the losses. Such an understanding of the urban system and urban water system can be achieved through systems of thinking, essential for strategic planning. Systems thinking will enable the participants to understand the characteristics of urban systems; the traps and opportunities in the urban systems; and, the identification of the systems levers for change to reduce losses from the systems, not just the water loss. The participant will learn that is not just water that is lost from the urban systems and will understand the other elements that are flowing through the pipes and more importantly start exploring why are these losses happening before starting to quantifying them.

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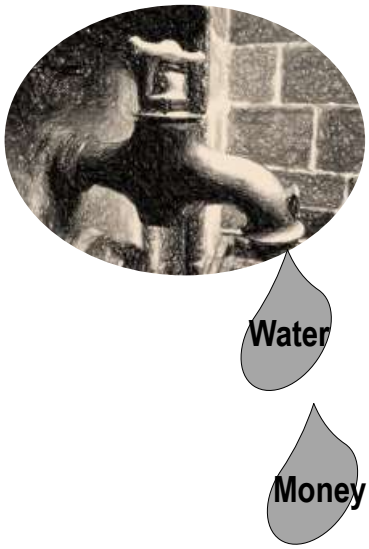
1. What is lost from urban water systems?

Water loss in urban water systems is a widely discussed and debated topic among engineers, economists as well as among policy makers who deal with urban service provisions. The approach and discourse towards addressing water loss has been predominately on reducing the loss of water from the pipes (physical loss) and the loss of revenue (apparent loss), commonly known as non-revenue water reduction programs by the urban water management authorities. Widely acknowledged water Knowledge hubs such as International Water Association (IWA) also advocate a resource efficiency-based perspective that calls for a techno centric approach to prevent water losses and to consider water as an economic good to minimise the revenue loss. The prevalence or dominance of engineering, economics or engineering economic approaches in dealing with water loss is not surprising. This is also evident through the recommendations of Performance Based Contracts (PBCs), from agencies such as world bank, as an effective approach to reduce the non-revenue water. Hence, from this perspective what is lost is water and revenue.



1.1 Brief history of water loss reduction in India

The terminologies such as leak detection, unaccounted for water and non-revenue for water is not new in India. The awareness about water loss and the need to manage the same has been in vogue at least in the last four decades. One of the Indian water works association (IWWA) conference papers in 1987 (D.N Young, 1987) on rehabilitation of water distribution systems discusses about leakage and emphasises that leakage is not a separate issue and it has be considered together with broader strategies like system rehabilitation and system management. In the same conference, based on the experience in Philippines PPA Jose (1987), puts forth the argument that the leaks are due to old service connection, lack of funds for repair and lack of capacity , which leads to high cost of production and undue operation and maintenance expenditure. The desire in those times was to connect the water system to a computer based data acquisition system to build an accurate data base with the modern equipment to acquire data such as pressure, flows, pump & valve status, energy flow and

water storage (D.B. Field et, al, 1987). This desire still persists in spite of advancements made in installation of supervisory control and data acquisition (SCADA) systems. Water lost from urban water systems in South Asia was pegged at 40% in 1980's (C.G. Chandler, 1987), remained at the same level in in 2010's (World bank ,2011) and has not changed even in the year 2020, as evident from the figures from Ministry of Urban and housing affairs Service level bench mark performance data (Wateraid, 2018). Although leakage control is recognised as a symptomatic cure and not the systemic cure, the emphasis has been always on leakage control necessitating accurate measurement of leaks and realistic costing of water lost. The emphasis on reducing physical leaks, non-physical leaks as well as cost recovery has been suggested to improve the performance of urban water systems (J. Richardson, 1987). The need for consideration of local factors, training and funding have always been suggested in addition to equipment, technology and procedure in the last four decades of talk about leak reduction in India. Also among those vintage discussions, one can notice the suggestion for different solutions, i.e. differential levels of service, for different areas of the same city that are driven by innovation, flexibility and commitment to progressive development based on equity and equal opportunity for all the urban residents (M.Seager, 1987). Any successful nonrevenue water management program will need to address technical issues within the overall institutional, organisational, and managerial environment, if it is to remain sustainable in the long run (Water and sanitation program, 2008). The aforementioned suggestion for sustainability, now reiterated also through the Sustainable development goals (SDG) perspective, has remained in the air and has been echoing for the last 40+ years but has eluded the practice on ground in the Indian urban water context.

1.2 About this course

This Tailor-made training course on water loss in urban water systems adopts an comprehensive approach to understand and apply water loss reduction techniques with the objective of contributing to multiple Sustainable development goals by reducing water loss in

urban water systems . The water loss, audit, reduction methods form the core of this course, which is similar to the 100's of courses on Non-Revenue water available with water utilities across the world. The unique salient point of this course is the approach towards this engineering core using the help of systems thinking that will enable the municipal engineers to understand the urban systems and urban water systems from a different perspective. This will enable our municipal engineers to plan, design and implement the engineering and management activities that would not only address the revenue aspects of water loss, but also the sustainability aspects of urban water systems, which we all aspire to achieve.

1.2.1 Learning objectives

The key objectives of the training course are

- To establish a common understanding of definitions, concepts and current approaches in NRW – commercial and physical losses
- To enhance knowledge on developing district meter areas (DMAs) to manage losses, pressure management, water quality
- To provide knowledge on water balancing quantification methods and water audit
- To develop individual / group strategies and work plans to implement NRW Management approaches
- To provide understanding of NRW reduction program from a urban utility management and urban systems perspective

1.2.2 Course highlights

The highlights of the course of the course are

(i) compilation of latest information on water audit, water loss reduction methods and techniques together with asset management of water infrastructure;

(ii) introduction to a software selection matrix to identify the appropriate open ware NRW software from a suite of 11 software packages to their context that can help in carrying out NRW assessment or NRW reduction planning & intervention or NRW monitoring & benchmarking;

(iii) use of systems thinking to understand water loss in urban water systems to frame comprehensive water loss management and asset management plans.

1.2.3 Course structure

The course is structed based on lectures and capacity building exercises that are prevalent in premier capacity building institutions on water education like IHE Delft, where the learners are exposed to multiple perspectives to understand and analyse a concept or a context. This course is structed in a way so that it not only enables the engineers to learn and apply the techniques but also critically assess them from the perspectives of a city administrator to an end user. The course is structed into the following four modules (Chapters 2, 3, 4 and 5):

- ✓ *Module 1: Understanding water loss methods and instruments*
- ✓ *Module 2: Introduction to urban water distribution*
- ✓ *Module 3: Asset management of urban water systems*
- ✓ *Module 4: Systems thinking*

What is being offered?	**Module 1** ***Understanding water loss methods and instruments***	**Module 2** ***Introduction to urban water distribution***	**Module 3** ***Asset management of urban water systems***	**Module 5** ***Systems thinking***
Objective	• Be able to apply the various water loss methods in the local context	• Be able to refresh and contextualise the hydraulics, demand and O&M aspects of water distribution system.	• Be able to identify the various components of asset management and apply risk-based asset management in their local context	• Synthesise the concept of systems thinking and be able to analyse the urban water system based in systems thinking
Brief contents	✓ Introduction to non-revenue water ✓ District metered areas ✓ Water balance ✓ Organisational management ✓ Commercial management ✓ Leak detection methods and instruments ✓ NRW software selection matrix ✓ Performance indicators in water loss management ✓ Steps for preparation of action plan for water loss management	✓ Water transport and distribution systems ✓ Water demand ✓ Steady flows in pressurised networks ✓ Design of water transport and distribution systems ✓ Network construction ✓ Operation and maintenance ✓ Hands on exercise on EPANET	✓ Asset management basics (✓ Risk based prioritisation of assets ✓ Risk based asset prioritisation software tool	✓ What is system thinking? ✓ What constitutes a system? (Urban water system) ✓ Why systems surprise us? ✓ What are the system traps and opportunities in an urban water system? ✓ What are the leverage points in a system?
Who is it for?	○ Section, Division and Circle Engineers and Managers	○ Section and Division Engineers and Managers	○ Section, Division and Circle Engineers and Managers	○ Section, Division, Circle and Zonal Engineers and Managers
Didactic	▪ Self-learning ▪ Content in training manual ▪ Powerpoint presentations ▪ Face to face or live lecturers ▪ Open courseware learning platform ▪ Individual reflection exercises ▪ Group reflection exercises	▪ Self-learning ▪ Face to face or live lecturers ▪ Open courseware learning platform ▪ Individual reflection exercises ▪ Hands on software training	▪ Self-learning ▪ Powerpoint presentations ▪ Face to face or live lecturers ▪ Open courseware learning platform ▪ Individual reflection exercises ▪ Group reflection exercises ▪ Hands on software training	▪ Self-learning ▪ Exclusive content in the training manual ▪ Face to face or live lecturers ▪ You tube videos ▪ Individual reflection exercises ▪ Group reflection exercises

Chapters 6 and 7 of this guidance literature elaborates in details as to how one can put together the learning outcomes from these four modules can be put together in one's own water supply systems context to create utility specific water loss and asset management plans. These two chapters together deserserve to be the fifth module, but it is not presented as a module as it is difficult to master them individually in a self learning more as it requires plenty of group reflection and deliberation exercises to digest and apply the concepts to your local urban water system context. Detailed description of each module, specific objectives, module delivery and didactic tools are presented in the beginning of each module. These four modules can be self-taught or self- learnt. The learning will be effective when assisted by the process of self-reflection by comparing the concepts with your day to day work in the urban water systems you work through. Please do not be surprised at the drastic difference in the number of pages or thickness of the chapters when you print them. This ToT guidance literature is a hybrid of newly written text, existing text and presentations and videos from relevant knowledge sources in the worldwide web.

The module on understanding water loss using systems thinking was developed from the scratch based on "Thinking in Systems" by Donella Meadows; "Hydraulic City" by Nikhil Anand and from the experiences encountered by this author in various urban water systems in India and abroad. The next chapter which contains systems thinking concepts, narration and example, are the reading materials for this module. There are reflection exercises at end of every important concept, which would help you understand the relevance of the same in your local context. The other three modules have been curated from the vast online collection of IHE Delft Institute for Water Education's open courseware and capacity building projects on water loss and urban hydraulics.

The module " Understanding water loss methods and instruments" comprises the link to the webpages that contain the presentations about all the aspects of physical losses and apparent losses based on IWA approach. The module on urban water distribution will redirect you to a page that contains the pdf version of a very well written book on Urban drainage systems design by Prof. Nemanya Trifnovic from IHE Delft. The book is written in a simple and lucid manner that will help you brush up the basic hydraulics as wells how to design a comprehensive urban drainage network using EPANET. There is an additional reflection module on contextualising Asset management, which is a compilation of practical things that a municipal engineer should know about the changing contexts such as climate change and socio-economic changes. I have tried to explain that using some of the peer reviewed open access literature and tutorials available online. All these information will be made available through a dedicated webpage after interactions and feedback with you ' The trainers' later next year, so that it is easy for you to train your engineers.

1.2.3 Who is it for?

This course is suitable for municipal water supply engineers and managers across the wide spectrum of hierarchy in any municipal water supply authority. The first three modules have heavy engineering content and are recommended for engineers at section, division and circles levels, whereas the module on systems thinking is recommended for engineers, managers and administrative department staff

1.2.4 Course delivery

This course is designed in such a way that that any municipal water supply engineer with about 4 to 5 years of experience can self-learn it using the various didactic tools of this training. A minimum of 15 working days @ 8 hours per day is anticipated to master the contents in the self-learning mode. Engineers and managers with relatively lesser experience might require assistance in form of a peer to peer learning or face to face training sessions with the experts. A three-day crash course face to face learning - if the conditions are favourable for a gathering of up to 20 learners - is highly recommended, after which the learners can go on a self-learning mode for a week or two depending on their exposure, understanding of the subject and their local context.

1.2.5 Didactic tools available and required

The following learning tools are available through this training to enhance the learning:

- Self-learning
    - PowerPoint presentations from Open courseware learning platforms
    - Descriptive contents from this training manual
    - Technical articles on various aspects of water loss from peer reviewed journals
    - Individual reflection exercises
        - excel sheet calculations
        - narrating the local water loss as well as management context
        - role play
    - Hands on software training
- Face to face or live lecturers
- Pre-recorded lectures (a possibility)
- Group learning activities
    - reflection exercises in a classroom mode using flip charts and markers
        - excel sheet calculations
        - narrating the local water loss as well as management context
        - role play

        - peer review of each other's context
    - guided hands on software training

- ***Useful knowledge hubs with resources on water loss***

1. Boosting effective ness of water operator partnerships
2. IWA water loss specialist group
3. GIZ guidelines for water loss reduction
4. FAIR – Asset management of flood infrastructure
5. Worldbank repositories on water loss
6. Leaksuite
7. IWA network resources
8. Free online courses in IHE Delft
9. Water Loss Management: Tools and Methods for Developing Countries – PhD Thesis
10. A review of non revenue water assessment software tools – Journal Paper
11. Dr.Taha Al Washali's researchgate page with state of the art NRW literature
12. EPANET
13. Dr. Assela Pathrirana's wiki on Epanet and other useful information
14. NRW course for water service providers in Kenya

2. *Understanding water loss methods and instruments (Module 1)*

Understanding water loss through urban perspectives will broaden the understanding of our municipal engineers and will enable them to seek answers on why water is lost and work out sustainable actions addressing the core of the issue. However, the essential evil and the devil in the detail is the quantity of water lost for the water and revenue losses to be minimised.

2.1 About this module

This module all about numbers, inflows and outflows of water and revenue. We will learn about the prevalent definitions of non-revenue water and ways to minimise it. It is imperative to understand the hydraulic and economic factors leading to loss of water, means to detect these losses, methods to measure the leaks and the know how to reduce the leaks. Multilateral co-operation agencies such as World bank, Asian development; bilateral co-operations such as GIZ; professionals associations such as IWA; knowledge communities such as Leaksuite promoted by domain experts are overflowing with information about water loss. One can be easily lost in the vast ocean of literature on the theory and practice of leak management. There are plenty of professional forums such as Building Effective Water Operator Partnerships (BEWOP), Community of Practice (CoP) comprising water utility engineers, economists, governance specialists and researchers.

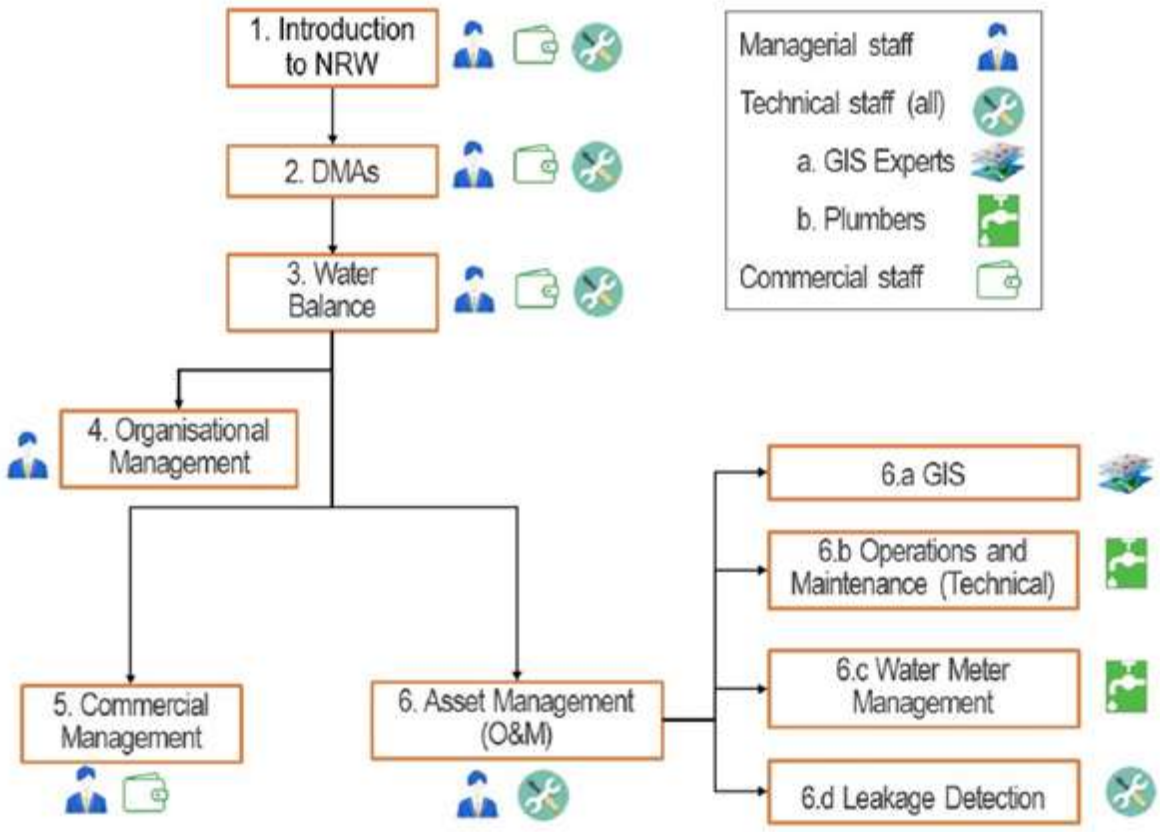
Learning objectives

Be able to apply the various water loss methods in the local context

Module structure

This module is borrowed from Building Effective Water Operator Partnerships (BEWOP), where the learning content on NRW water is categorised into six sections based on the

contents. The study materials are presented in six categories as presented in the following diagram. In order to facilitate learning and to guide the interested learners across departments of the water utility to quickly browse the water loss study material of their interest, each section is tagged with an icon denoting the relevance to Managerial staff, Engineer/ Technical staff and Commercial staff. This does not mean that the Section on "Operational management" is only meant for managerial staff. This section deals in depth about the managerial aspects related to water loss, which is relevant to all the personnel in the urban water utility. An engineer or GIS planning staff upon reading the "Organisational management" module will be able understand the perception about water loss from a managerial point of view in the water utility and vice versa. Summary of contents in each of this section is presented in the subsections below in this chapter to get a gist of this module. Section six on asset management is elaborated separately in Module 3 (Chapter 4). In addition to these six section in the BEWOP platform, an exclusive content on contextual selection of NRW software is presented as a section at the end of this chapter.



Module delivery & Didactic tools

- Self-learning with the help of content in this guide, links to free NRW software webpages, Journal papers and Building Effective Water Operator Partnerships (BEWOP) website
- Lectures either face to face or live online
- Reflection exercises
    - Individual and group reflection exercises
    - excel sheet calculations

- narrating the local water loss as well as management context

Sanaa's revenue gain story : *Researcher and Municipal Engineer Dr. Taha Al Washali from Sanaa Water Utility narrated the following incident. The water utility of Sanaa in Yemen was struggling to meeting the operational costs as it was dependent on the infusion of funds from international aid agencies, as the country is war-torn. The international agency insisted for uniform level of service to all the citizens of Sanaa, which is fair from a humanitarian perspective. The agency was running short of funds to purchase additional fuel to generate electricity to run the water treatment plants and pumping stations as the money from the international agencies were mainly used to pay the salaries of the staff. The managers were looking for a way to fix this gap. Sanaa's water districts were paying different water tariffs, the affluent districts playing more as their metered volumetric tariffs were higher compared to other districts. Dr. Taha suggested that supply to the affluent districts be increased to generate more revenue. This proposal was kept aside by the management as they feared resistance from international agencies, who would object to the difference in levels of service. Since Dr. Taha had friends in the GIS planning department and in the finance department, he sat together with them and prepared a map of Sanaa's water districts showing improved water supply and corresponding revenue generation figures, which would eventually lead to self-sufficiency in terms of funds. This impressed the managers and they agreed and the map was used in the consultations to convince the international humanitarian agency supporting Sanaa. It always helps to know how to handle a spanner in addition to mastering book-keeping or vice versa.*

A collection of materials comprising theory, case studies and exercises on the basics of water loss, district metered areas (DMA), IWA water balance, Organisational management, commercial management and asset management is available at Building Effective Water Operator Partnerships (BEWOP) website. This compendium on water loss was developed by IHE Delft in collaboration with the Dutch Water utilities. It is highly recommended for the trainers and trainees to browse this website and learn about the water loss basics, as well as the apparent and Real loss management methods from this website.

Please click here or on the figure in "Module structure" to access the BEWOP learning platform. It would take about 20 hours for a municipal engineer in a self-learning mode to understand these topics. In addition to the contents in BEWOP learning platform, information curated by experts on water loss management can be obtained from the various water loss management resource hubs, some of which are mentioned below:

1. Boosting effective ness of water operator partnerships
2. IWA water loss specialist group
3. GIZ guidelines for water loss reduction
4. NRW course for water service providers in Kenya
5. Worldbank repositories on water loss
6. Leaksuite
7. IWA network resources

2.2 *Classical IWA approach on water loss*

<table>
<tr><td rowspan="8">System Input Volume</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 Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="6">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="4">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Metering Inaccuracies and Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to Point of Customer Metering</td></tr>
</table>

Standard IWA water balance

The IWA approach (Liemberger and Farley) is based on counting or measuring what is flowing in and out of the systems., i.e., the measurement of water, as well as the accumulation of revenue. The classical IWA approach on water loss considers water as an input or inflow into the urban, rural or industrial water supply system and divides it into streams that yield revenue (revenue water) and streams that does not yield revenue (non-revenue water). The performance of the water systems is assessed based on what can be measured through the system. Simple and straight forward, without any ambiguities. By adopting this water balance standard we will be able to classify and know how much water is consumed and how much of it is lost and state it out authoritatively . Whether metered or unmetered we will be able subclassify the quantity of that was consumed, for which revenue was generated and the quantity that was given away without income. We know how much water was produced and we know how much was consumed, hence the balance is the water lost. Perfect!

Of the lost water some of them might have leaked from transmission mains, storage tanks and leaked from the service connections, and these are called real losses. Some kind of operation and maintenance action can be taken to reduce or avoid these losses. So, we know how much water has been lost physically, the water consumed and what was put into the systems. These number should tally. But they usually don't!!! Apparently some more water is lost (Apparent loss) without the knowledge of the authority. Some meter reader might have made a mistake while reading the connection and the flow meters have error margins in measurement, that make them either overread or underread. All these correspond to some kind of human error or machine error which can be estimated to a fair degree of accuracy and can be called us "Metering inaccuracies and data handling errors". So, the number should tally now. No, they don't. Why? Because someone might be stealing water or we don't know

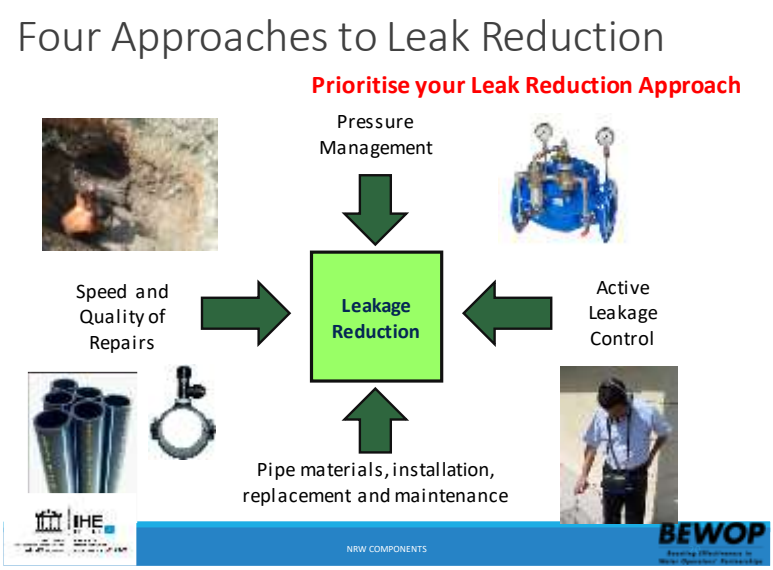
water is happening, which is called “unauthorised loss”. Since the balance sheet is based on water measurement and revenue collected & counted, it is easier to provide guidance to ascertain authorised consumption, address real losses, estimate metering inaccuracies and data handling errors. There are plenty of engineering, management and accounting procedures that can address all these challenges. However, according to IWA, it is difficult to provide general guidelines of how to estimate unauthorised consumption and is always deemed as a difficult task. *How do we then estimate the unauthorised losses?* IWA only suggests that estimation of unauthorised loss should be done in a transparent, component-based way so that the assumptions can later easily be reviewed. What cannot be measured now can be reviewed later! How and why to measure the unauthorised losses? No answers. May be seeking answers as to why the unauthorised losses are happening is not necessary to make the balance sheet, unless these losses are a deluge and not a trickle. In life what is not necessary is also not important most of the times. That which is out of sight is also out of mind. When there is so much to do, especially for a municipal engineer like you, who has the time to seek why unauthorised losses are happening.

The exciting thing about the IWA approach is that most water utilities around the world acknowledge it and use it as a best practice to ascertain the water balance, classify the streams and take action to reduce the losses. This also helps in documenting and sharing of best practices among the peers in controlling the leaks in the respective streams. Further the percentage of water lost or the non-revenue water, expressed in terms of percentage of water produced by the utility, is used as a bench marking tool to assess or compare the performance of utilities across the country or worldwide. One of the comprehensive benchmarking or performance indicator that is widely used is the Infrastructure leakage index (ILI). The Infrastructure Leakage Index (ILI) measures how effectively a utility or water service provider is managing its distribution network for controlling real losses at current operating pressure levels (Alegre et. al, 2006). However, this does not imply that pressure management is optimal, and it may be possible to reduce the volume of real losses (but not the Infrastructure Leakage Index) by improved active pressure management. It is a measure of how well repairs, pipelines and asset management and active leakage control are controlled. We will study about ILI in detail in the chapter 3, that elaborates more on the engineering aspects. Plenty of advancements have been made with respect to the technology and methods with respect to the prevention, detection, measurement and reduction of leaks. According to Liemberger (2016), though every loss reduction strategy is different, they all answer the following questions: HOW MUCH water is lost? WHERE is the water lost? WHY is it lost? WHAT needs to be done? HOW to make water loss reduction sustainable? Also Liemberger (2016) is of the view that if these five questions can be answered we will know everything and just have to write our water loss reduction strategy. May be.

The following sections briefly explains the contents of the NRW sub modules and the hands on exercise for the learners to familiarise with the concepts.

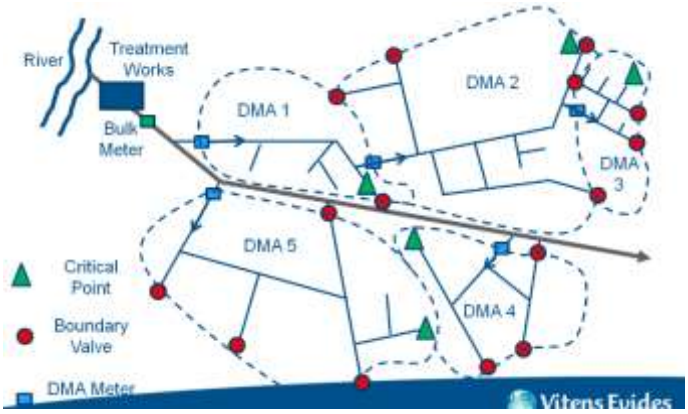
2.3 *Introduction to NRW*

This section comprises a presentation which introduces the basics of (a)NRW; (b) components of NRW; (c) approaches taken to reduce NRW; and, (d) the common indices used to represent NRW. Also the participants can enhance their understanding of the NRW by practising the assignments. Also upon successfully understanding the basics of NRW the participants will be able to assess their water utility using the NRW self assessment matrix. [Click here to upload the webpage containing the presentation and exercises.]

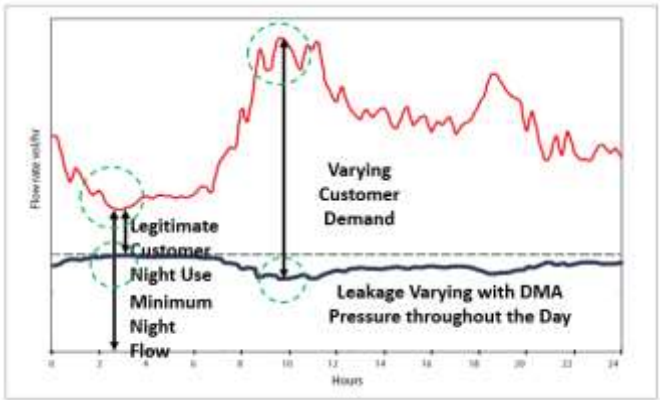


2.4 *District Metered Areas*

This part of the training will enable the participants to understand the concept of DMA, how to create DMA's , the role of DMA's in NRW management and Caretaker approach in DMA's. By creating DMAs as NRW reduction/management pilot areas, NRW can be analysed in more detail and the effect of NRW reduction measures monitored. [Click here to upload the webpage containing the presentation and exercises.]



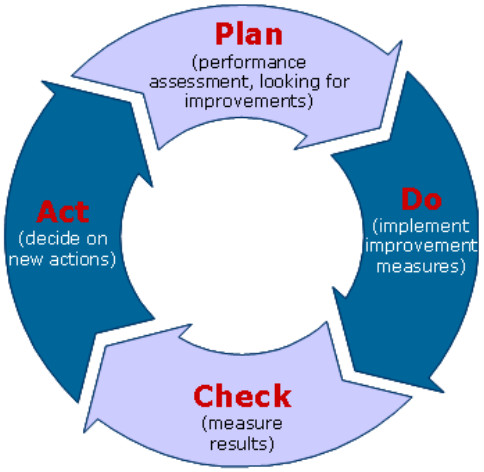
2.5 Water Balance



In order to understand NRW quantitatively and qualitatively is essential to know about Water balance as to how much water is supplied and where it ends up. This section highlights the various ways in water is consumed and invoiced. This understanding will enable the participant to distinguish between various types of consumption and losses. [Click here to upload the webpage containing the presentation and exercises.]

2.6 *Organisational Management*

Understanding the organisational setup and setting up the NRW task team are the first organisational steps towards NRW reduction. This module will enable the participant to do so. Further upon understanding this module the participant will be able to come up with Key performance Indicators (KPI), monitoring of KPI's, Plan-do- check- act cycle and create a multi year NRW strategy.



Click here to upload the webpage containing the presentation and exercises.

2.7 *Commercial management*

This sections elaborates in detail on the issues related to commercial management such as unbilled consumptions, meter reading errors, accounting errors and important administrative components. Upon completing the assignments the participants (managerial and commercial staff) will be able to analyse the commercial management of NRW components in their respective water companies. Click here to upload the webpage containing the presentation and exercises.

The section comprises the following:

- Approach commercial management (Ppt)
- Exercise - house to house survey
- Exercise - billing analysis
- Exercise - billing analysis (excel)
- Exercise - standard operating procedure for billing
- Exercise - minimum requirements Customer Database
- Exercise - minimum requirements Customer Database (excel)

2.8 Asset management - O&M

This section gives an overall exposure of all the O& M activities to managerial staff and all the O&M staff from all disciplines. Such an overall exposure to these staffs is necessary so that there is a understanding and appreciation across various teams with the company. The curative and preventive approaches as well the customer relations with respect to O&M are dealt with in this section. In addition there also sector specific O&M training modules on:

- GIS,
- technical operation and maintenance,
- water meter management and
- leakage detection

Click here to upload the webpage containing the presentation and exercises.

2.9 Software tools for NRW

Several software tools are available that can assess the performance of nonrevenue water (NRW) in water distribution networks and plan for reduction measures. Some of these tools are freely available. The creation of these many tools and different versions of each individual tool indicates the promising future of NRW software development. This review comprises some freely available tools for water balance establishment, NRW performance assessment, and NRW reduction planning. Most of the tools have been developed to establish standard annual water balances and recommended performance indicators (PIs) for the entire network. Some tools have been developed to intervene and reduce the leakage in a district metered area. Key features increasingly being included in NRW software include uncertainty analysis, recognition of supply intermittency, and accommodation of a guidance matrix and benchmarks. Leakage assessment is fully recognized, and leakage reduction analyses are increasingly growing in the software tools. However, much less attention has been paid to assessing and options for reducing apparent losses. Although a comprehensive NRW management tool for monitoring, planning, and intervention is not currently available, developing a comprehensive tool is worth-while, in the form of one package or a kit of smaller tools. Toward this goal, this section provides insights and recommendations addressing topics of intermittency, normalization, multi-method assessment, planning for the reduction of apparent and real losses, and estimation of the economic level of water loss

2.9.1 Introduction to freely available tools

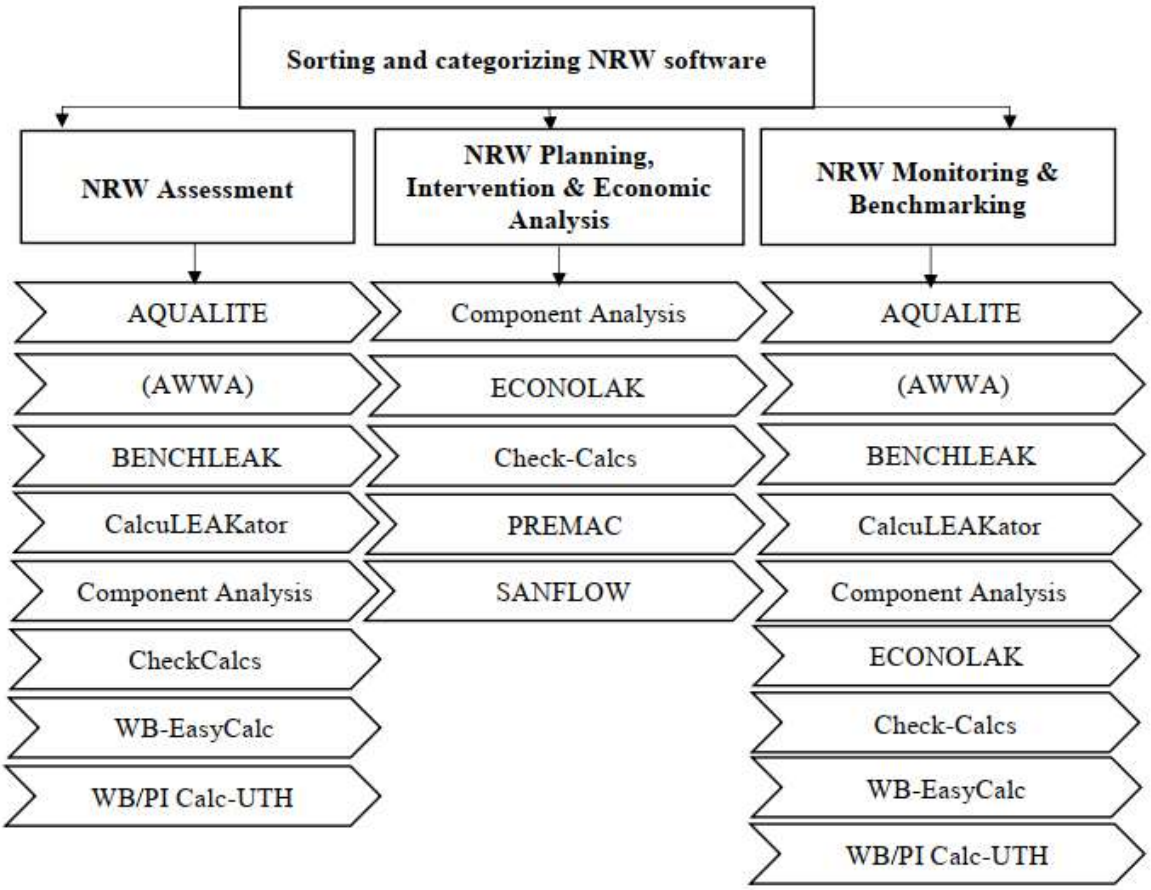
As mentioned earlier, a wide variety of NRW software tools are available. These tools can be broadly categorised into NRW assessment tool; NRW planning, intervention and economic analysis tools; and, NRW monitoring and bench marking tools. NRW assessment tools are used to calculate the various components and sub components of NRW in the top down

approaches such as IWA water balance or water and waste water balance approach; and in the bottom up approaches such as night flow method. The NRW planning, intervention and intervention tools are used to assess the effectiveness of pressure management; active leakage control, such as economic level of leakages, minimum total cost curve approach and economic intervention frequency approach; speed and quality of repair; and, pipeline asset management. The NRW monitoring and benchmarking software's assist in the computation of performance assessment of systems such as IWA's performance indicators which are about 170 in number across many disciplines. If you are interested in knowing more about these PI read Lambert (2015). The two well known IWA PI that can be computed using some of the NRW software are Unavoidable annual real losses (UARL) and Infrastructure leakage index (ILI). Some of the software tools are also used to normalise these performance indicators for intermittent water supply systems. A list of 11 NRW software tools and their salient features are presented in the table below:

Model name	Type	Purpose	Main outputs
Aqualite software	Windows-based Model	To calculate water balance based on top-down approach and the performance indicators for specific WDS	NRW Assessment, Operational Indicators, Financial Indicators
(AWWA) software	Excel-based Model	To calculate water balance based on top-down approach and the performance indicators for specific WDS	NRW Assessment, Operational Indicators, Financial Indicators
Benchleak software	Excel-based Model	To simplify the assessment of water balance and the KPI	NRW Assessment, Operational Indicators, Financial Indicators
CalcuLEAKator software	Excel-based Model	To calculate water balance based on bottom-up approach in accordance with IWA methodology and the performance indicators for specific WDS	NRW Assessment, Operational Indicators, Financial Indicators
Component Analysis software	Excel-based Model	To offer a comprehensive analysis tools. It includes economic leakage control intervention strategy evaluation, failure frequency analysis, leakage component analysis, and show the key water loss PIs	NRW Assessment, Operational Indicators, Financial Indicators ,Real loss Component Analysis, Evaluation of Location and Time Reduction, Economic Intervention, Frequency, Pressure Management Options

Model name	Type	Purpose	Main outputs
ECONOLEAK software	Excel-based Model	To recognize the factors that influence the active leakage control	Operational Indicators, Component Based Analysis, Economic leakage Level
Leaks-Check-Calc software	Excel-based Model	To estimate IWA WB and its components with performance indicators PIs	NRW Assessment, Operational Indicators, Financial Indicators, Pressure Management
Premac software	Windows-based Model	To manage the pressure in the WDS	Pressure assessment for each zones.
Sanflow software	Windows-based Model	To evaluate burst and background losses in water distribution systems based on bottom-up approach and BABE concept	Real Losses Component Analysis
WB Easy Calculator software	Excel-based Model	To estimate WB based on Top-down approach and analyze the performance indicators	NRW Assessment, Operational Indicators, Financial Indicators
WB PI-UTH software	Excel-based Model	To estimate the WB according to IWA first and second modification	NRW Assessment, Performance Indicators

Al washali et. Al, (2019) performed a detailed assessment of these 11 software tools and they have come up with a user classification of these tools which is presented in the figure below:



2.9.2 How to select the right tool?

2.9.2 How to select the right tool?

Upon in-depth analysis and evaluation of these eleven software tools Al washali et. Al, (2019) have also come up with a context specific selection criterion for this software for each of these three categories. The criteria levels recommended by Al washali et. Al, (2019) presented in the subsections below.

2.9.3 NRW assessment

Criteria levels for software took to be considered as an NRW assessment tool

SN	Criteria	Level	Characteristic
1	**Consideration of different methods of NRW assessment**	Full	• Tool integrates more than one method of NRW assessment
		Partial	• Tool considers only one method of NRW assessment
		None	• Tool does not consider any method of NRW assessment
2	**Consideration of the uncertainty analysis**	Full	• Tool considers the uncertainty analysis in all components of WB.
		Partial	• Tool considers the uncertainty analysis in the main components of WB.
		None	• Tool does not consider the uncertainty analysis in the WB.
3	**Level of detail in water supply assessment**	Full	• Tool considers all components in water supply assessment
		Partial	• Tool considers the main components in water supply assessment
		None	• Tool does not provide details in the assessment of the water supply
4	**Level of detail in apparent loss assessment**	Full	• Tool considers all sub-components in apparent loss assessment with options.
		Partial	• Tool considers the main sub- components in apparent loss assessment
		None	• Tool does not provide details in the assessment of the apparent loss
5	**Level of detail in real loss assessment**	Full	• Tool considers all sub-components in real loss assessment
		Partial	• Tool considers the main sub-components in real loss assessment
		None	• Tool does not provide details in the assessment of the real loss
6	**Level of consistency of the results**	Full	• Software has results consistent with the manually controlled spreadsheet including the confidence limits.
		Partial	• Software has results partially consistent with manually controlled spreadsheet.
		None	• Software has results not consistent with the manually controlled spreadsheet.

2.9.4 NRW Planning, intervention and economic analysis

Criteria levels for software took to be considered as an NRW Planning, intervention and economic analysis tool

SN	Criteria	Level	Characteristic
1	**Consideration of Pressure Management (PM) policy**	Full	• Tool considers the implementation of PM policy per each specific zone
		Partial	• Tool considers the implementation of PM policy for whole system
		None	• Tool does not consider any PM policy
2	**Consideration of ALC policy**	Full	• Tool considers the implementation of comprehensive ALC policy
		Partial	• Tool considers one method for implementing ALC policy.
		None	• Tool does not consider any ALC policy
3	**Level of detail in component based-analysis**	Full	• Tool analyzes the RL components with high level of details
		Partial	• Tool analyzes the RL components with partial level of details
		None	• Tool does not analyze the components of the RL
4	**Consideration of speed and quality of repairs policy**	Full	• Tool considers the implementation of speed and quality of repairs policy by analyzing the unreported/ reported losses in high level of details.
		Partial	• Tool considers the implementation of speed and quality of repairs policy by analyzing the unreported/ reported losses in low level of details.
		None	• Tool does not consider any speed and quality of repairs policy

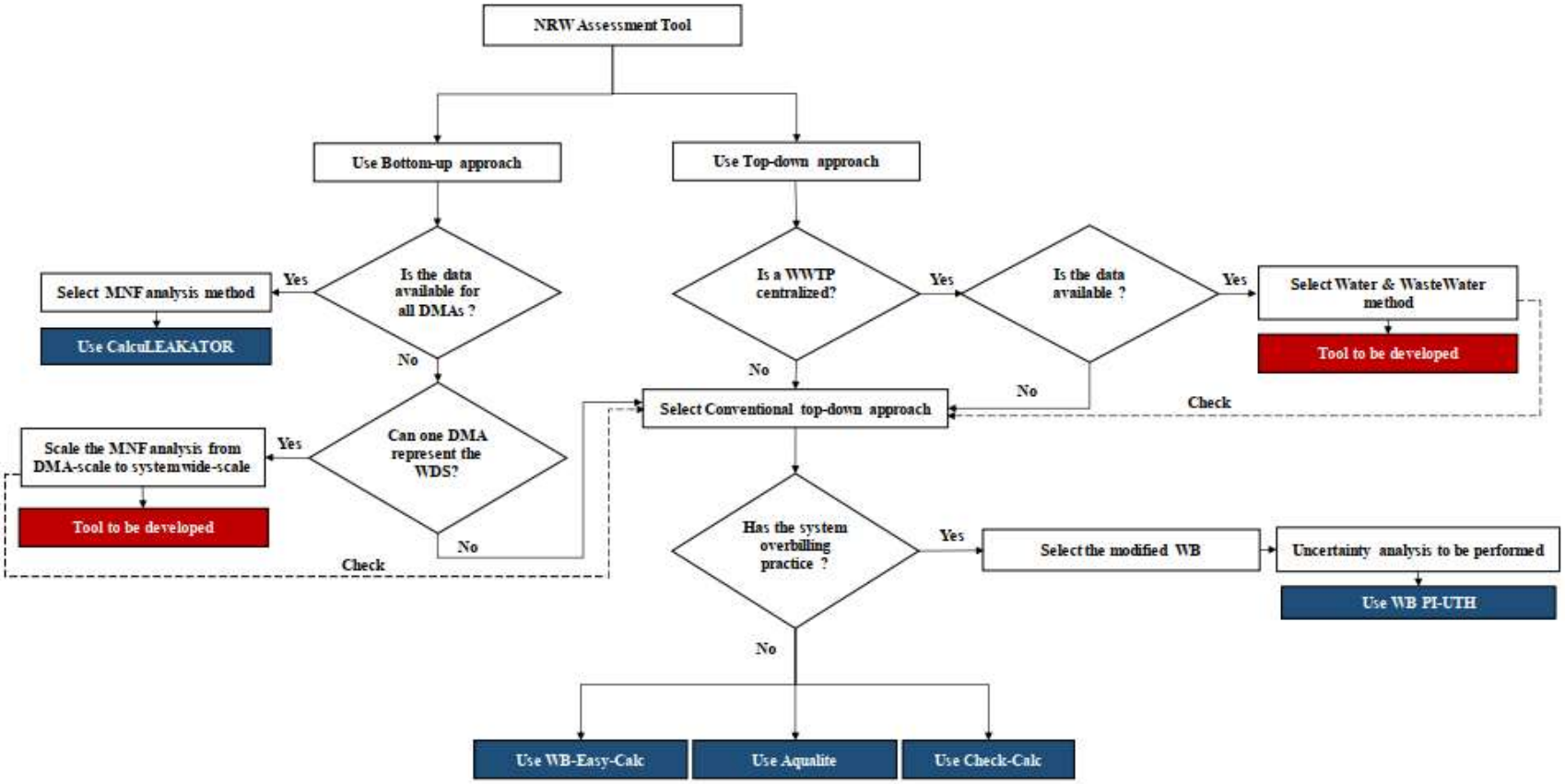
2.9.5 NRW monitoring and benchmarking

Criteria levels for software took to be considered as an NRW monitoring and benchmarking tool

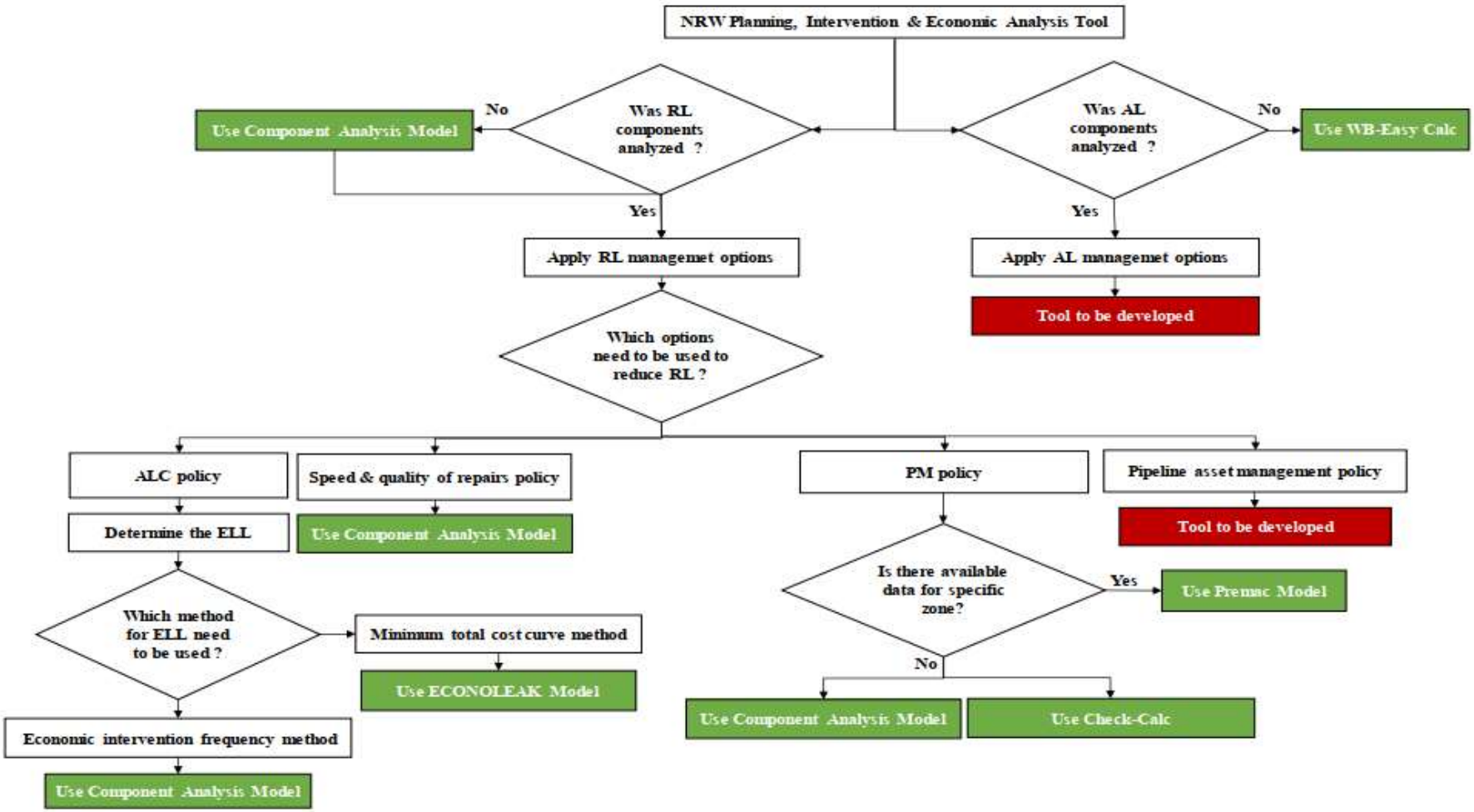
SN	Criteria	Level	Characteristic
1	**Level of detail in pressure assessment**	Full	• Tool considers the average pressure in each zone including the uncertainty analysis
		Partial	• Tool considers the overall average pressure including the uncertainty analysis
		None	• Tool does not provide details in the pressure assessment without uncertainty analysis
2	**Level of detail in supply time assessment**	Full	• Tool considers the supply time per hour for each zone.
		Partial	• Tool considers the supply time as percentage of time pressurized for whole system.
		None	• Tool does not consider the intermittent supply in the assessment.
3	**Consideration of uncertainty analysis in PIs assessment**	Full	• Tool provides uncertainty analysis for all PIs.
		Partial	• Tool covers the uncertainty analysis for only the main PIs.
		None	• Tool does not consider the uncertainty analysis for the PIs.
4	**Level of consistency of the results**	Full	• Tool has results consistent with the manually controlled spreadsheet including the confidence limits.
		Partial	• Tool has results partially consistent with manually controlled spreadsheet.
		None	• Tool has results not consistent with the manually controlled spreadsheet.

2.9.6 Guidance for selection of purpose specific NRW tool

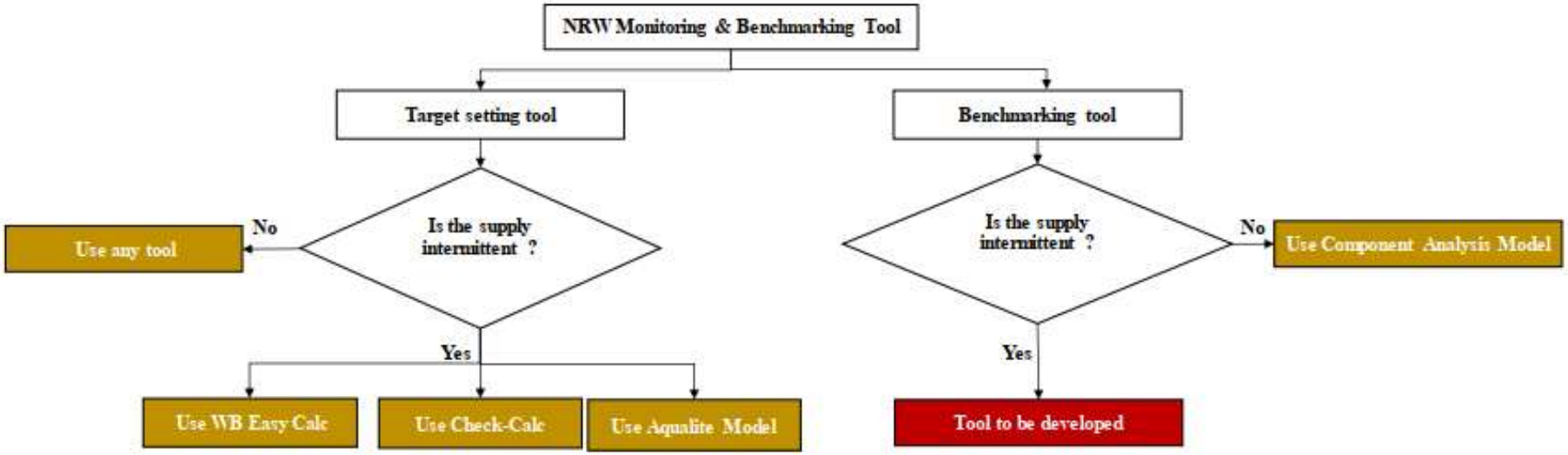
Al washali et. Al, (2019) developed a framework for incorporating the missing elements in the tools and also came up guidance flowcharts for the selection suitable tools for every context which are presented below:



Guideline for selection of the suitable NRW assessment tool



Guideline for selection of suitable NRW planning, intervention & economic analysis tool



Guideline for selection of suitable NRW monitoring and benchmarking tool

If you want to know more about the software tool selection for NRW read the journal paper by A review of non revenue water assessment software tools – Journal Paper.

Reflection exercises

- ***How do I apply the water balance method in my city? Top down or bottom up?***
- ***What are the hinderances towards calculation of water balance in my city?***
- ***What is the proportion of NRW in my system?***
- **Is apparent loss high or real losses high in my system? Explain**
- **Are unauthorised connections a problem in my system? What is the proportion? In what ways are these unauthorised connections occur? Why do these happen? Why on why's?**
- ***What is the Infrastructure Leakage Index for my system?***
- ***What are the actions that can be taken to reduce the water losses, both real losses and apparent losses in my system?***
- ***What is the order of prioritisation of these water losses reduction losses?***
- **Does the order of prioritisation vary depend upon who makes the assessment? Why?**
- **Which NRW software tool is useful / suitable to my context?**
- **What are the factors that hinder the planning or implementation of water loss reduction actions in my city?**

3 Introduction to urban water distribution (Module 2)

Pipes are the lifelines of urban water distribution systems. Pipes along with the reservoirs, pumps and values constitute the skeletal framework of the urban water systems. Understanding the rules governing the flow through the pipes, i.e., hydraulics, is essential to understand the behaviour of the system.

3.1 About this module

Understanding the hydraulics and hydraulic structure alone does suffice the understanding of the system. One needs to understand where is the water required, when is the when required and also variation in requirement of water, i.e., water demand. Understanding these two important technical domains will help in designing the water supply systems, construction and operation and maintenance of water supply systems.

Learning objectives

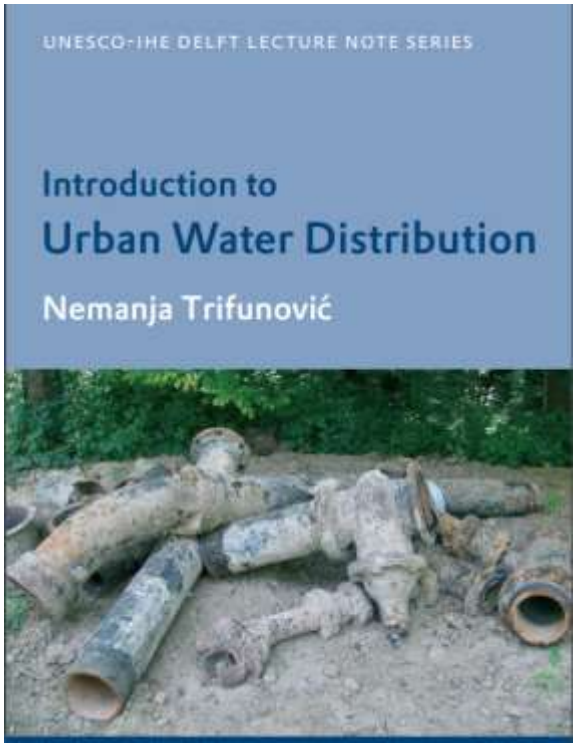
- Be able to refresh and contextualise the hydraulics, demand and O&M aspects of water distribution system.
- distinguish between different network configurations and supplying schemes; recognise various consumption categories and their growth patterns, including water leakage; define the relation between the main hydraulic parameters, namely the demands, pressures, velocities and hydraulic gradients;
- demonstrate understanding of the steady-state hydraulics for specified demand scenario, by being able to select appropriate pipe diameters, indicate optimum location of reservoirs and identify the number and size of the pumps used to supply the demand in the network;
- apply the above theoretical knowledge by learning to perform computer-aided hydraulic calculations and predict the consequences of demand growth on the hydraulic performance of particular water transport and distribution system;
- analyse the implications of various operational modes of pumping stations and compare the investment and operational costs for various network layouts and supplying schemes;
- propose preliminary hydraulic design of the network that will integrate economic aspects, choose adequate components and pipe materials, and judge technical solutions dealing with the network maintenance, rehabilitation, and expansion.

Module structure

As mentioned earlier, there are libraries and libraries or books and a life time of online tutorials available on these topics. It is not wise on our part to reinvent the wheels when someone has already crafted one to suit our needs. One such books is Introduction to urban water distribution by Dr. Nemanja Trifunovic, Associate Professor at IHE Delft. It is a very well written book and self-explanatory, that can be easily mastered by experienced Urban water engineers like you. There is a free online course on Water transport and distribution based on

this book. This module is a guide to the specific section of that course. The course is free but you have to create a login profile at the IHE OCW platform.

Module delivery & Didactic tools



- Self-learning with the help of on line Water transport and distribution course by Dr.Nemanja Trifunovic
- Lectures either face to face or live online
- Hands on software training - EPANET
- Reflection exercises
    - Individual and group reflection exercises
    - excel sheet calculations

It would take at least 35 to 40 hours for a municipal engineer to go through the online course and understand the exercises. There is no short cut. We can teach you the nuances of modelling in 2 hours, but it is practice that makes you a modeller. No amount of reading on driving or a couple of hours of demo can make you a good driver. But knowing the driving rules by heart helps. A quick dash through these chapters can be done in two or three hours during the online or face to face training sessions.

3.2 Water transport and distribution systems

This part deals with the:

- definitions and objectives of transport and distribution
- piping, storage and pumping;
- types of distribution schemes and network work configuration.

Click here to access this online course chapter or click on the picture.

3.3 Water demand

In addition to the terminologies this section elaborates on:

- the consumption categories detailing water use by various sectors,
- various demand patterns,
- demand calculation,
- demand forecasting and
- demand frequency distribution.

Click here to access this online course chapter or click on the picture.

3.4 Steady flows in pressurised networks

This section delves into the :

- conservation laws
- energy and hydraulic gradient lines
- hydraulic losses
- single pipe calculation
- serial and branched networks
- looped networks
- pressure related demand and
- hydraulics of storage and pumps

Click here to access this online course or click on the picture.

3.5 Design of water transport and distribution systems

This section elaborates on the planning phase; hydraulic design; computer models as design tools; hydraulic design of small pipes; engineering design. Engineering design is about the finer details of pipe materials, joints, fittings, valves, water meters, fire hydrants, service connections, indoor installations, storage and pumping stations, standardisation and quality assessment. Click here to access this online course or click on the picture above.

3.6 Network construction

This section elucidates the preparation of site, pipe laying and pipe jointing. Click here to access this online course or click on the picture below.

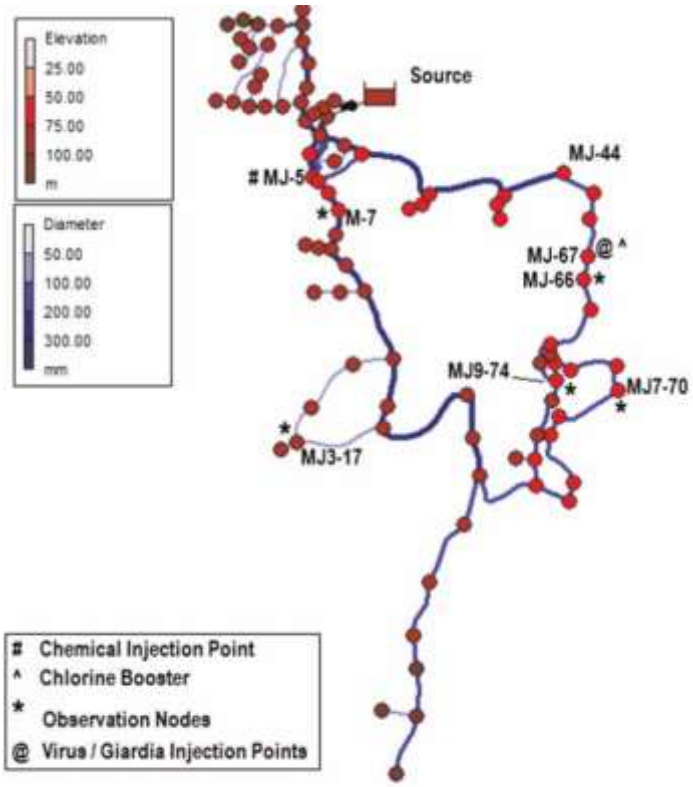
3.7 Operation and maintenance

The operation and maintenance chapter describes

- the critical aspects of network operation,
- network maintenance and
- network operation.

Click here to access this online course or click the picture.

3.8 EPANET tutorials



Minneriya water distribution network – Sri Lanka.

EPANET is a free to use, open ware versataile software used in the simulation of hydraulics and water quality parameter of water distribtion networks. The software and instruction manual can be found in the follwing link: Epanet turorial. There are number of add ons available for epanet either in form of graphical user interfaces or as source code to simulate pressure driven demand, complex water quality parameters ect.,

Hands on exercise on how to prepare data for Epanet, data input, schematisation of network, solving the hydraulics, trouble shooting and computation or water quality parameters such as residual chlorine will be demonstrated during the face to face lecture or during the live online interactive sessions.

Reflection activity

- *Practice the design exercise mentioned in Appendix 1, Appendix 2 and Appendix 5. Try to rework on these exercised based on your water supply system.*
- *Try to make a schematic version of your raw water pumping system or transmission system comprising gravity or pumping systems in Epanet.*

4 Asset management of urban water systems (Module 3)

As a common person when we think of the term “Asset” the first thing that comes into our mind are the possessions that we have such as house, agricultural land, housing plots, cash in hand, Jewellery, Stocks, mutual funds etc. In that context, we often think about asset management as a way of investment to increase the size of the asset or the value of assets. This is also the image that our bankers and investment mangers such as ICICI Bank or HDFC Bank or Kotak Mahindra creates in our mind. We see asset managers as someone one who can take care of our portfolio of investments and will maximise the returns from them also ensure the safety of our investments and assure the returns on our investments. The goal of our personal asset management is maximising returns on investments and minimising risk on investments using a set of principal assets.

4.1 About this module

We the Municipal Engineers are also asset managers. How does our asset management and the goal of our asset management differs from that of an investment banker? Our primary or principal asset is our urban water network comprising intake works, treatment plants, pipes, pumps, reservoirs, values and SCADA systems, office buildings, furniture, vehicles and stationaries associated with them. In addition to these principle assets we are also in charge of the capital , operation and maintenance expenditure that goes into the creation and sustenance of these assets. In the past and also at present in many context the management of these assets is primary based on the provision of water service to the urban citizens as mandated by the administrators or managers of the urban systems. Hence the essential asset management were mainly related to the maintenance of the asset to keep up the service or to restore the service when there is a breakdown. The management of the assets were mainly reaction in nature, fix what breakdown or fix what might breakdown. Many urban utilities have a taken a cue from industries such as Off shore oil drilling platforms and have adopted the risk-based asset management, which is a common practice in that field. Also, the common practice or the fast spreading practice among the water utilities is managing pressure to manage the condition of assets and to manage leaks. Maintaining the optimal pressure reduces the strain on the systems that helps the engineers to keep the systems in order which

in turn reduces the real losses. Maintaining the system in order also brings down the risk of failure.

Learning objectives

Be able to identify the various components of asset management and apply risk-based asset management in their local context

Module structure

This module is structured based on the introduction of risk based asset management and how to prioritise the network of assets based on consequence of failure and risk of failure. This module follows the approach taken in BEWOP where there is an introduction to the theory of risk based asset management, use of a software tool to carry out this assessment and guidelines to use this tool.

Module delivery & Didactic tools

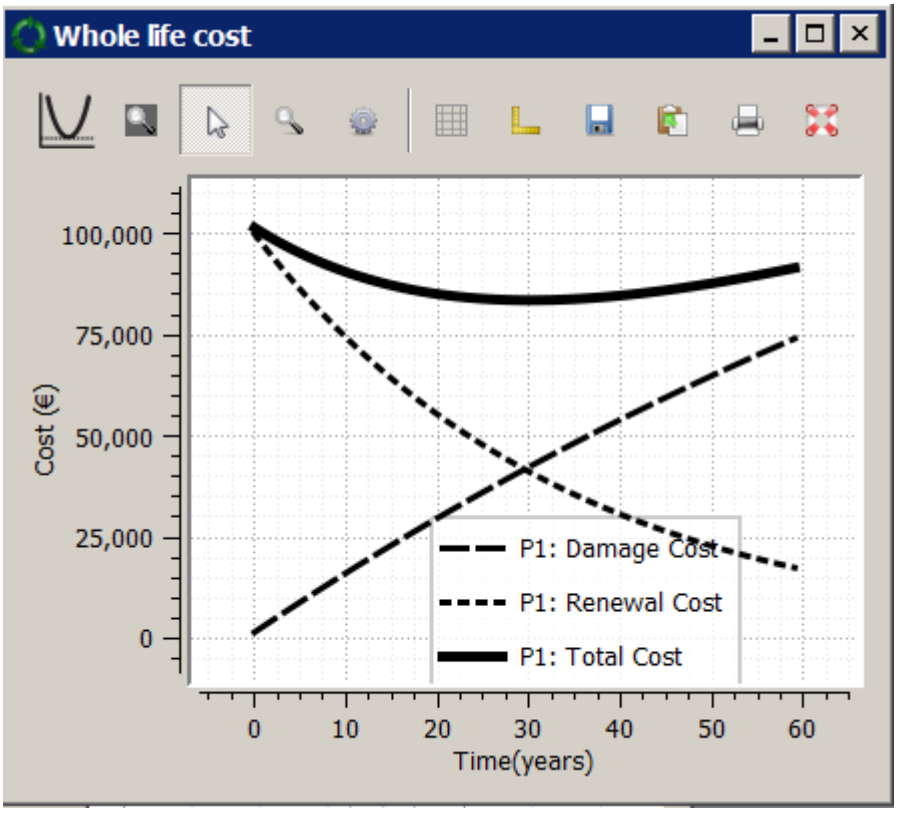
- Self-learning with the help of BEWOP learning platform on asset management
- Lectures either face to face or live online
- Hands on software training – Risk assessment tool
- Reflection exercises
    - Individual and group reflection exercises on localised networks or sample networks

4.2 Risk based asset management

What is risk-based asset management? Risk based asset management is a process that aims at minimising the risk of failure of the assets based on the probability of the failure of an asset and the consequence of the failure of the asset on the system objective or goal. The assets are categorised as a high risk or low risk assets based on the consequence of failure and probability of failure and actions such as repair, servicing, replacement or monitoring are planned accordingly. A old cast Iron transmission pipe from a vintage treatment plant to a commercial district, which bursts often is a high risk asset as disruption leads loss of revenue and knock on effects and hence repair teams are always kept on standby. A newly built over head concrete water storage reservoir is a low risk asset, where as a sabotage on water quality is a high-risk incident that cannot be ruled out, but is less likely to happen (low probability) and is kept under constant surveillance. Failure of bulk meter in a district metered area or a house service connection does not have major consequences though they might occur often can be classified a low risk asset. The categorisation of assets is not permanent as the condition of assets change with respect to time and purpose. A water main on MG Road might have been a high-risk asset as it was supplying water to the Government hospital last year, consequence of failure of supply to hospital being very high. The water main might have been labelled as low risk asset this year as the Government hospital was shifted to a newly built location.

4.3 Asset management software tool

Although risk based asset management works on the simple equation based on probability and consequence, innumerable assets in the urban water systems under the jurisdiction of Municipal engineer makes the categorisation a challenging task. There are tools that can help the Municipal engineers to perform the risk based categorisation of assets. One such tool is the Asset management software tool developed by Dr. Assela Pathirana of IHE Delft, that uses a EPANET model of a water supply network to carry out the risk categorisation of assets. The trainers are encouraged to go through the Asset management software tool in the BEWOP learning platform to learn the tool and apply it in their urban water systems. The module contains an introductory presentation, software and the tutorial. Click here.



Risk based asset management can help the municipal engineer to prioritise the assets in order to prevent or reduce failure of asset and failure of service, which can help in streamlining the operation and maintenance processes. Is the Operation and Maintenance budget at your disposal? Why plan it and use it only when something breaks down, that is to restore the service or restore the condition of the broken asset? Why not use it to make the condition of asset better than before? You are the Kings and Queens or the Lords or Dons of O&M budget and can use it in creatively to manage your asset. Why not think about of the box to fix a pipe when there is a break down, it that a problem or is that a opportunity to improve the pipe asset at the particular place? Expanding the boundary of your system in your mind and bringing in other perspective to analyse the context to plan the improvement of assets is necessary. What is that context? A context that not just analyses where the pipe is in the water systems and what affects the pipe, it's a contextual analysis of where the city is and what affects the city from across the world. Confusing, brace for impact!

Reflection activity:

- *Which assets do you think are at risk in your water supply system?*
- *What is the condition of these assets?*
- *Can you make a risk matrix comprising probability of failure and consequences of failure?*
- *Where do you your assets fall in this risk matrix?*
- *What are the type of actions that you would take to reduce this risk?*
- *Will this additional information on risk change the order of priority of procurement or implementation of projects aimed at improving the service levels of your water supply systems?*
- *Are these actions and the NRW actions that you have planned connected? Can you bring about a synergy between these actions?*
- *When you made the risk matrix did you consider only the physical assets and the physical conditions or did you also think about opportunities and threats? Explain*
- *What was the time horizon for your risk assessment? Explain why you choose that time frame.*

5 Systems thinking: looking beyond the engineering horizon (Module 4)

Do we know the answers to the five question on water loss really well, especially the "Why"? Not really. Maybe we might have to need a reordering of the questions and put "Why is water lost" first and emphasis it over "How Much?", i.e., shifting the emphasis from what can be measured to what is important.

Comprehensive understanding of water losses is necessary to plan and implement actions in urban water systems that are sustainable and meaningfully contribute towards sustainable development goals (SDGS). Currently, there is a lack of alterative thinking or approaches that comprehensively look at urban water loss from multiple perspectives. The answer or answers for why "unauthorised losses" are happening can be found out only through such diverse perspectives. There are everyday challenges arising out of the complex social and political realities in urban water context and the myriad ways with which the engineers, managers, as well the physical water supply systems itself handles these challenges. This interplay between the engineering – economics – social – political elements and objectives in the urban water systems kindles the understanding of the functioning and management of urban water systems from different points of view or perspectives. South Africa has a free basic provision of water and the IWA Water balance table was modified locally to suit this context (Kanakoudis and Tsitsifli, 2010). Also in context such as in Greece there is a minimum water connection charge that is level though the usage is less than the quantity on which the water tariff is levied and this can also be accounted for in a separate category as "Minimum charge difference" (Kanakoudis and Tsitsifli, 2010).

<table>
<tr><td rowspan="6">Annual System Input Volume</td><td rowspan="3">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption</td><td>Free Basic</td></tr>
<tr><td>Billed Unmetered Cconsumption</td><td>Recovered Revenue</td></tr>
<tr><td>Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td>Non-Recovered</td></tr>
<tr><td rowspan="3">Water Losses</td><td>Unbilled Unmetered Consumption</td><td rowspan="3">Non - Revenue Water</td></tr>
<tr><td rowspan="2">Apparent Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling Errors</td></tr>
<tr><td colspan="3">Real Losses</td></tr>
</table>

<table>
<tr><td rowspan="6">Annual System Input Volume</td><td rowspan="3">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption</td><td>Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td><td>Non-Recovered</td></tr>
<tr><td>Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="4">Non - Revenue Water</td></tr>
<tr><td rowspan="3">Water Losses</td><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="2">Apparent Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling Errors</td></tr>
<tr><td colspan="3">Real Losses</td><td>Minimum Charge difference</td></tr>
</table>

Context specific modification are not only necessary to arrive at a water and revenue balance but also to achieve the SDGS. SDGS cannot be achieved if we cannot find out why the unauthorised losses are happening. How can we address the challenge when we do not know why it happens? How can I pacify my angry friend when I don't know why my friend is angry, even though I know how much of anger my friend is possessed with by the words my friend uses or the things my friend break? IWA approach on water loss is a proven process for managing water loss from an engineering-economic perspective. IWA recommendation and methods are ideal for engineers working with a water supply utility or system, but are not comprehensive enough for engineers who are working through the water supply systems. Hence the pragmatic Indian UWS engineers needs to understand and think not only about urban water systems but about the urban systems as a whole in order to understand why these unauthorised leaks are happening. Such reasoning is necessary in addition to the IWA water loss formulas and performance indicators such as the the much-revered Infrastructure leakage Index (ILI) to assess the performance of urban water system.

5.1 What is in this module?

This module is about "thinking about thinking" exercise (one of the right ways to think right). This module introduces an urban water systems analysis process based on systems thinking that will enable our municipal engineers to understand the various aspects of water loss and contextualise the challenges as well as the outcomes.

My dear municipal engineers,

It is the your local (contextual) understanding of the urban system, which is based on the understanding of the ground reality, that enables you to operate and manage the urban water systems not just by meddling with the values but with your value judgement. From "Valves to Values" all that makes the difference is "U" (you). This value judgement is not only due to your rational thinking brain but also thinking with your heart. The invisible but the gradual course correction towards the right urban water system goals happens subconsciously as you operate through the systems, which is due to the slow but steady changing paradigm shift of urban water systems being conceived as socio-technical systems in your minds.

Learning objectives

Synthesise the concept of systems thinking and be able to analyse the urban water system based in systems thinking

Module structure

The module on understanding water loss using systems thinking was developed from the scratch based on "Thinking in Systems" by Donella Meadows; "Hydraulic City" by Nikhil Anand and from the experiences encountered by this author in various urban water systems in India and abroad. The next chapter which contains systems thinking concepts, narration and example, are the reading materials for this module. There are reflection exercises at end of

every important concept, which would help you understand the relevance of the same in your local context.

Module delivery & Didactic tools

- *Self-learning with the help of content in this guide and open online resources*
- *Lectures either face to face or live online*
  - *Work on case studies during lectures*
  - *Reflection exercises based on learners context*
  - *Revise the reflections exercises in Modules 1, 2 and 3 based on the learning outcomes from this module.*

5.2 Looking beyond the classical IWA approach on water loss?

Is ILI the right indicator or the best way to assess the performance of Indian urban water systems? Can achieving the recommended ILI enable any urban water authority in India to achieve the SDGs? Goals should be set only after a proper understanding of the systems. Understanding the urban water system means understanding the following: what is the system is made of; how does the system behave; why is the system exhibiting these behaviours; what are the traps and opportunities in the system; and, where can the system be influenced or changed. Also it requires a paradigmatic shift in understanding that the urban water systems are not technoeconomic systems but are socio-technical systems. The transformational change in mindset would enable engineers to analyse the indicators such as ILI from a critical urban systems perspective. Is it possible to incorporate the social components along with ILI come up with some kind of social infra structure leakage index? Why not? There are precedence such as triple bottom line benefit approaches put forth by American Water Works Association (AWWA) which considers economic, environmental and social cost-benefits to decide upon the rehabilitation and asset management of urban water supply systems. Processes from such precedence can be expanded and made comprehensive to cover all the aspects of urban water supply systems.

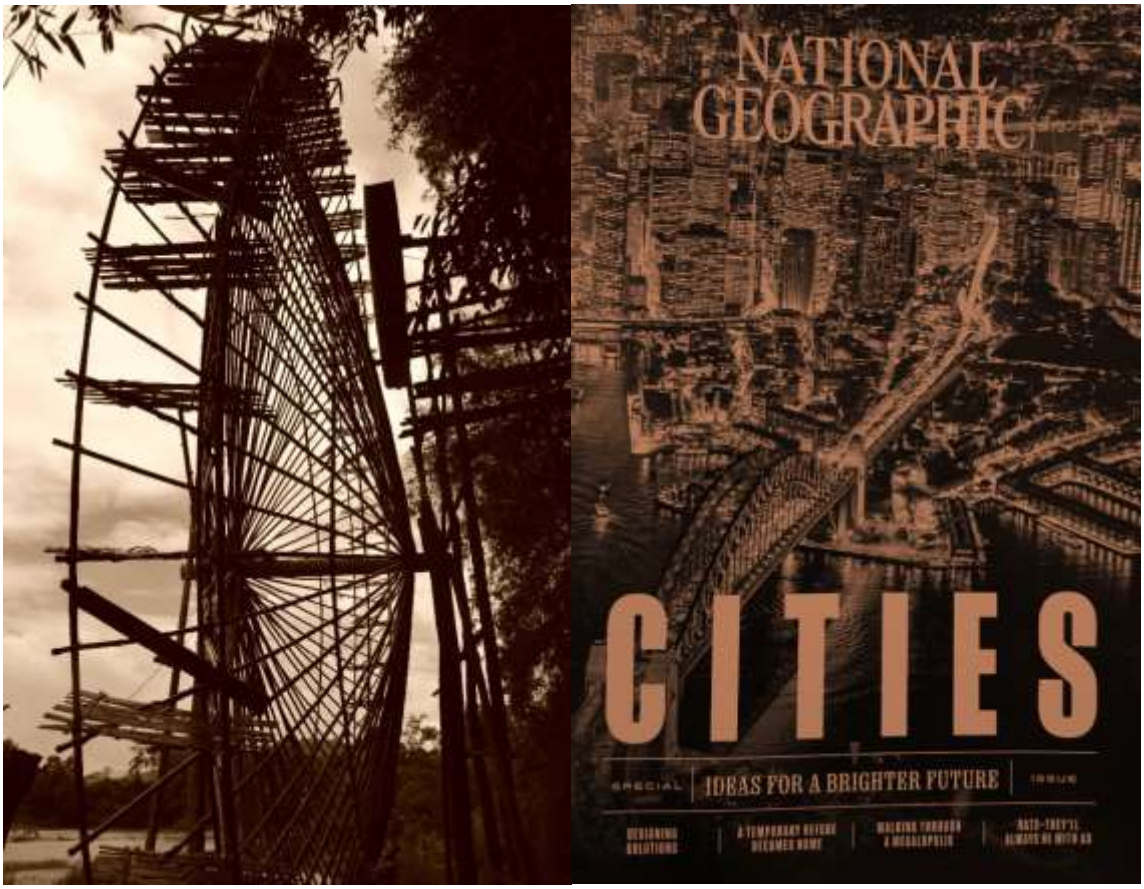
ILI is fine as long as engineers work on the urban water systems with a focus on techno-economic outcomes. However ILI becomes outdated or solves only the part of the problem as engineers work through the urban water systems that are a socio-economic- political-technical quagmire. Aren't leaks playing a role in reducing social friction and brining a truce among communities? Aren't engineers looking the other way or knowingly overlook some illegal connections? Is that incompetence or corruption from the part of the engineers? or Is that social justice and equality served through the pipes !!!? Hence it becomes necessary to assess the context from the socio-technical perspective that can somehow adapt infrastructure leakage index to become socially inclusive and to adopt comprehensive section process such as triple bottom line benefits in consultation with all the actors in the system.

Few years ago, upon reviewing my research article, my PhD Thesis supervisor Professor Emeritus Ricard Ashely's sarcastically remarked "Mohan, stay away from nuns and non's". Non-Revenue water, what is that? Water that does not yield revenue! Does non-revenue water not have attribute on its own? Why not call it as lost water or pilfered water? why should we characterise it for what it is not? That is wired like the term non-vegetarian and anti-Indian, the terms that only we Indian's understand or does not understand properly but use it most of the times. The use of prefix 'non' comes from our binary thinking from a specific perspective, like the non-revenue water coming out the revenue perspective. This is due to the training of our minds to take decisions based on binaries such as yes or no; true or false; on or off; 1 or 0, etc, where are things are fuzzy in reality like the 100's of shade of grey between black and white. In all the IWA Water balance sheets we start with water at the left and end up with revenue on the right. It is what that is on the right that decides how we divide the components the table. It is the revenue orientation that resulted in the revenue based

Story box - Being an Engineer with a heart

I think it was Circa 2003, when Bala Sir was a 56-year-old, just retired engineer from Kerala Water Authority and was my Boss in the engineering consultancy. Myself and Bala sir were involved in the acquisition of land for laying a 900 mm diameter raw water transmission pipe through Kottayam and Aalapuzha district in Kerala. The pipe had to cross Vembanad Lake and we had proposed the pipe landing and alignment across the property of a fisherman who was ready to sell the strip of land for the pipe alignment. We finalised the alignment and invited our project director, Lokesh sir, to inspect and approve the alignment so that we could proceed with the acquisition of land. Lokesan sir was about 70 years old and was former managing director of KWA. Lokesan sir had a good look at the alignment; walk with us on and around the alignment; and asked about the details of owner of the land. Myself and Bala sir gave him all the details. He asked me what was the necessity to take it across the fisherman's property and not along the road. I told him that that taking the pipe along the road meant two additional 90 ^{o} bends, an extra 200 m length of pipe on ground and an extra 100 m under water. That would increase the capital cost as well the pumping costs since additional bends and length cause loss of head due to friction and turbulence. Lokesan sir with a smile told us that the alignment is good alignment and we had put our brains in designing it. We were happy. However, he quickly added that it is an alignment without a heart. I was perplexed. I did not understand what he meant. He asked me if I would sell the land if I had owned it. I was barely 23 years old when this story happened and said yes thinking only out of my inexperience with life and from technical perspective. He asked Bala sir the same question and Bala sir said no. I was even more confused. Looking at the confusion on my face, Lokesan sir asked Bala sir to explain me the reason for his no. Bala sir said that the property value would come down when a huge pipe passes through it and also people would hesitate to buy it. Lokesan sir told us not to put that poor fisherman in trouble and asked us to change the alignment, though it would cost the project more. That was my first lesson on looking at engineering designs from a social perspective and also to use my heart in addition to my brain for designs.

sub-components such as billed metered and billed unmetered. What if we had the following pairs instead of Revenue and Non-revenue water: Tranquil water & troubled water; sustainable water & questionable water;



Multiple perspectives are necessary to understand the multiple intricacies and hidden context in the urban water systems. Hence it is neither prudent or sustainable for the diligent municipal engineer to spend the time and resources only to get trained or exposed to the technical aspects of water loss. In this age of information there are plenty of resources available through platforms such as International Water Association (IWA), Building Water Operator Partnerships (BEWOP) etc., that can facilitate self-learning among the urban water engineering community. Training of the engineering minds to think around the urban water systems i.e., looking into the urban system is essential in addition to honing their technical capabilities. Municipal engineers are in a unique and privileged position that enables them to understand the urban water systems, as well as change the systems from within. The central idea of this training is to make the municipal engineers realise that they have been working through the urban water system and not working on the urban water system. In addition to the engineering water loss aspects concerning design, operation and implementation, the learning and knowledge aspects that need to be strengthened are the perspectives about urban water systems from user, operator, manager and governance perspectives. Hence this training of trainers is about enabling the engineers to look at urban water systems based on systems thinking and from the perspectives of users, operators, managers and governors of

urban water systems, i.e., to look beyond the leaks. Why to reinvent the wheel when we can make it sustainable by understanding and strengthening the spokes of the wheel?

You must have noticed that the phrase “water loss” is used instead of “non-revenue water here in this guidance literature. Use of the phrase “water loss” and avoidance of the phrase “non-revenue water” is intentional in this guidance manual in order to bring the focus on the various aspects of loss of water and not just on the revenue loss. Unless we get used to the change of terminologies and use it, we will be mentally struck to the old mindset. For example, our perception about sewage as a resource will not be registered into our mind unless we stop using the phrase “Waste Water” for what flows out of our kitchens, showers and toilets and start using the word “Sewage” instead.

5.3 Socio-political turbulence in a laminar water flow

The act of leakage measurement is born out of the desire to control the flow of water through technological means. The act of measurement or approximation is enacted based on the type of connections. The common topology of connections are as follows: Metered and documented; documented but not metered; known but does not exist on paper; unknown to engineers. From an engineering point of view the inability to quantify the leaks or loss of water is usually attributed to (i) unstable intermittent pulses; (ii) unknown paths of flow; (iii) unclear supply or service area boundaries; (iv) physical condition of the network; (v) absence of measurement devices; and, (vi) lack of agreement or consensus on measurement methods. Hence there is an understanding that as flow and leaks cannot be measured it cannot be effectively managed. Engineering minds are trained to arrive at decisions based on solid numbers. It is the reasoning based on quantitative data that leads to the strong belief that what cannot be measured cannot be managed. On contrary, the socio-technical nature of the urban water systems have led to evolution of subconsciousness of the municipal engineers who have knowingly or unknowingly moving past the concern about measuring leaks and are moving in the right direction of fixing leaks to keep the systems working. The engineers in addition to being the “Sentinals of pipes” and have also meta-morphed as the “Lords of the Leaks”. This is due to course correction in goal of the water supply system, where the goal of maintaining social order and harmony has been accorded priority over the primary objective to supply of water as an economic good. This system response or correction to the increase in demand and the widening socio-economic divide among urban citizens is due to the self-organising capacity and resilience of the urban water systems comprising its actors. Proactive leakage management can ensure a smooth laminar flow in the pipes, reduce the water loss and maintain a stable pressure in pipe network. However, it can increase the turbulence in the urban society as it takes away the leaked water, which is a buffer, lubricant and shock absorber that keeps the urban engine by keeping the social and political pressure under check. Engineers are smart and know fully well that they work with water and are not working for water and that they are the transmission shaft of the socio-political-administrative engine.

Although the loss of water from the system is physical, at times, it is not possible to quantify or classify it as a leak. This may not be due to the absence of measuring devices or the lack of technical know-how but rather due to complex socio-political relations and nexus that is

hidden in the urban system, which the urban water system serves. Municipal water systems are socio-technical in nature which necessitate the analysis of the system from this perspective to understand the challenges and to get the desired outcomes. Hence is it imperative to understand that the measurement or quantification of leak is dependent on the socio-political context in which it is measured. The operational concern and priority of a municipal engineer is not the measurement of leaks but fixing the leaks and keeping the urban water system functioning. The prioritisation and fixing of leaks by the ground personnel is based on the socio-political and material reasoning. It is the municipal engineering staff's social intuition that guides their approach to analyse and address a leak or in disconnecting an illegal connection. These reasoning abilities and socio-technical knowledge is tacit, which is hard to elucidate or document and is often referred to as the gut feeling.

Story box: Thenali Rama and Brinjal

I don't think Thennali Rama and Krishnadeva Raya need introductions. It was the beginning of season of Brinjal in Vijaynagar and the King Krishnadeva Raya was in love with brinjal and all his meals invariably contained brinjals in one or the or the other form. He said "Rama, Brinjal is the best vegetable in the world. What do you think?" Smart Rama, though he dislikes the vegetable, said " Of course Raya, Brinjal is the best and it is the king of vegetables". This voracious Brinjal eating continued day after day for a month and these songs of praise and dialogues about vegetables were also repeated in one or the other form. One day during lunch Raya said all the sudden "Rama, these brinjals are tasteless and disgusting; they should be banished from my table from next time". Rama was waiting for this golden moment as he was also fed up of this brinjal binge. He said " Yes Raya, Brinjal is the worst vegetables in the world they are not worthy for a Kings meals". Raya nodded approvingly but added immediately, "But Rama you were praising the Brinjals for so long and told me that they are versatile vegetables and is the King of Vegetables. How come you change your mind all the sudden". Pat came the reply from Rama. "My dear Raya, you are my king. I serve you and not the Brinjal" 😊

Moral of the story - Engineers serve the urban system and not the urban water system 😉

5.4 Relief through leaks and not relief from leaks

It is not only the potential difference that makes the water flow in the urban water systems. The social and political pressure seems to have a higher influence in making the water flow and it determines the time of flow, duration of flow, place of flow and the recipient of flow. Illegal connections overriding disconnection orders are an unavoidable reality (a handy social pressure release mechanism) in a heterogenous unequal socio-political- technical context and cannot be eliminated altogether. It can at the best be managed. Such flows would be accounted as apparent loss or leaks by an academic or a consultant; and, as an egregious deviation from best management practice by a benchmarking or rating agency. However, these leaks in reality are the assuaging leaks or relief leaks as far as the municipal engineering

staffs are concerned, although the omnipresent existence of such leaks will never be acknowledged. “I don’t know what you are talking” about will be the response of the engineering staff, in spite of them being the prominent actors in the production of social leakage by not acting against leaks or not plugging the leaks wilfully. It is this subtle act of understanding between the engineers, urban citizens and corporators (municipal councillors / ward members) that gives the semblance of municipal councillors ruling the water supply systems, whereas the engineers actively lord over and manage the leaks. Thus, in the urban Indian context the social and political pressure matters more and hence the management of the leaks takes precedence over the water pressure management.

5.5 Water loss in the context of SDGs

Metering – leak reduction - 24 x 7 water supply – privatisation? These words generate a lot of hype and fuss among policy makers as well as the urban citizens, be it apartment residents or slum dwellers. The connections between these four phrases are fuzzy and they are understood differently by different actors, which range from increased revenue, efficient use of water and time, better control over the system, fear of getting disconnected from the system, etc. The way with which an actor in an urban water system relates to these phrases or interprets the relationship between these phrases depends very much on: who the actor is; the type of thinking that drives the reasoning ability of the actor (bounded rationality); and, where the actor draws the boundary for the urban water systems and the elements that constitute the urban water systems, i.e. visualisation of the urban water system by the actor. An urban utility bench marking professional might see a positive relation between these four phrases that would result in a sustainable resource utilisation through responsible production

and consumption (SDG 10). For urban slum dwellers privatisation is a nightmare that would disconnect them from the cities water supply as private water suppliers might insist for a legal water connection, which is impossible to obtain without proper land tenure documents. This plausibility runs contrary to providing water and sanitation to all (SDG 6) and reducing inequalities (SDG 10). 24x 7 water supply can create a better context for enhancing gender equality (SDG 5) and enable a decent working environment and economic growth (SDG 8). It is imperative to understand the urban water system from all these perspectives in order to move towards these goals without negatively contributing to one or more goals or to the detriment of these actors.

What about water loss in the context of urban migrants? The COVID-19 crisis exposed how fragile and vulnerable our urban migrant workers are. Dignity and social inclusion is inadvertently compromised in the quest for progressing towards the target, economic efficiency and satisfying the need of those with a socio-political capital or influence. The mission mode of achieving targets (e.g. toilet constructing under Swachh Bharat Mission) leads to the exclusion of marginalised or lack of understanding of the socio-cultural aspects. These are accorded priority only in the last phase, when a 100% achievement of the target is envisaged. However, from a leaving no one behind (LNOB) SDG perspective the marginalised migrants should have been accorded the highest priority. The service provision or management of urban water system should have be redesigned from this LNOB perspective. This requires reframing the boundary of urban water systems based on sociotechnical systems thinking and expanding it further as a social- technical – political- governance systems. Such a perspective or mindset can enable the actors to think about apparent loss reduction or economic efficiency not in terms of disconnecting the people with difficulties to pay and rather devise means that can empower them to pay, which is a sustainable outcome.

Story Box: Is water an economic good or a basic right?

Myself and Bala sir are back again 😉. In our project area the actual length of pipes in the distribution systems exceeded the planned length in Kerala water supply project. We were asked to come up with a map of a smaller network matching the planned length. Myself and Bala sir were involved in that exercise together with the Kerala Water Authoritie`s local engineers and made a preliminary map. These maps were sent to the chief of hydraulic section of the consultancy in Thiruvananthapuram. We were called to Thiruvananthapuram for consultations. Myself and Bala sir explained them why and how certain streets were cut and certain street were retained. There was this small fishing hamlet with about 100 houses that was about 2 or 3 km west of Thuravoor. The access to the village was a through a single road across a swamp with high ground water. The Chief was not happy with the proposal to extend the pipes to the fishing hamlet as the cost would be high and said that it is waste of money. Bala sir who is usually soft spoken was annoyed at this remark and said sternly that " No no no, you cannot sit here and decide who gets water and who don't, water should reach there irrespective of whatever it costs. Water is not about money but is about life and decent living". The fishing hamlet next to the sea had no source of drinking water and all the residents had to encounter hardships in collecting water from neighbouring villages. If these residents were not to get water then the millions of rupees invested in the huge project would be a wasted investment from a humane point of view, as the people elsewhere in the project area had access to some form of secondary water sources. From Bala sir's point of view the pipe alignments should always be finalised from position of the most vulnerable beneficiaries and not from the economic point of view. Bala sir succeeded in retaining the pipes to the hamlet 😊

Such an understand of SDGS and the urban settlement goals or multiple objectives can help us in changing our perspective. A perspective that looks at leakage management not as an event driven engineering act but as a socio-political process, which uses engineering as the means through the urban water system in order to maintain the vital parameters in the urban environment, i.e. maintaining the optimal water, social and political pressure. The vantage position of the municipal engineer provides an opportunity that enables them to understand the underlying structure of the urban systems (including urban society) and to critically analyse and improve the urban water system based on an all-encompassing perspectives. This is already evident from their everyday operation and management of water systems where their actions are based on pragmatism and not based on protocols.

Systems thinking is a tool that can help the engineers to structure their thinking about urban water systems. Analysing the SDGs and water loss from the systems thinking point of view will help the engineers to frame water loss not only from a SDG 6 perspective(water and sanitation) but also from other SDGS perspectives such as SDG 3 (health), SDG 5 (gender equality), SDG 8 (decent work), SDG 9 (innovative infrastructure), SDG 10 (reduced inequalities), SDG 11 (Sustainable cities) , SDG 12 (responsible consumption and production), SDG 13 (Climate action) and SDG 17 (partnership for development) that are impacted by

water in an urban context. Comprehensive thinking with a change of mind that acknowledges the need for contextual objective -subjective reasoning is necessary to put systems thinking into practice across the hierarchy of urban systems management authorities. Until this happens, the marginalised urban citizens will be under the mercy of a benevolent engineer or a corporator with a tacit understanding of urban systems, who would only repeat " don't tell me what you are doing" or " I don't know what you are talking about" depending upon who asks the question.

In India, water is intermittently present with respect to time and space but continuously occupies the minds of the people in the urban water system, whereas in developed economies water is continuously present with respect to time and space but is almost absent from the minds of people and is taken for granted. ***What brings the urban water to the foreground in the minds our urban citizens in India, whereas water is relegated to the background and is rarely thought by those urban citizens in the emerged economies? Is what that sets our water worlds apart the continuous high-quality water, flowing through well-maintained pipes, pressured through state of art pumps and monitored by science fiction level high tech control units that also debits money from the banks accounts of their happy consumers? Not really.*** Water supply systems remain in the foreground in India (urban as well as rural) because of the huge difference in the socio-economic condition among the population, where the personal struggle, the presence and exercising of the socio-political connections to obtain water makes it more visible. A real liberation and freedom is when the body and minds are free from the worry about water, heating, electricity, food and transport. Some of us who are from the water starved villages might know how it felts when taking bath under a shower in a relative's house or in the hotel room in a city. I still remember the first time, nearly 30 years ago, I was under a shower in my Aunt's house in Chennai. I was up in the clouds like the happy girl in the Liril advertisement as I used to help my mom fetch pots of water from the street tap every evening in my village, not an easy task.

5.6 Setting the context for Water loss using systems thinking

Who does not like a laughing child? We all cherish the mental image of a laughing child. Imagine the smile of a childing holding a chocolate. I always thought that I would be able to pacify a crying baby by giving a chocolate. This works. Does it work always? This may not work every time. The baby might start crying after eating the chocolate or does not stop crying even after getting the chocolate. Only the parent or the experienced baby sister who knows the child will be able to identify why the child is crying and will be able to give what the child needs, which could be milk or sleep or changing the diaper. Sometimes even the parents cannot find out why the child is crying, but an experienced Grandma from the village who is in no way related to the child or has never seen the child before will be able to find it out and make the child smile, Magic. The Grandma usually does that by looking at the child, lifting the child, touching the child, looking around the crib or cradle and the house, talking to the parents and listening to their narration of events and also their actions that happened from the time the child started crying or even sometime before the child started to cry. This is a classical example of systems thinking or systems approach, which has remained with us since

time immemorial. Now replace the words “crying child” with “leaky pipe or water loss”; “chocolate” with “new pipes or pumps”; parents or baby sitters with “municipal engineer”; and grandma with “retired engineer” a down to earth person who is much sought out, respected and held in high esteem even after retirement by the fellow engineers, municipal administrators and urban citizens alike. Isn’t this scene familiar to most of us who are meddling with urban water systems?

5.6.1 What is systems thinking?

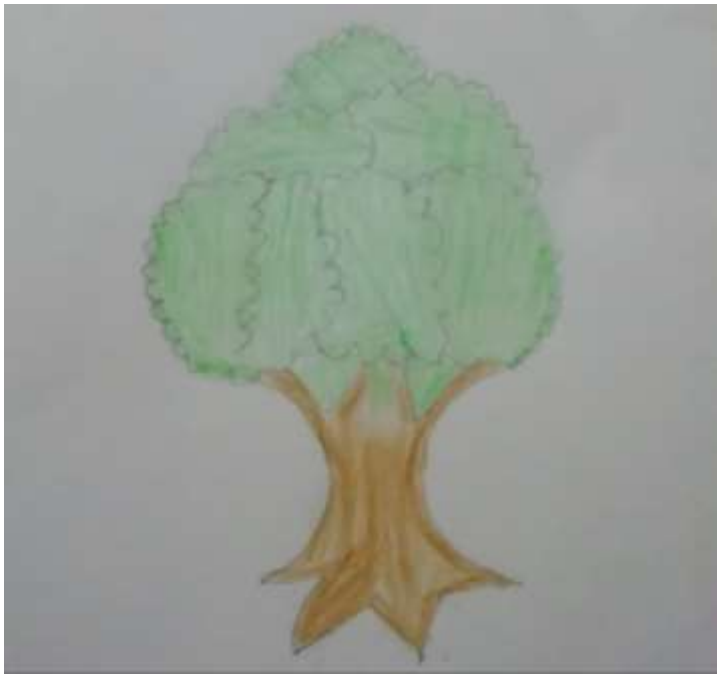
Systems thinking is a way of thinking that help us identify the root cause of challenges and identify new opportunities. Systems approach or systems thinking is seeing “systems as a whole”; where problem structuring and solving requires an understanding not just of the components of the system, but also of their interrelationships and their relation to the whole. In the context of urban water systems, systems thinking can help us explore the different ways of seeing and thinking about water loss or urban water systems beyond engineering and economics perspectives.

What is a System – A system is an interconnected set of elements that is coherently organised in a way that it achieves something. Examples of systems are the human body where interconnected elements make up systems such as digestive system, nervous system; language systems where the individual letters and words are connected through a set of rules (grammar) to convey meaning; municipal water supply systems that are made up of pipes, valves, pumps, reservoir and people. A system is made of several subsystems. A tree is a system which is made of number of subsystems such a leaves, branches and roots. The tree in itself is a subsystem in the forest, whereas the forest is a subsystem of the natural ecosystem.

What is in a system?

A system is made of many things, things that are visible and things that are invisible. A system has three components viz., elements, interconnections, goals or functions. In a system called tree the elements are leaves, branches, trunks, roots that are visible. There are also millions of microorganisms at every one of the elements which are not visible to the naked eye. Interconnections are what that keeps all these elements together such as the force of attraction or bonding between the cells, the law of physics which are not really visible. The functions of a tree is to propagate itself and support the ecosystems through it services such as provision of fruit, being a habitat for birds and animals, release of oxygen, etc. The three basic components of the systems – elements, interconnections and functions – manifest or sustain themselves through the presence of three other attributes that are flows, buffer and feedbacks. The flows in the tree is what enters and emerges out of the system. Water, nutrients, and carbon dioxide are the inflows; whereas oxygen and water due to transpiration are the outflows of the trees. The feedback in the trees are the mechanisms and signals with in the system that regulate the functioning of the tree. In a hot day the when the evapo-transpiration is more, the leaves send signals to the roots to pump in more water or when the

winter approaches the signals are sent to the leaves to send back the nutrients to the branches or to the trunk before they wither away, for the tree to survive the harsh winter. Wood, fruits and seeds are the buffers or stock or capital of the tree that sustains the identity as well as the function tree. Systems are easy to comprehend due to cognition. For example, though tree is a system comprising elements, such as leaves, branches, trunk and roots, at the very sight of it we understand it as a tree and not as elements due to cognition and our perception towards that system since childhood.



- ***Reflection exercise: Try listing the elements, interconnections, goals, functions, flows, feedbacks and buffer in the urban water system***

Elements – Elements are the actual stuffs that make up the system, i.e., physical stuff in most of the systems. For example, leaves and branches are the elements in a tree; stomach and intestines are the elements in the digestive system; and pipes and pumps are the elements in a water supply system. Elemental function or object function is the basic function of the element in a system. For example, the elemental function of stomach is to digest and tooth to bite and chew in the digestive system; and in a water supply system the pipe's function is to convey water and pumps are meant to build pressure.

Interconnections – Interconnections are the relationships hold the elements together. Interconnections can be physical as well as signals such as rules or logic. Eg: Water and law of physics are interconnections in both the digestive and water supply system. Signals, rules and logic as interconnections are not visible in systems and are a bit difficult to comprehend whereas elements are easier to comprehend. Network or network assets in a urban water systems are intricately connected objects that enable the flow, such as, the pipe network system, electrical system, information system, social networks among the urban citizens as well as the engineers. The processes associated with the functioning of those subsystems are networked interconnections.

Goal or function – Goal is the intended purpose of the system or the value that is desired out of the system. The purpose of the digestive system is to digest food to generate energy for the body and the purpose of water supply system is to supply water to the needs of public or earn revenue to the water authority. The systems achieve the goal by making use of the elemental function and interconnectedness of the elements, which is the state of objects or elements or assets that are being connected with each other in order to achieve the desired

goal. For example, the physical interconnectedness between the pipes in the water supply system and the mental interconnectedness between a father and son in a family system. No amount of changes in the structure of systems will bring about a drastic change in the functioning of the system until the interconnections and purpose of the systems remain intact. Remember the subtle change of urban water systems purpose from water supply to social order.

Flows are the lifelines of systems. The inflows and outflows of the systems are the indicators of the functioning of the systems. Birth and death; inhalation and exhalation; eating and defecating; profit and loss; deposits and withdrawals; success and failure are some of the flows in the systems that we commonly come across. The flow of different constituents into the systems gets converted into buffers depending on the interconnections with in the systems. Our body converts the food, water and oxygen into body cells and energy, and sends out the rest in form of carbon dioxide, urine and faeces. The beat of the systems can be ascertained by observing the flows of the systems. Most of the times we are able to determine our health by looking at our pulse, breath rate and blood pressure, i.e. by merely observing the flows the condition of the system is ascertained. The same goes for urban water supply systems as well. Water, energy, money and people flow in and out and through these systems. Like the blood in the human body, the loss of water or blockage of water beyond an extent brings the system to a stand still or to complete collapse. Very much like the blood, water carries a lot of essential minerals that are limiting factors for our growth. Though water in the urban water systems and blood in the human body are playing similar roles in the respective systems they both have a unique characteristic or role play in each of these systems. Unlike water, blood is not consumed by the human body in which the generation and flow of the same in a closed loop is paramount for survival. On contrary, water that loosely flows in and out of urban water systems in addition to essential minerals also carries dignity, an important component for human survival. Is it not strange that our human minds are conditioned through stories and narratives to relate pride and dignity to blood and not to water?

Buffers are the accumulation of flows in the system that have a purpose or value. Buffers are the accumulation of memory or history of the flows in the systems which are either physical, such as wealth, muscle mass or body, wood, water, heat; or nonphysical, such as feelings, goodwill, confidence or trust. Are water supply systems unique as water is both the flow and buffer in this system? Urban water supply systems comprises multiple buffers or stocks such as water, money, energy, trust, dignity and confidence. The value of these buffers are not absolute and are relative, which depends upon the actors, perception of the actors, place and timing of the actors and buffers in the systems. A liter of water has no value to me when it flows freely through the tap in my house but is invaluable when I am struck in a middle of desert or if I have to wait for two hours in a queue to get a pot of water. Getting deeper into this buffer definition business will lead us to a philosophical confusion, i.e., what is the difference between buffer and purpose, is body the buffer of mind or body the buffer or mind? Let us not get into that Karan Thaparish or Sashi Thaoorisque hairsplitting arguments. In our understanding, buffer is something that can be counted or felt which deems the system useful or makes us feel the usefulness of the system. In the story of the crying child and granny, buffer is the trust that the parents or the community has on the Grandma, which was

established due to the accumulation of experience of the Grandma with babies over the years.

Feedbacks in a system are essential to maintain the buffers in desired quantity or in the desired state so that the system advances towards it objective. Feedback backs are the information exchanges or signals from point to point or one point to many points or many points to one point or many points to many points which lead to changes in flow that subsequently lead to change in the buffer and ultimately affecting the function of the system. When the leaves have got the required amount of nutrients or the right amount of water it sends signals to the roots to stop the intake of water and nutrients. This information exchange regulates the flow of water and nutrients within a desirable limit so that the leaves can maximise the production of energy and store it in the form of starch, which is a buffer or stock. Such information loops which regulates the flow to enable the use and accumulation of buffers are called stabilising loops or balancing feedbacks. Turing off or turning on a tap or a valve, switch on or switching off a button, making a request for additional monetary resources to improve the pipes, fixing a leak, making an application for a water supply connection and paying the water bills in time are balancing feedbacks. However, there are information exchanges or signals that will trigger actions will push the system away from the goals by upsetting the buffers. Sudden drop in temperatures continuously for three or four days amidst a hot spring might trigger the panic signal about the early onset of winter and cause the plants to shed leaves. All us vividly remember or have gone through the infamous "Toilet paper" crisis in the end of March 2020 with the onset of Covid pandemic, where all toilet paper rolls disappeared off the shelfs of supermarkets. This was based on a rumour that the toilet paper producing factories would be converted into mask production factories. We are also the living testimonies of effects of such rumours flying in and out of our smartphones. Such information loops which disrupts the flow, that in turn disrupts the use of buffer or the depletion or exponential growth of the buffers are called runaway loops or reinforcing feedbacks. Leaving the tap open all the time, making an illegal connection, neglecting periodical maintenance, reactive maintenance, not paying the water bills, poor communication with the urban citizens are runaway loops. Such runaway loops lead to loss of water, loss of money, loss of energy and lack of confidence on the urban water systems.

Read Donella Meadow's " Thinking in systems" if you want to have a deeper understanding about the basics of Systems thinking or Watch these videos in the Youtube channel.

Meadows, D. H. (2008). *Thinking in systems: A primer*: chelsea green publishing.

5.6.2 Why are we surprised by the systems? Systems characteristics

Every system is unique and behaves differently. The complexity in the systems behaviour has the origin in its characteristics. It is the combination of these characteristics that brings out different behaviour from the same systems at different times and at different places. We might have often been surprised by the way the same person behaves like a completely different person in a different place, an introvert colleague in the office meeting might be the first person to jump on the dance floor in a local bar. Everything that we relate with this world

is based on our mental models. Our mental models depend on what we see or feel through our primary senses; how we perceive the relationships; where we draw the boundaries; what we think are the limiting or determinant factors; how much time it takes for something to happen or the time taken by us to understand or act; and, most importantly the kind of perspective or perspectives with which we analyse the systems comprise our mental models.

Events: Human minds are attracted to events that are big, spectacular and out of ordinary, like the Chennai floods 2017. Why did it flood? Our minds do not pay attention to what is happening in the background in the everyday life or changes that happen gradually. It is hard to notice the difference in the everyday growth of a tree or our body. We realise that we have become obese when our health breakdown results in hospitalisation or when we collapse in the middle of an important meeting. We don't realise and that we have become obese or quickly forget it when we are gasping for breath when forced to climb up or down a stair when the elevator breaks down; or when we try to get into that favourite Kurta that was brought in memory of the Delhi trip few years ago; or when a childhood crush who has not seen us in a long time points it to us. Oh Oh you look round and chubby now! This is due to our failure in not noticing and analysing these frequent small events in our everyday life and to see the pattern in it, i.e. our behaviour over time. Behaviour originates from our own 'body – mind' system structure, i.e., our mindset, attitude, life style and priorities. Trying to address the problem based on a single event is not going to yield good results but analysing the system by looking the history of system behaviour can reveal from where the problem is coming out of the system. When we consult a dietitian, the dietitian asks us to make a note or record of what we eat and what we do in a week or 10 days so as to us to get an idea of our behaviour and suggests a change to our diet and lifestyle accordingly. Not divulging that information and expecting a cure is like pressing a button to change ourself magically at the wink of an eye. May be photoshop can help. Miracles happen only in fairy tales and not in real life systems. Events are the outcome of the behaviour which originates in the system structure or system configuration. Was the Chennai Flooding 2017 only due to a 1 in 100 year rainfall event? Think about it. Our urban water system is full of such events, leaks that are big and small; complaints that are big and small; public protests that are big and small; deficiency or budgets in budgets that big and small. The practice of recording all these events and analysing the behaviour of these events with simple or complicated engineering models, brainstorming or audit will help the operators and managers to understand the real problem. Why are there so many leaks in Indranagar and nobody is complaining? Why are so many complaints coming from Malligaikuppam when there are too few leaks? This will help the engineers understand the technical, social, cultural, economic and political structure and connections in the water supply systems that causes the events.

- ***Reflection exercise: Where there any spectacular events in my urban water systems such a dramatic pipe burst, road block by the urban citizens demanding water, power outage affecting water supply, etc? Why did that happen? Were there signals indicating the onset of this event that went unnoticed? Was this event not avoidable? Take one event and analyse it like the " Air crash investigation" programme in National Geographic TV.***

Story of a cow and the veterinary doctors

A farmer had a cow that was giving milk in abundance. The farmer noticed that the cow was becoming weak and not eating properly. The farmer took the cow to the young veterinary doctor, who had recently joined the animal clinic in the village. The doctor inspected the cow thoroughly and ran multiple checks. The doctor found out that the dung of the cow was not how it should have been. The grass that the cow ate were partially digested. The doctor suspected some disease in the gut of the cow and started medications for it. The conditions of the cow did not improve and the doctor eventually forgot about the cow. After a few weeks during an evening stroll the doctor went around the farmer's house and asked about the cow. The farmer took the doctor to the cow, which was eating well, the dung was in the right consistency and was perfectly healthy. The surprised doctor asked how this miracle happened. The farmer said that the elderly traditional veterinary doctor from the nearby village visited the cow few days ago and the cow's condition improved after the visit. The doctor was astonished and visited the traditional veterinarian to enquire about the cure of the cow. The elder said that he inspected the cow and upon checking the tooth the elder found that one of the teeth had outgrown a tad more than the other tooth. That was causing pain for the cow while chewing the grass, which made it chew less and eat less causing indigestion and weakness. The elder filed the teeth and let the cow get back to the normal routine. Most of the times we look for solutions and problems everywhere and fail to notice them when they are smiling right in front of us.

Non linearity: The cause is not always proportional to its effect. The taste of soup increases by adding a salt to it. That does not mean that the taste will keep on increasing as

we keep adding salt to it. It will become non palatable beyond a point and any more addition of salt will only make it worse. This is called non linearity. It is this nonlinear behaviour of systems that causes the systems to swing to opposite behaviours. A tree needs water to grow but if we keep on watering it, its roots and stem will rot. Nonlinear effects can be understood by observing what sugar does to us, what sleep does to us and what love does to us. In physical systems it possible to identify the range of non-linearity based on past observations such as establishing an optimum blood sugar level; or pressure in pipes by experiments and models. In case of social systems or psychological systems it is hard to establish the range and one must pay careful attention to the day to day functioning of the systems to find out if system is about to swing. It is not possible for many of us to say when someone close to us who has been complaining that "You don't pay attention to me" will have a mood swing and start yelling "Give me some space". Such behaviour is not unique to individuals but can also be seen in big systems like governments. A case in point is our interactions with governments demanding appropriate services and rights. Our questioning and activism draws out positive response from them to an extent, but when it goes beyond a point it invites the wrath of the government that responds with its might, ending up in spectacular events., such as demonstrations, riots, police firing, etc. It is very hard to determine the point of inflection. Someone higher up in the government administration once told me " In a Bamboo factory if you put a bamboo you will get paper, in government if you put a paper you will get a bamboo, Mohan. So, you will have to be very careful and think before you ask them anything." Understanding the non-linear behaviour of the system is very important before playing with it. Non-linear behaviours are present in our urban water systems as well, such as the flow of water; pressure in the pipe; and corrosion; the pricing of water and willingness to pay; the duration of intermittent supply and tolerance, etc.,

- ***Reflection exercises: Is flow of water, pressure in the pipe and corrosion the only nonlinear behaviours observed in the urban water supply system? Does the pricing of water and willingness to pay exhibit a non-linear relationship? What about the duration of intermittent supply and tolerance to it?***

Non existent boundaries: Most of the real-life systems do not have a clear boundary in a complete sense. It is difficult to say where one system ends and the other systems starts. Where does black end and white starts as there is a whole range grey shades in between? Where does the roots end and the trunk starts in the tree? Like beauty, borders are in the minds (perception) of the beholder. A border between two states is a political or administrative boundary that does not completely contain a language or culture. There are Tamil speaking villages on the Kerala side of the border and Malayalam speaking villages on Tamil Nadu side of the border. There is a zone of transition but not a clear boundary for this socio-cultural-geographical system in spite of an administrative boundary. Such boundaries regions are rich with diversity and become the play grounds for new systems to thrive and evolve. The Palakkad Tamil and Nagarkoil Tamil in the north and in the southern borders of Kerala and Tamil Nadu are not just two distinct dialects but are two distinct cultural identities. Though seemingly technical in nature, is to possible to draw a boundary or distinguish between the engineering and social tasks of a municipal engineer or a plumber in an urban water supply system? The chaotic nature of the task, as well as the chaotic nature of the urban systems makes it impossible to draw a line between their duties as there is a seamless continuation between the social-technical-political- cultural – economic systems. Although they work on the technical systems, they work through all the other systems. Whether it is to fix a leak or in negotiating with a ward councilor or social worker to limit the number of illegal connections in a ward, the engineers will have to be creative in redrawing the system boundaries in their mind in order to arrive at an outcome acceptable to all. There is a greater scope for learning in these fluffy transition zones and we need the mental flexibility to redraw these boundaries a thousand times depending on the context. Absolute boundaries do not exist. We simply draw them on paper and in our mind to understand the problem and resolve it. Our efforts in giving life to the rigid and unnatural boundaries are a source of friction and trouble, like the three learned idiots, who gave life to the lion's corpse in Panchatanra tales.

- ***Reflection exercise:*** **Where are the apparent boundaries or zones of transition in my water supply system? How many such zone of transition exist, such as socio-techincal;**

socio-cultural; techo-religious etc.,? What are the learnings from these zones of diversity? What stands out or what is unique out of these learnings?

Layers of limits: Although systems are limitless with respect to boundaries, there are certain elements that limit the functioning of systems, i.e. to start the functioning, sustain the functioning and to stop the functioning between a limit and beyond a limit. A tree or a plant is a good example of a system with transcending boundaries, limiting factors and limits to growth. Tree is connected to elements and systems that are below ground, on the ground and above ground. A tree needs water, sunlight, air, nutrients, protection from being eaten by animals during the initial days, etc. For a tree to thrive it needs all these elements in right proportions. You could drench it roots with water and nutrients but keeping it in a dark room will not make the tree grow. It needs sunlight for growth, may be keeping the window open for two hours a day might help. We need to understand what limits the growth or functioning of the system and create conditions so that these elements are available beyond the minimum limit required for growth. These limits and the limiting factors change as the system progresses towards the goal. We need not supply water any more once the tree has taken deep roots but we may have to supplement it with more nutrients if we want to harvest a good amount of fruits or prune the side branches if we desire for a tall round trunk to be cut for timber later. Similarly, there are limits to growth and limits to functions, since systems cannot function perpetually, like the trees that cannot grow beyond certain height and time period. The urban water supply system is like the tree that spreads on, above and beneath the ground; serves people on the ground in its vicinity; expects rain and resources from above the ground and from far. Money to build a water supply projects in Kerala is wired all the way from an international cooperation bank in Manila or Tokyo. Although water is the primary limiting factor for the water supply system there are also other important limiting factors. What is limiting the service in my urban water system: water available at source, energy available to treat and supply, carrying capacity of my pipelines, availability of spare parts for regular maintenance, competence of the staff, technology, bureaucracy, political buy in, social acceptance, implementation regulations and guidelines? Further the water systems have functional limits, such as number of people served, area covered and quantity supplied, etc., if stretched beyond these limits its function start suffering. Similarly, water lost from the system can be sustained to a limit beyond which it becomes unstainable. There is a limit up to which illegal water connections can be tolerated. If these requests fall below the desirable limit for such connections, the system would account these connections under apparent loss. If it exceeds the limit due to the concentration of such beneficiaries in

a particular area or if the urban citizens take the system for a ride, the whole systems would be strained that results in culmination of actions either to expand the limits or curtail the demand. Limiting factors and limits to growth are like the air in the bicycle tires, which cannot be seen but without which we cannot move and too much of it leads to a system break down. Salt in the soup.

- ***Reflection exercise: What are the limiting factors in my water supply systems? What are the limits to growth to my water supply systems?***

Ubiquitous delays: A tree takes time to grow. Waiting is the part of system creation and system management. Patience. Every system has a delay in responding to the inputs, delivering the outputs and adjusting itself to feedbacks. That does not mean, we have to wait till the problem becomes obvious, but give it sufficient time to respond after learning how much time does it usually take for typical system responses. Foresights are essential to assess the system performance. There are many delays in the urban water supply system that range from few minutes to few years, i.e. the time taken for the water to reach the tap from the time it is pumped (few minutes) and the time it takes from project formulation to project implementations (few years). These are the delays that can be modified to improve the system performance through various actions, such as reducing the leaks, maintaining the pipes, establishing various direct channel of communication with the citizens to redress the complaints faster.

- ***Reflection exercise: What are the delays that matter the most in my water supply system? How does the modification of these delays address improve the functioning of water supply system? Are there inordinate delays in my systems, i.e. feedback that should have come with in a specified time period are either missing or taking too long, why? What can be done to resolve this situation?***

Bounded rationality: When we have a hammer, every problem is a nail. Bounded rationality is the point of view of the actor in the system based on the capabilities of the actor and the information available with the actor about the system. How we relate with the system depends upon who we are and where we are. A tree is a playground for a child, it is the child for a gardener, home for a little bird, it is a resting place for a traveller and it is a source of wood for a carpenter. The decision we take also depends upon when (short term or long term) and for how long (one time or intermittent or continuous) the outcomes or changes are expected. It is not uncommon for actors to take decisions based on the events they experience with the systems and with their limited understanding. Let us take the case of a headache. Someone who has time will sleep for a while to get over it, someone who is busy will take a pill or apply a balm to get instant relief. However, this does not address the problem as headaches are usually the symptoms of something that has gone wrong elsewhere in the body such as eye problems, not eating properly, stress, etc., Addressing the problem requires looking at the history of head ache, when it occurred, how long it prolonged, how did it disappear, what are the resources one has at the their disposal to treat it, etc.

An engineer's headache! Do you know what is Engineers einstellung or Normative thinking? It is a mechanised state of mind that has been trained to solve a problem in a certain way and refuses to explore other ways of solving it. This is how it was done and this is how I will keep doing it. I am an engineer; I am trained to think like one; and, I will only think like an engineer to solve the problem at hand. That is bounded rationality in a nutshell. Urban water supply systems have numerous problems, where multiple actors try to analyse the problems based on their limited understanding or bounded rationality. The unresolved problems, controversies arising out of actions such as metering, privatisation, selection of locations for tube wells or overhead reservoirs or material selection of pipes, treatment methods are mostly due to bounded rationalities. Expanding the boundaries by exploring the context from other perspectives might help in coming up with actions that are effective and less controversial. Discussions with all the relevant actors or constant engagement with various actors over a period of time might help in overcoming the bounded rationality. Being headstrong without applying our mind is the reason for engineer's headache.

Role play exercise: *Think aloud about water in your city through the eyes and minds of some typical actors and characters in your urban water supply system. What would these urban residents think about the water supply of your city?*

- *Engineer (Engineer Ebrahim)*
- *Plumber (Water Vettrivel)*
- *Municipal commissioner (Commissioner Gayathri)*
- *Corporator (Corporator Kathiresan)*
- *House wife (2nd floor Sivagami)*
- *Working women (Maria teacher)*
- *Social worker (Amnesty Venkat)*
- *Slum dweller (Welder Pandi)*
- *Senior citizen (Parvathi Paatti)*
- *Senior citizen (Retired Superintending Engineer Arockiadass sir)*
- *Street vendor (Milk Mani)*
- *Primary school student (Johnny Boy)*
- *High school student (Jullie Girl)*

What would be the urban water narratives or perspectives or stories through these characters?

- ***Reflection exercise: What are the bounded rationalities in my urban water systems and urban system? How does that affect the actions in the urban water supply system? How can I resolve this challenge of bounded rationality?***

5.6.3 Systems trap and opportunities in Urban water system

Systems always surprise us because of the number of visible and invisible connections or relationships between the elements. Although it is difficult to predict how a system would behave in future, it is useful to understand certain type of behavioural outcomes that are prevalent in most of the systems and reoccur in some systems. These are known as system archetypes or habits. Think about the following typical family habits in my middle class monthly wage earning family. There is always a short of money irrespective of how much I earn? My family members have been told to spend less and irrespective of that there is a short fall every month, why? I cannot do anything to overcome the deficit and I keep working more to earn a bit more money. Oh, my neighbour has a new car, let me buy one better than that. Why is the top management getting hefty bonus packages and trainings abroad, when me and my colleagues in production are not even getting increments? I should pay the credit card dues of my son if he defaults as it hurts my pride to have a defaulter in my family. How can I reduce my taxes, Shall I show my vacation trip to Paris as a business trip expenses incurred on market study for my consulting assignment? Is earning for my family and caring for their expenses my ultimate objective? These are some of the typical habits of our family set up, a system we all live in. There are hidden traps as well as hidden opportunities in these typical habits and understanding them will help us understand systems better and guide them towards their goal. We will be less surprised when the system exhibits these habits in the future and will start to think how to avoid the behaviour if it is undesired or how to sustain it if the outcomes are desirable. Not to be caught in these traps is to recognise them in advance so that they can be modified and made to work in our favor, like the shrewd politicians in power who make use of the news and social media to work in their favor. Politicians are able to do that as they understand the beat of the system and are very well aware of the traps and opportunities that the system presents.

Policy resistance or Fixes that fail: It can be defined as the situation or situations where the actions taken by the actors to improve the system performance does not improve the system. Actions are taken are repeatedly but they fail to achieve the purpose. For example, many of us regularly complain about our income not being sufficient and end up looking up at other means to supplement the income, such as taking up an additional job. Does that fix the problem? In most cases we only end up overworked and stressed, never being able to bridge the gap and caught in the trap. This can due to the mindset or the bounded rationality that make us think that increasing the income is the only way to overcome the gap. We get fixed to this thought and forget that are limits to the effort in making more money. Else this could be due the actions of different actors pulling the system in different directions. One or two members in the family earn more and more but all the three other members in the family keep spending more and more as they keep receiving the money they ask for. May be increasing the income was not the correct solution. A cursory or

a in depth analysis of the family expenditure might reveal that there are unnecessary expenditures, which can be avoided to reduce the deficit. Do we really need that expensive vacation? Is it necessary to change the car? In this case, the analysis of why the income generating actions have failed gives the opportunity to find out the right actions that can help us avoid fixes that fail.

Our municipal water supply systems are full of such fixes that fail and the analysis of the same presents the opportunity to learn lessons. Desired amount of water not showing up at the tap of the urban citizens in spite of increasing the water pumped into the system gives us the opportunity to explore and fix the physical leaks and to prevent water being stolen from the system. Repeated instances of drilling tube wells or constructing overhead reservoirs due to the political pressure from corporators is a fix that fails, the documentation of which can form the basis for argument for a proper feasibility study in the future. The effectiveness of some of the water management measures should be explored through this policy resistance system lens. We have always done it this way and will continue do it this way is a recipe for failure.

- ***Reflection exercise: What are the technical factors contributing to the water loss fixes that fail repeatedly? What are the social factors contributing to the water loss fixes that fail repeatedly? What are the political factors contributing to the water loss fixes that fail repeatedly? Has water rationing and intermittent water supply addressed the water demand issues? What are the opportunities in my urban water system to reduce physical losses? What are the opportunities in my urban water system to reduce apparent losses?***

Tragedy of commons: Tragedy of commons is the classic system trap where everybody thinks someone else or everybody else is working towards the system objective, whereas they continue with their behaviour or action that goes against the goal or function of the system. There is this story of a mayor who wanted to test the collective behaviour of the city residents. One fine morning the mayor requested all the urban citizens to donate to a good cause by emptying a glass of milk in a container kept in a closed room of the townhall. It was announced that nobody would seem them emptying milk in the container. In the evening when the mayor inspected the container it was full of water and not milk. Everyone had

poured a glass of water instead of milk thinking "Why waste a glass of milk from my home when nobody is watching and others would be pouring milk anyways". This is called the tragedy of commons. Likewise, in case of the example mentioned in the " policy resistance" section when the family decides to fix the gap by reducing the expenditure and leaves it to the voluntary behaviour of the individual and the individuals do not change the behaviour thinking that others would change. This will lead to the status quo as before or even to a worse situation, where one or more family members starts spending more thinking that others saving will compensate the runoff behaviour from their part. This is applicable for other situations such as buying a car, disposing garbage or casting our vote. Either in disappointment or in a fit of rage, in order to teach the inefficient government of the day a lesson, most of us vote for a candidate with extreme ideas thinking others would have voted for the right candidate and end up living with the tragedy for 4 or 5 years. Traffic congestion, garbage littered streets or poor tax revenues are examples of tragedy of common. Tragedy of commons can be avoided through creating awareness, personalisation of common (pay for excess) and regulation. When awareness is not working then the use of resource (inflow and flows) can be monitored and excessive use of resources regulated or put strict penalty or monitory mechanisms in place so that actor has access only to the right amount of resources and pays more if needs more. One or more of these measures are necessary for preventing the tragedy of commons. Trust but verify, is a time-tested process to avert tragedies.

Tragedy of common behavior can be seen in urban water systems as well. People using water for gardening and for swimming pools in a dry season; employing handpumps and suction pumps to draw more water in water systems with inadequate pressure; making illegal connections and construction of underground sumps, are some of the tragedy of common archetype in urban water supply systems. A combination of awareness, regulation and personalisation measures are necessary to avert the tragedy of commons in the water supply systems.

- ***Reflection exercise: What are the tragedies of common behaviours in my urban water system? What is the role of metering in averting tragedy of commons? What is the role of privatisation in averting the role of commons? Are there opportunities to create the right environment for my urban citizens to feel the sense of belonging to the water supply system and become responsible for it? How can there be a feeling of empowerment and liberation from the every day task of collecting water?***

Drift to low performance: It is the case of a system that has consistently under-performed and has accepted the under performance of the system as the new normal. Rather than looking at what went wrong and how it can be rectified, the goal is compromised, i.e. to actual state is perceived to be the desired state. We would have noticed this behavoiur of the system from within ourself and in a number of things outside that we are a part of. Many of us who have been actively doing exercises such as walking or cycling might

have reduced it or stopped it because of laziness and blame it rather on getting old or lack of time or some other alibi? Yes I should have done that but…… plenty of examples!!! Slow and steady we drift away. We have would have witness many of our friends or relatives or colleagues or sometimes ourselves ranting that the government has become so inefficient and should not expect anything better than the current level of services that we get, whereas it should be delivering much better results. What about doing something about? Hmmmm, why take trouble someone else will do it. Congratulations " Tragedy of commons" has joined our team newly.

Systems drifts into a low performance coma when its performance is compared to its recent previous performances and not to the desired performance level. Oh my god you failed in 2 out of 5 subjects when you are supposed to pass in all the subjects. Yes Dad, it is ok. Last month I failed in 3 subjects and I am improving you see. The baffling response would be "Yeah, you know I keep failing in English and Maths all the time, so why make a big fuss when I have failed in history also this time. Chill Dad". Indulging in clever statistical gimmicks to show that the urban water systems is not performing badly is a not an uncommon practice. We are not the only people doing it bankers do, politicians do it, municipal engineers do it. Oh my god your urban water loss is 25% and not at 10% which is the bench mark. Yes sir, it is ok. Last year it was 30% and it is less this year, we are improving you know. The baffling response would be " Yeah, it was already 23% last year so it is only a marginal increase, why make a big fuss about it when everybody is getting water and nobody is complaining about it". Being flexible is a good attribute and a necessary quality but one should never be flexible with respect to the goal of the systems, performance objectives and the service levels of the water supply systems. Do you know how the service selection board interviews for the officers in the Indian military services is done? They don't select the best out of the cohort, whereas they select only those who satisfy the army's selection criteria. In a batch of 100+ cohort if everybody satisfies the criteria they will all be selected, if no one satisfies the criteria they will not be recommended for training. "Sorry Gentlemen, none of you are recommended" were the departing words of the Indian army major who declared the results to a room of about 30 young men, where I was one among them a few decades ago. Flexibility in service levels and comparison to past performances is a good thing if the urban water supply system has consistently exceeded on service levels, such as controlling the leaks even excelling the bench mark value of 20% . If it is 150 lpcd for everybody everywhere at 20 m of water head 24x7 in my city, it has to be. If you can create awareness about demand management to your urban citizens and make them reduce the per-capita demand to 120 litres without compromising health and lifestyle, you are the best!

- **Reflection exercise:** ***Has my urban water system drifted to under performance? Are there signs of my system drifting to under performance? How can I arrest the movement of my system towards underperformance?***

Escalation: Let them stop first! This is a classic fight of catch me if you can between

different actors in a system that leads to difference in the value proposition or quantity of a buffer or between two buffers that leads to the collapse of the system. Two kids start a mock fight hitting each other, hitting harder than the other with every blow and within no time it becomes a real fight. Both of them end up getting hurting or reprimanded by the parents. The buffer or stock in this case is anger or feeling belittled which rapidly increases with the increase in blow and escalates in a system breakdown. The same happens in case of a cut throat competition between two companies competing for market space or two countries trying to outdo each other in accumulating weapons where they think increasing the military might and nuclear stock pile would serve as a deterrent. "We vs Them: India – Pakistan", where we have invested a huge amount of money and human resources in the pretext of national security. Though a deterrent, it is draining the investments that we could have made to improve important human development indices of the country. Although negotiating the way out an escalating situation is hard, it is possible. Both the sides expect the other side to stop first. Let them stop first and we will stop. This could be due to various reasons, ego, fear, being considered weak, backlash from constituents with vested interests etc. Why look here and there for examples of escalation when we can sit back, relax and look at all escalation dramas happening in our own house among family members or in the virtual realm of Twitter and other social media platforms ;P

Escalation is omnipresent in most of our water supply systems, both in the physical realm as well as in the social realm. Be it pipes or people there is escalation. Water is lost due to leaks and we pump in more water and more water gets leaked. This will only keep escalating forever unless the leaks are fixed or the pipes break one day due to the weak soil support around them as the leaks weaken the surrounding. People are not paying their water bill so the administrator decides not to improve the water services, people don't pay as the water service is not improved. Who will budge first? Engineers allow some social leaks in form of illegal connections (Don't tell me what you do) and with a short span of time there is a proliferation of illegal connections. When they can have it why not me? This will quickly escalate into a serious problem resulting in the termination of all such connections inviting a huge backlash, unless the engineers devise a way out of it with the help of local community leaders and politicians. This is something that happens in most of our urban water systems.

- ***Reflection exercise: What are the escalations in my water supply system? What triggers these escalations in my urban water system? Where are the escalation hotspots or flash points in my systems? What can be done to stop the initiation of escalation? What can be done to stop the progression of escalation?***

Success to the successful: 'The rich get richer and the poor gets poor'. This is not a vague political campaign statement or a dialogue out of a movie lashing out at the society, be it capitalist, communist or socialist. This is the reality in most of the socio-economic systems, which are unregulated. The people with access to resources - be it money, influence, authority or information - makes use of those resources and become better, whereas those who do not have access remain at the same level or slip back or the increasing socio-economic- cultural- political divide make this worse for them. What prevents the ultra-rich in spending their money on genetically modifying them as genetic engineering and biotechnology has developed to the extent of producing tailor made super babies. This is a perfect cocktail of success for those with access to wealth, information and authority. Successful actors are those who understand the system in its entirety in terms of its elements, relationships and the functions and play with the feedbacks in such a manner that they get advantage over other actors in the system. We have come across stories of people becoming rich by using insider information to invest in certain companies or sectors in stock markets. There are rules that prevent such behaviour but is mostly left the mindset of people, i.e. ethics, to refrain from such behaviour to take undue advantage of their position. Such behaviours that give undue advantage to few actors and put most other actors in disadvantage will not be tolerated in a long run. The system will revolt to restore the balance, like the infamous French revolution of the past or the Arab spring in our times. Social justice measures such as reservation in education, job and opportunities try to maintain a level playing for all the actors by regulating the access. Success to the successful behaviour can be seen in our urban water systems as well. People with an assured continuous water supply – in posh residential colonies and gated communities - go on with their lives and focus on other things that can improve their material, cultural and social wellbeing. Whereas, people who are dependent on water supplies that are intermittent and erratic are tied to their tapes as the water schedule, quality and place of availability of water dictates their personal and professional life. Also the "well behaved" neighbourhoods that pay the water bills regularly are those ones who get their water systems maintained properly and their

complaints addressed promptly, where as the " rogue" neighbourhoods that do not settle their bills and complain frequently may not receive the same level of service. Does Malligaipoo Kuppam and Indra Nagar in Adayar, Chennai receive the same level of service?

- ***Reflection exercise: Is this "Success to the successful" a reality or a myth in my urban water system? To what extent is this prevalent in my system"? Is there anything that can be done to prevent the " Success of the successful" in my system? How can there be a feeling of empowerment or liberation from the everyday chores of waiting and collecting water?***

Shifting the burden to the intervenor (Addiction): People get addicted to certain habits like drinking coffee or smoking. These habits create a perceived reality that is different from the actual reality by hiding the symptoms. When the body is tired of work and needs some rest coffee removes the tiredness, which is a symptom, and prolongs us to work.

Some addictions, such as drugs like heroin, don't just remove symptoms but block the real signals of the reality and create a different perception altogether. It is not just people who get addicted, systems also get addicted to certain behaviour. During the recent financial crisis, we saw that many reputed banking agencies which were thought as too big to fail actually failed. It was attributed to their reckless behaviour of undertaking too much risk and lack of self-regulation. How come such systems become reckless? The recklessness was due their lack of understanding and misjudgement of the current reality as these banking systems were intoxicated with the perceived reward of their risky undertaking that ignored the symptoms and denied the signals of reality. This risk-taking behaviour and recklessness had origins in their unshakable faith that the government will intervene and infuse money and will not let them fail. They shifted the burden on an external intervenor who has interest in not letting the system fail. Imagine a bank breaking down where all the depositors, most of whom are wage earning class lose their money and the chaos that ensues and the Government steps in to save the depositors. It will be a political setback for the Government of the day not to intervene and the bankers know it too well. Remember the recent fiasco related to Punjab

and Maharashtra Co-operative Bank (PMC). This kind of behaviour can be seen in many organisations and individuals all around us. Why take trouble in cleaning the room when mom does it anyways? Our great and kind Indian Moms! The system enters the trap as the intervenor takes it from the brink of collapse and gives it a temporary lease of life every time, but does not force it to change. That is like maintaining the life of a person in a hospital ventilator without giving any treatment to help the person recover from that state.

Systems won't change unless change is forced upon them. It is not uncommon for a water supply system not being able to recover the water usage charges from the urban citizens to cover its capital, operation and maintenance expenditures. The state always steps in to cover the financial gap in form of a grant. Urban citizens who are habitual offenders in terms of non-payment of water bills also know that the government will write off their bills before elections. Breaking this addiction to underperformance and avoiding praying in the last minute is a difficult task. Analysis of addiction gives an opportunity to analyse the system and strengthen it to stand on its own. Such systems should not be treated with kid gloves. It is not ok for them to fail.

- ***Reflection exercise: Does my urban water utilities resist financial and administrative reforms? Is there political backing for these reforms? Will there be a public back lash, due to fears such as steep increase in water tariff? Why is the natural correction mechanism of my urban water system failing? How can the obstacles to the success removed? How can the mechanism for success made more effective?***

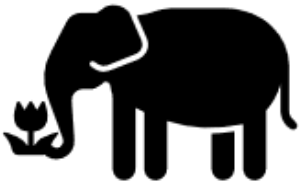
Rule beating: Rule beating is a typical case of following the rule on paper but not in spirit. Rules are followed or shown to be followed to avoid punishment or disincentives and not for the sake of achieving the objective of system. I lived in a boarding school and our Matron used to visit our dormitory every Tuesday morning to check if we kept our dormitory clean and if we organised our personal lockers properly. The purpose was to instil this habit of cleanliness, maintaining things in proper order and make that a habit in our everyday life. We were smart!. Our dormitories resembled a war zone from Wednesday morning to Monday night. On Monday night, all of us got together and cleaned the dormitory and put it in order for the Tuesday morning inspection. We followed the rules but that never served the purpose of instilling the habit of being in a well-ordered fashion every day. Surprise checks at any time in the week would have prevented us from beating the rule and make us follow it in spirit. We can notice such instances of rule beating all around us. People become very creative when it comes to rule beating, be it a school going child or a politicians and business tycoons, who create shell companies in tax havens to launder money, to avoid taxes and to show illegitimate incomes as legitimate ones. Most of the countries in European union leavy a tax on inheritance as one of the steps towards reducing income gap and wealth inequalities. Even if someone accumulates wealth and passes it on to the family there is a tax on it and the countries social system benefits from it.

Urban water supply systems are not an exception to the rule breaking behaviour. Is it not common at all levels of hierarchy in the water supply administration and management to sit

on the allocated budget till the last minute and spend on something that is not very well thought of to avoid less funds being sanctioned for the following year? There is one District metered area exceptionally doing well in terms of curtailing water losses, way below the targets and there is an adjacent district metered area doing bad. Combining them on paper or on ground, to be technically correct, with a sluice valve that is closed for ever can show the water loss just below the target and save the engineer from embarrassment. Will the engineer overcome the temptation to do it and meticulously work on the DMA with heavy water loss and strive to achieve the target? Water always flows through the path of least resistance and so are we trying to comply with the rules with least possible effort, unless we have the vigour for the betterment of the system. Are there creative ways in framing the rules and targets in such a way that in whatever form the rule is beaten it should help in the progress towards the urban system goal?

- ***Reflection exercise: Are there rule beating behaviours in my urban water system? Who are the actors indulging in rule breaking behaviours? What are the specific rule beating acts? How can they be avoided or minimised? What are the creative ways of preventing rule beating behaviours in my urban water systems? Who are the most important constituents in preventing rule beating acts?***

Seeking the wrong goal: Most of the times well maintained, capable systems get caught in a trap because they are used to seek the wrong goal. That is like using an elephant to carry a bunch of flowers or engaging M.F Hussein to paint the walls of your house. Elephants are to be used for moving mountains and M.F. Hussein is to be commissioned to paint art forms that transcend time. Systems seeking the wrong goal may not be obvious in certain instances and might look perfectly well for an insider as well as an outsider. Things will openly come out only when the systems get themselves deeply entrenched in a trap or when controversies breakout. Is it not a wrong goal to continue the practice of Orderlies in the Police and Military services that demeans and demotivates the bottom rung of the forces? Why should capable men be tending the dogs and polishing the shoes of the superior officers under the disguise of discipling and hierarchy? One of the reasons the systems drifts towards the wrong goal is because of the attitude of the hierarchy that thinks the elements are there to serve the hierarchy, whereas the very purpose of the hierarchy is to serve the elements and take them towards the desired goals. Seeking the wrong goal also occurs when an element or a sub-system starts using its capability to achieve desirable results for itself and not in the interest of the entire systems. This behaviour can be seen in the way some of the news media's behaviour in India. They tend to repeat the views of those in power so as to increase their revenue and to increase their proximity to those in power, whereas the purpose of news media is to serve as the watch dog that ruthlessly scrutinises the functioning of the government of the day. Instead of being the watch dog on behalf of the citizens became the propaganda organ of the state. This is a classic example of systems seeking the wrong goal.



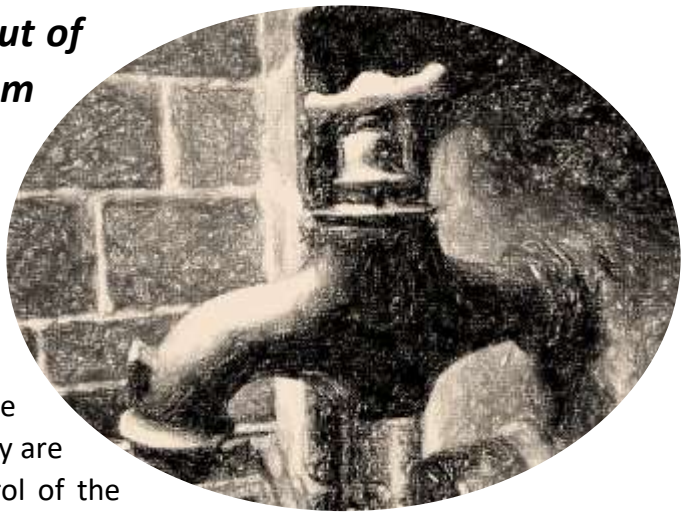
The functioning or goal seeking behaviour of the urban water systems should be scrutinised and deliberated by all the actors across the hierarchy to assess if the system is heading towards it goal or heading elsewhere. Is the ultimate goal to provide water at whatever cost it might incur? Is it's ultimate goal to be efficient and independent in terms of water as well as financial resources? Is it a goal to be a service provider with a complete administrative autonomy or remain as an intimate organ of the state? Should the water utilities ultimate objective be the relegation of the thought about water to the back of the minds of the urban citizens like in emerged economies? Why would I think about water when I know for sure that there will be water when I open any tap in my house? This seems to be a nice goal.

- ***Reflection exercise: What is the goal of my urban water supply system in the current context? Is my goal delivery of water with minimal loss of water? Is my goal delivery of water by an agency that retains its financial independence? Is my goal assisting the city administrators to maintain social order?***

5.6.4 A dozen levers for system intervention

A system can be intervened in multiple ways in multiple places to change the behaviour or functioning of the system. The flow to the systems can be modified, the feedback loops can be tampered, the structure can be changed, rules and interrelationships can be meddled with. There are a number of ways to change to system. However, all the changes do not affect the system in a same way. Some changes are hardly noticed, where as some changes make a drastic difference. Rather than the effort put into bring in the desired behaviour, what is important is where we make the changes that has a ripple effect in the system. There are a dozen pressure points in the system which are amenable to change. These are the levers that can be turned in either ways or replaced to trigger change in system behaviour. Similar to the sensitivity of the human body, the artificial systems too are very sensitive and responds to the change in some of these pressure points, whereas it does not respond or respond enough or respond quickly in some other pressure points. Knowing the effectiveness of these points can help us leverage change. These twelve leverage points are presented as follows in the order of least effective point at number twelve and the most effective point at number one.

12. Changing the flows into or out of the systems changes the system the least. Of course, chocolate and milk will pacify the child but that will not help the child change its tantrum. It will only cry more or often next time knowing that it will get a chocolate if it cries. That is juggling with what we give to the system and what we takeout of the system. This will give a false sense of illusion to the intervenors that they are changing the system and they are in control of the system. The behaviour of the system can be changed over time only if the change in flow can



be sustained. Classic example is the act of government pumping in money to revive the economy or introducing tax cuts to increase consumption. Has that improved the economy? That is like the new year resolution that most of us make "I will eat less fried chicken and reduce my weight", a resolution that most of us cannot hold fast even for a week. Change of flows will have to be done in accordance after a thorough assessment and understanding of system behaviours such as limits to growth, non-linearity and delays based on the observation of past events. This is called playing with the numbers, which we engineers are extremely good at, next only to statisticians. Operators and managers of a water supply system cannot change the way water is consumed by changing the quantity of flow and timing, unless they put tremendous effort in sustaining that change. It is difficult to make the system dance to our tunes through carrot and stick approach. People would find other ways to get water. Then why are we engineers so much obsessed about measuring the flow? We love numbers and we think in numbers, leading to that illusion that we can control the flow if we can measure it exactly, whereas in reality we can at the best only approximate the flow. So why bother to put so much money and effort into getting something that has the least effect on system. Also it is our bias towards flows and numbers that leads us to the fixation on events and not focus of the underlying system structure. If 1000 people block the highway and protest demanding more water or when there is a major burst in a main line, do we not often resort to temporary relief measures by meddling with the flows or pressure; change a section of pipe or increase pressure just to buy peace for the time being. Also the stark reality on ground is that most of the times, it is the operation of the systems that is in control of the engineers and they are seen to be acting by the other actors in the urban system only if they the play with the flows. Gaming with numbers and flows on an ad hoc basis will not lead to system change. There will be instant gratification but the problem will persist and pester.

- ***Reflection exercise: Have we resorted to the input/output juggling exercise in our water systems? Where in the urban water systems is that more common? What were the outcomes of such juggling exercises?***

11. It takes time and tremendous effort to change the system by changing the buffers.

Buffer or stock or capital is the accumulation of what flows through the systems in a strict physical sense. As buffers are accumulation, they take time to change in big systems. Buffers are also the accumulation of what evolves within the system because of what is flowing into the systems. For example, people flow into our lives and we make friends out of people, who are our buffers or emotional capitals or shoulder stocks in terms of sharing joys and sorrows to lead a meaningful life. We take time to build friendships by interacting with so many people (flow) and end up creating an intimate circle of friends (buffer). The frequency with which we meet people is not the same rate with which we make friends though both are related. We can turn on and turn off a tap quickly to fill a small cup but what about supplying a metropolis with "enough water" every day. The delivery of water

to the urban citizens from a water buffer such as reservoir behind a dam or an overhead tank is not merely through the operation of a pump or turning massive valves. What is the volume of water that can keep my urban citizens contended? If water was the only buffer in our system can we change the volume of water available at the source or in reservoirs quickly. This is not possible immediately as these volumes are enormous and depend on the rainfall and riverflows. Some water supply systems such as that of Mumbai has enough buffer (volume of water) to take care of the social and physical leaks and ensure a flow that keeps the urban citizens contended. If you observe Mumbai's or Chennai's water supply system critically you will realise that it is the buffer that changes or determines the flow. Though changing the quantity of stock can change the system it is very difficult to change them as it requires large amount of time and resources.

Also the obsession on numbers or flows is due to the lack of understanding of buffers in urban system. Thinking of water as the predominant stock or the prime capital is due to the boundary rationality or the usual normative thinking of an engineer who looks at urban water system as technical system and not as a sociotechnical system. By redrawing the boundaries mentally and by being creative, engineers can start looking at the interplay of pipes and people and come to an understanding that buffer or stock or capital in an urban water supply system is not only water and it is also money, trust, authority, dignity, harmony and social order. Urban citizens trust the system based on the regularity with which water is supplied, quality and quality of water supplied, speed at which the grievances are redressed, and attitudes of those in the hierarchy who serve the system. All these factors constitute the buffer or stock or capital in an urban water supply system which is hard to visualise and almost impossible to quantify.

Trying to change the urban water supply system by increasing only the water buffer is not only inefficient from a resource and economic sustainability point of view but can also upset the collective responsibility (behaviour) of the system. This act places the burden on systems managers, operators and administrative and absolves the urban citizens as well as the managers from responsible use of water. This creates as kind of addiction like behaviour, knows as shifting the responsibility to intervenor. We don't care what you will do but we

need water and what we do with water is not your business!!! Such an attitude from the urban citizens can arise both out of oversupply and undersupply history. Non linearity. Same is the case when money or revenue buffer is replenished through last minute bailout packages by the government, that will never encourage the urban water authority to change their operation, maintenance and administration of their urban water systems. Why bother when money will always flow from a central reserve? When an urban water supply system gradually or abruptly drifts to underperformance it erodes the buffer capacity of the urban system and brings it dangerously close to the flashpoint. To sum up, the primary buffer is the confidence that the urban citizens have on the water supply system, whereas it takes time to trust and build confidence.

- ***Reflection exercise: What are the buffers in my urban water systems? What do the actors in my urban water systems think about the existence of different buffers? Is there a change in number of buffers in my systems across time? Are water systems unique as water is both the flow and a buffer in the system?***

10. Structural changes are hard to make and need considerable amounts of time, resources and authority. The physical structure of the system can only be done slowly and there are many limiting factors to effect the change. We might have the aspiration to change the house or change the colour of house, but it is hard to act on it as it requires time, money, necessary permits or agreement from all the family members. Mammoth water supply systems like the cities of Mumbai and Chennai can be changed only gradually. Most of the times these changes have least effect on the overall operation of the system though effects can be felt locally. For example, changing a pipe or adding a pump can improve the water supply in a neighbourhood but it`s effect on the citywide performance is negligible. Also how do we change it without temporary disruption in service. We are not underplaying or undermining the necessity of maintaining the structural integrity of the physical urban water network such as pipe, valves and pumps. Seemingly mundane leaks might escalate into a catastrophic event disrupting water supply for days. Lack of structural integrity and lack of proactive maintenance would drift the system to low performance. Proactive maintenance regimes are necessary for the water systems to function but will not lead to a system wide change. When we look at the structure of the system it is not just the physical structure – pipes, pumps and valves - it is also the organisational structure or the hierarch which administers, manages and operate the system. How easily can the jurisdiction of an assistant engineer in urban water system delimited, can the monetary limit on the procurement power of the assistant engineer changed easily?

- ***Reflection exercise: What is time, effort and money spent on making structural changes in my urban water system? What are the different kinds of impact realised through structural changes? How long does the impact last?***

9. Delays are the hard realities in any system and cannot be changed easily although change in delay can change the system behaviour.

One needs to understand that change takes time and has to be patient, give it time and wait of it happen after taking appropriate action. Being impatient like the curious restless little monkey that pulls out the plant every time to check the growth of plants after watering them is of no help. *Remember the story of the greedy man and the golden egg laying duck.* Do you realise that it takes time to change the flow or the buffer? The time taken to change the buffer or flow or for the change to happen is delay. It is not always possible to modify, i.e., increase or decrease, the response time of most of the natural systems. How can we make the plant grow fast? All that can be done is to create a conducive environment for the plant to grown. Though attempts can be made in engineered systems, it takes a while to understand the delays by observing the way the systems behave. Intermittent water supply and continuous water supply are the outcomes of the difference in change in delays of water flow in a water supply system, Continuous water supply systems have near zero water delay, whereas intermittent water supply systems have a delay of few hours or a few days. How these operations result in a completely different system behaviour, both physical and social behaviours, is very obvious. Some of us who grew up with the intermittent water supply regimes might have witnessed friends, who are think as thieves, start fighting like sworn enemies while trying to get water from a street tap during limited supply hours. The future performance or working or behaviour of the system can be changed by modifying the delay in the feedback of system response at the present time. When we want to make a change in urban water systems we need to consider the delays that are

intrinsic to the system and explore the possibility to change them and how they might affect the behaviour. Some of the systemic delays in an urban system are the time that takes for water to flow from one place to another; time taken for repair and maintenance; time taken for procurement; a typical municipal budget cycle; time taken for approval of a project by the municipal standing committee; time taken to convince the urban citizens to carry out major reforms. For example, if one wants to reduce the delay due to the apprehensions about metering of service connections among the urban citizens, awareness campaigns and public consultations have to be organised with the help of self-help groups and grass root level agencies well in advance. Understanding the system will enable us to learn to account for the delays and to live with Delays.

- ***Reflection: What are the delays in my urban water system? Which delays can be quickened to improve the functioning of my urban water system? Which delays can be slowed down to improve the functioning of my urban water system?***

8. Establish and strengthen balancing feedback loops that can help the system achieve its desired goal.

These actions are known as balancing feedback loops as they keep the systems in balance by stabilising their behaviour and make them progress towards the goal or help them achieve the purpose of the function of the systems. Balancing loops are like the guardian angels of the system. Such loops will have to be sustained and improved. For example, walking for 30 minutes a day is a good action that helps in keeping the body healthy, paying taxes is good for the development of the country, taking public transport is good to relieve traffic congestion and abate pollution. The feeling of contentment or a burp after having three Idlis for breakfast is a balancing loop, which indicates that the food intake is sufficient for the needs of the body and does not require anything more. Such actions have to be encouraged. As mentioned earlier, proactive maintenance, prioritising and plugging the appropriate leak, supplying water at scheduled hours in case of intermittent water supply, pressure management, are some of the actions that help in functioning of the water supply systems. Maintaining an open and honest communication with the urban citizens through formal and informal channels is also a balancing loop. “Don’t tell me what you do” in case of social leakages is also a part of

balancing loop in a socio-technical water supply system. Hence a municipal engineer has to be creative in redrawing the boundaries of the mental model of the urban water system to identify its functions and feedback. The art of boundary setting is an essential trait for a good municipal engineer in order to identify and establish feedback loops. Balancing feedbacks are essential to provide water at the right time and at the right place to all the actors all the time.

- ***Reflection exercise: What are the feedbacks missing in my urban water system? Are there delayed feedbacks in my systems? What are the functions that my UWS provide?***

7. Identify and weaken the runaway feedback loops that hinders the system to progress towards achieving its desired goal. These actions are known as runaway loops as they destabilise the systems by reinforcing bad behaviour, over doing and affect the function of the systems. Runway loops are like the devils that are to be kept in check or avoided altogether. For example, walking is a good habit but excessive walking is bad for the knees, watching movies is relaxing but watching them in excess affects ones productivity, investing in stocks is a good idea but investing all your savings in one stock does not seem like a wise decision. I feel full after having three idlis but I also have a desire for a scoop of Pongal after getting the smell from the next table, which is the trigger for runaway behaviour and has to be desisted. It is like striking the right balance between being complacent and overdoing things; and also not doing things that seem right but yields negative results. In urban water supply systems whenever there is a complaint about inadequate water at the citizens tap the gut feeling would be to pump in more water. If the problem was a leak in a corroded main, the excess water and pressure would lead to more water being lost and creating a vicious circle of more water – more pressure – more leaks leading to pipe bursts and flooding of the street. This is not only the case with real losses but can also happen with apparent losses. If we keep telling " don't tell me what you do" and do not check once in a while, there will be a proliferation of illegal connections which will be difficult to disconnect at a later stage. This might also happen at the organisational level with practices such as accepting small gifts which might appear trivial and harmless, but one day become a social menace surfacing as corruption. It is not always the wrong actions that trigger the runaway loops. Runaway loops can also be triggered by the right action in the right time but at the wrong place; right action but not in time at the right place; right action in wrong time at a wrong place. If runaway loops have a free run then it will lead to the tragedy of commons, proliferation of rule breaking behaviour and escalation of undesired consequences thorough out the system.

- ***Reflection exercise: What are the runaway loops in my urban water system? Can privatisation weaken the runaway loops in my urban water system? What role can I play to identify and weaken the runaway loops in my urban water system? What role can the urban citizens play to identify and weaken the runaway loops in my urban water system?***

6. Information, which is honest and straight forward, communicated to appropriate actors in a simple language at appropriate time can change the system behaviour. 

There is so much of flow of information around us. Its not just living beings that communicate with each other. In this age of information technology machines communicate among each other and to humans. Information and communication forms an important part of thinking and decision making at all levels. When someone does a favour to me and when I say thank you, I am letting the person know (i.e. informing the person) about the gratitude I have for that person. If I feel the gratitude and do not communicating my feeling through a "thank you" by speaking out or writing a letter or texting or sending a meme or a gift it might create an impression in the mind of other person that I am such a thankless person and can lead to the change of behaviour to me next time when I ask for help. Such information should also be sent at the appropriate time or with in a desired time period. A 'Thank you' communicated today for a favour that I got two months ago will not be appreciated in the same manner as a ' Thank you' with in a day or week. Do you see the link between the information and delay and system behaviour!!! The trust of people on service providers increases when information about delays or disruptions are informed honestly and in time. When the train company or bus company lets the users know in advance about the disruptions days in advance or about the delays due to breakdown in real time with alternate travel suggestions or route options the users start trusting and appreciate the services more in spite of the inconvenience. In many instances it is not lack the of service but the lack of information that annoys the urban citizens, for example the status of application regarding a water connection.

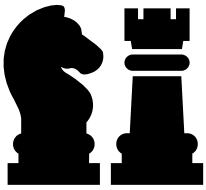
Many water utilities have started addressing these information gap and flow through mobile apps where the users can pay their bills, know their consumption, scheduled maintenance activities, unforeseen disruptions, health advisory regarding boiling water in case of contamination, etc. Also informing the urban citizens about how their pricing of the water is done, how are the extension projects and rehabilitation works are prioritised, helps in establishing the trust. Metering (bulk or consumer) is basically an information generation exercise that helps the engineers to know the pulse of the system to improve the system performance by knowing its physical behaviour. Then why does metering generate so much controversy and is looked at with suspicion or fear as a step towards privatisation among urban citizens. Why is metering not looked at as the step towards water conservation, efficiency and sustainability? Is that a communication problem? Will meters be welcome if they can help an urban household in knowing how much water they spend compared to other households in their neighbourhood? Am I better then my neighbour? Can that lead to a behaviour change?

It is information that strengthens or weakens the balancing loop and runaway loop. We have come across plenty of events, rather patterns, where the unsolicited biased information that we get through multiple channels, such as social media platform and television channels with

political inclination, influence public opinion that strengthens the runaway loop. This results in gossip mongering, mis-judgement, perception of the reality that is completely different from the actual reality that leads to social unrest or structural bias or even change of Governments. *Honest and open communication of appropriate information on time comes first and always*. More importantly, access to information determines the system dynamics and the system behaviour. Information is power. Which actors have access to the information and who doesn't have information determines the balance of power in the system. For example, the Right to Information Act has changed the way we, the people of India, relate with our government as it helps us keep an eye on the hierarchy to ensure that decision making is transparent and accountable in the public eyes. Denying information is denying power.

- ***Reflection exercise: Are there information gaps in urban water system? What are they and where are they? Have I got the information wrong at any time in my Urban water system? What was the consequence? Where is the scope for improving the communication? What are the creative ways with which I can establish communication with the actors in my urban water system?***

5 . Rules of the systems determines the scope, boundary and freedom of the system.



Changing the rules can change the way actors behave in the system. It is through rules the system incentivises stabilising acts, constrains deviations and punishes run way actions. For example, look at the game of football where the rules are in such a way that when the players puts effort and send the ball in to the goalpost their team is rewarded with a goal (incentive), whereas when the players touch the ball with their hand or tackle it hard the ball is taken away from them and given to the opposite team, which takes the advantage from the their team (constraining behaviour). At the same time when a player manhandles a player from the opposite team or cause wilful harm or indulges in abusive behaviour the player is warned (yellow card to refrain from committing that act again). The player is sent out of the game upon indulging in the same behaviour (red card as punishment) and that puts the team in a disadvantageous position. What if there was no incentive – the players would be loitering with the ball aimlessly, or what if there is incentive but no punishment – the game would resemble a bunch of hooligans fighting on the street. Changing these rules can change the way the players behave in the field. We also see instances where players become creative in breaking the rules to avoid punishment. This needs creativity on the part of rule makers to in order to come up with rules that cannot be broken or followed only for the sake of following it but harming the system. As punishment against rape has become severe the rapists tend to kill the victims to destroy the evidence to escape from the punishment. This not only beats the objective of ensuring safety to those vulnerable to rape, but also puts their life in danger. Amassing disproportionate amount of wealth and passing them on as inheritance is looked down up on in the advanced economies in European union. There is nothing that morally or legally forbids an individual to pass on the hard earned income to the family. Although not

forbidden inheritance is discouraged through levying of inheritance tax which is as high as 26% in some countries. The average tax on inheritance in European Union is about 14%, whereas in India it is 0%. Do you see how individual's rule bending behaviour becomes an advantage to the system and contributes to the built up of social security buffer, as well takes it towards the goal of narrowing down the economic inequalities. It should not be fear of punishment but rather the incentive and recognition through behaviour change that should propel the system towards its goal.

A level playing field is ensured through the rules. Rules determine who gets what and strives at reducing the inequalities in the system, be it access to water, education, health, employment, opportunities, freedom of expression or dignity. It is through the set of rules the system managers determines which actor gets a water supply connection or waiver of water bills, who will be disconnected, who will be warned and who will be reconnected based on the behaviour of the actor that could warrant incentive, constraining order or punishment. Some of the common rule breaking behaviours one notices in the urban water systems are illegal connections, non payment of water bills by the urban citizens; not delivering water in time, not delivering appropriate quantity and quality; not delivering water at appropriate place for all by the utility operators; and tampering of water meters and underreading of meters by the meter readers at the behest of urban citizens for exchange of favors. Rule breaking is also noticed at the level of policy makers who actually make the rules. These are acts which appear perfect when seen in isolation but goes against the system goals when the system boundary is expanded.

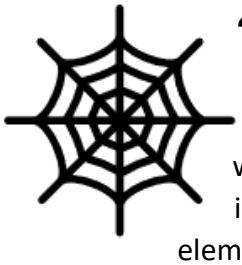
Intermittent open defecation: A classic rule beating tale

Is the tenure ship of land mandatory for getting a water connection? It seems to make sense, if not anybody could get a water connection to any land parcel. The Swachh Bharat Mission (SBM-G) rural guidelines explicitly mention that the provision of toilets should be delinked from land tenureship and even those who have encroached on the land should be provided with the toilets. One can cleverly argue that delinking tenureship and toilet is not a SBM(U) guideline. What prevents us from applying it in an urban context when some of the marginalised and left behind ones are urban citizens, such as the urban migrant labours. Clubbing together the precondition for a water supply connection and no preconditions for toilet provision creates a paradox. You can have a toilet but you cannot have water. What is the use of toilet without water? Technically speaking subsidy or support can be provided to build a toilet and SBM mission targets can be achieved on paper as toilets are built. However without a water connection these toilets cannot be used or can be used only intermittently, which defeats the purpose of universal sanitation coverage. So are we now stepping into an era of intermittent open defecation in addition to intermittent water supply? Have we accomplished our mission in spite of doing our job?

The reality of the socio-technical urban system necessitates the urban engineers to be compassionate in application of the rule, most of whom in practice are, in order to maintain

the social order or maintain the imbalance within the tolerable limits for the sake of their peace of mind. They indulge in creative rule beating that serves the evolved the goal of the urban water supply system, which is not only service efficiency, but also social service provision and social order. Have you come across the story " All about a dog" written by A.G. Gardener – Rules are for men and men are not for rules.

- ***Reflection exercise: Can't we come with a rule that can lead to a creative water pricing with a water loss cess that can incentivise the urban citizen. Can the water bill be based on fixed tariff with an additional cess that is levied in proportion to the total water loss in the district for an unmetered connection? Can the water bill be based on block tariff based on metered consumption have a differential cess that is levied in proportion to the real loss and exempted from apparent loss for a metered connection? Will this lead to awareness about water loss among the urban citizens, metering of connections and sustainable behaviour?***



4 Enhance the self-organising capacity of systems so that they become resilient to change. Every system has the capacity to organise itself to keep up its functioning and get back on track when it is disturbed. This is made possible due to interactions and interrelationships between the physical, nonphysical, living and nonliving elements in the system, be it our own body or urban water supply systems. For example our body organises it self when it is disturbed or gets hurt to the changes in the environment. Most of us feel uncomfortable for a couple of days when the seasons changes or cannot a sleep for a few days when we move to a new place, which is the part of process of getting used to the change. The change involves the body, mind and environmental elements. Changes big or small, gradual or drastic can be handled by the system by understanding the resilience capacity of the systems; the systems self organisational abilities and the hierarchy with in the system. Hierarchy, is the arrangement of a system into various connected sub-systems that enables self organisation. Self-organisation helps to focus on a specific task or function as well as limiting the spread of change with in a part of the system or pass on what is only essential. Our digestive system self organises its self and repairs itself. It only pass on the signal to other systems or the brain when it is too full or gets no inputs or when it get undesired inputs. Our brain is not constantly thinking about these process consciously, though it happens subconsciously. This conscious and subconscious organisation of the brain or mind in itself is an example of self- organisation. Conscious activities, such as the act of walking, swimming or driving, become subconscious activities as a part of long term self organisation process of the mind. The reversal of subconscious activities into a conscious one happens when these activities are hindered or disturbed due to changes in the environment. These changes are possible due to resilient nature of the human mind, which is a complex system, that quickly makes the switch to avert danger or reduce damage. So setting up a hierarchy can enable self organising behaviour that can make the system resilient. However, when setting up a hierarch one must remember that the purpose of the hierarchy is the serve the elements of the systems and enable them to achieve the function of the

system. Hierarchy's purpose is not to command and control but rather observe, guide and serve.

In a physical sense the flows in the urban water supply systems organise themselves based on the laws of physics in an enabling environment setup by the various actors. In order to strengthen the self-organising behaviour of the urban water supply system, one needs to shift the focus from the self-organising behaviour of complicated physical elements in the urban water system to the minds and interactions of the actors, which is a complex non physical arena, that are hard to comprehend and model. Through this perspective one could even come to the conclusion that some leaks in a way serve to sustain the self-organising capacity of the system and increase the resilience of the urban water supply system due to its socio-technical nature. What can be labelled as inefficiency from an engineering economic point of view can be seen as the effective way to maintain social stability and harmony in an complex urban environment. Self-organisation in an urban water system happens between the human elements engineers – corporators – plumbers – urban citizens, who are continuously learning, creating, designing and redesigning the system as they flow and serve through the system. It is this self organisation process that needs to be understood, and reconfigured if necessary to achieve the desired system goals.

A municipal engineer in Chennai or Mumbai may not know what is bounded rationality or what is the difference between a technical system or social systems but is definitely creative when it comes to directing the leaks at their command to douse the flames of social fire that pops up here and there, every now and then. This is due to understanding of resilience, self-organisation and hierarcy of the urban water systems. Resilience of a system is hard to see and is only evident when the system is stressed and is forced to operate beyond a normal range. Resilience emerges out of the multiple feedback loops that are omnipresent in the systems. This is clearly visible or rather a day to day norm in urban water systems such as Mumbai or Chennai, where there is tremendous amount of stress on the system both from

the social side and the resource end. Hence the social self-organising capacity can be seen in action in both the cities, may be more visible and colourful in Chennai due to constrains in sourcing water and in a comparatively subtle manner in Mumbai. Why not encourage women self-help groups to tackle water loss in the city? When there can be Community lead total sanitation campaign why not community lead water conservation campaign in the water supply system?

The top down hierarchy when connected to the ground reality very well understands the resilience of systems or rather the tipping point at which the resilience fails and lets the leak to maintain the social order. It would be sub-optimal or catastrophic for the administrators to instruct the engineers to fix all leaks and not to expect the urban citizens rioting on the streets. Don't tell me what you do is also part of this subtle understanding between the actors across the hierarchy in the system. What is optimal for a technical system, might be a disastrous for a socio-technical system. So, can we let it leak! And the good Lord said, Let there be leak and there was leak 😊.

Loss of resilience comes as a surprise when much more attention is paid to the play of the physical elements of the water systems such as pipes, valves and pumps and not its playing field. Thinking of urban water supply system as a socio-technical system can shift the attention from the pipes to people and their interactions, which has happened subconsciously, to an extent, among those dealing with contexts such as Mumbai or Chennai. However there are limits to resilience and the resilience of the systems should not be abused. The complacency among the administrators and operators emboldened by the resilience at play has created an illusion or a perceived reality that the urban citizens will forever tolerate or accept the systems drift to low performance; tolerate the success of successful; and, patiently bear with the escalation of the situation. The actual reality is a ticking timebomb that has to be diffused immediately. Playing with the resilience reserve of the urban water supply systems is similar to the play of the naughty little monkey playing with the little wedge between the wood being split. All of us know the end of the story, Ouch! Resilience is an emergency reserve that has to be preserved carefully and not drawn out for every day operations. Remember urban water system is an organised chaos, a little India that can never be controlled but can be cajoled.

Reflection exercise: Is my urban water system resilient? Were there instances where the resilience of my cities' urban water systems seen? How is the self-organisation evident in my urban water system? When does a water problem escalate from one level to another level? What role does the hierarchy play in my water supply system? Where am I in this trinity of hierarchy, resilience and self-organisation?

The talking trees

We all know what is WWW. It is the world wide web that is commonly know as internet. There is a different WWW, which is wood wide web. A group of researchers found out that the trees in the forest communicate among each other. Trees have established a communication network below the ground through their roots, where they exchange nutrients, take care of their saplings, help a fellow tree if it is under attack and even scheme and attack the trees that they don't like. Strange and unbelievable isn't it. Watch this video to learn more. It is amazing to see how the trees in forest organise themselves as a system with the help of a fungi and maintain channels of communication. Now we know that they whisper to each other and share secrets. Sharpen your ears to eavesdrop when you are in the woods next time.

3. Goals determine the behaviour of the system. Are we moving towards the right goal? This is the questions we all have been asking at some point in life or most often with a different phrase "What am I doing? Why I am I doing this?. Our attitude towards work, people or the world in general is dependent on the goal we have. For someone who wants to become wealthy everything around is a resource – human as well as material – which can be used (exploited) for increasing wealth. This can be seen in bigger systems, such as countries or markets whose goal is maximising or sustaining the economic growth and everything else, such as environmental pollution, social justice, becomes secondary. This leads to selection of implementation of actions geared to achieve those objective that focuses only on maximising the goal (bounded rationality) and ignoring the other feedbacks (balancing loop) that indicate the weaking of the system. Sometimes the goal seeking is so obsessive and pedantic that the focus is only on the process and beneficiary for whom the goal is intended is completely forgotten. Remember the story of Midas touch. The primary objective of the system is the sustenance of the system itself and we know that a system cannot exist in isolation. How can one focus on wealth creation when there is public unrest, hate and fear everywhere? How can the urban water supply system function if the urban social fabric around it breaks down?

What is the ultimate goal of our urban water supply system – 24 x 7 water supply? What is the function or identity of our water utility? Is that a service utility or a resource management utility or the organ of the state which ensures the welfare of people that tries to reduce the inequality gap? Or a mix of everything. The urban water supply system can sustain itself only if it contributes to the overall societal goal or goals in additional to its specific system goal, be it water service provision as a social good or an economic good . What some actors consider as a right goal can be seen as a threat by some other actors in the urban water system. Take up the case of privatisation which is seen as the efficiency improvement measure by administrators, that returns the best value for water and money invested.

Privatisation can be seen as the threat to their existence by some of the urban citizens as the state run systems due their intimate relationship with the politics and society are accommodative and benevolent to the suffering of these people. How the employees of water supply utility look at privatisation is a different story altogether. Hence the overarching goal of the urban system should be formulated in such a way that the collective behaviour of its actors are complimentary and results in a homing behaviour of the system, leading it to the desired objectives. For this reformulation to happen the boundary of urban water systems should be extended further into the domain of policymaking and governance that looks at what drives pollution, inequality, injustice, responsibility, social harmony, etc., that are linked to water. As mentioned earlier the Sustainable Development Goals (SDGs) can help the engineer and administrators alike to reformulate the goals of urban water system based on SDGS as the water is linked to multiple SDGS such as SDG 6 (water and sanitation), SDG 3 (health), SDG 5 (gender equality), SDG 8 (decent work), SDG 9 (innovative infrastructure), SDG 10 (reduced inequalities), SDG 11 (Sustainable cities) , SDG 12 (responsible consumption and production), SDG 13 (Climate action) and SDG 17 (partnership for development). The focus of urban water systems should move beyond water supply 24X7 and move towards SDGs365 as target. “We are not a 24 X 7 water utility, we are a SDGs365 utility”. Why focus on a single- or double-digit target when you have the competence and aspiration to go after a three-digit target.

- **Reflection activity and reality check: What is the vision and mission of my water utility? Is that comprehensive? Is it being put into practice? How should the goal be changed to reflect the reality and move forward?**

2. The mindset determines the goal, organisation, rules, feedbacks and structure of the system.

We act based on what we believe in. This is clearly evident in the actions of those who base their life on an ideology such as a religion. There are ample examples of such religious systems such as Hinduism, Christianity, Islam and other religions which are systems around a common goal, god, but have completely different rules and structures. It is the mindset from which ideas and systems are born, which is true for individual or a community as a whole. The life style of a person depends on what the persons aspires to become. Putting the thoughts in action; repeating the actions on a timely basis; and, processing the stabilising and run-away loops help the person maintain the physical and mental structure that helps to maintain the buffers envisioned by the thoughts in optimal limits. This is valid for farmer living in a small village in the middle of nowhere and to a frequent flying business tycoon living across continents or a priest in a monastery. The mindset determines who we are as an individual or as country. If the collective mind set of the country believes in a participatory democracy the political systems will frame its rules, structure and feedback such that the various flows such as natural resources, human resources and economic resources within the country help maintain the

buffers. Some of the democratic buffers in a democratic society are equality, fraternity and liberty, which includes the freedom of choice to the people to elect those who can make rules on their behalf as an inalienable right. Some other political systems have a different mindset which believes in a monarchy or racial or religious or ideological superiority that is paramount compared to the welfare of the citizens, i.e. putting pride before people. In such contexts the systems will be configured in such a manner that there will be no feedbacks, information channels and rules that will upset the enshrined superiority of the idea, resulting in a differential level of buffers with respect to equality, fraternity and liberty.

Established mindsets are known as paradigms, such as democracy, monarchy; capitalism, socialism; believers, atheists; comfort, conservation; conservative, liberal; etc. Water systems are also born out of such paradigms. Let me try to explain some of the water paradigms using the example of how we get food in the city, some of us cook by ourselves; some of us order it through apps; some of us who want it fresh and hot go out and eat; some who cannot afford to buy or cook go and eat from charitable institutions; some of us who has something very little to afford look for subsidised places to eat. Some the water paradigms are as follows: Everybody is responsible to source the water for their use and government has no role to play in that (Self cooking); Water is a fluid that flows through the pipe and will be delivered at any given point and at any given time in predetermined quantities and pressure in my urban water network based on the demand (Swiggy). Water is a basic right that every urban citizen is entitled to (Langar). Water is an economic good that must fetch good returns on the investment (Saravana Bhavan). People need water and cannot afford to pay all the cost that are incurred in the production and distribution and need to be supported (Amma Unaavagam). These are some of the paradigms that shape the physical and organisational setup of the urban water systems. Words arise out of mindset and words matter. Al Washali et al.,(2016) argues that " Leakage" is an appropriate word to be used in place of real loss. It may not appear like a drastic suggestion but there is a world of difference between these two words, i.e.

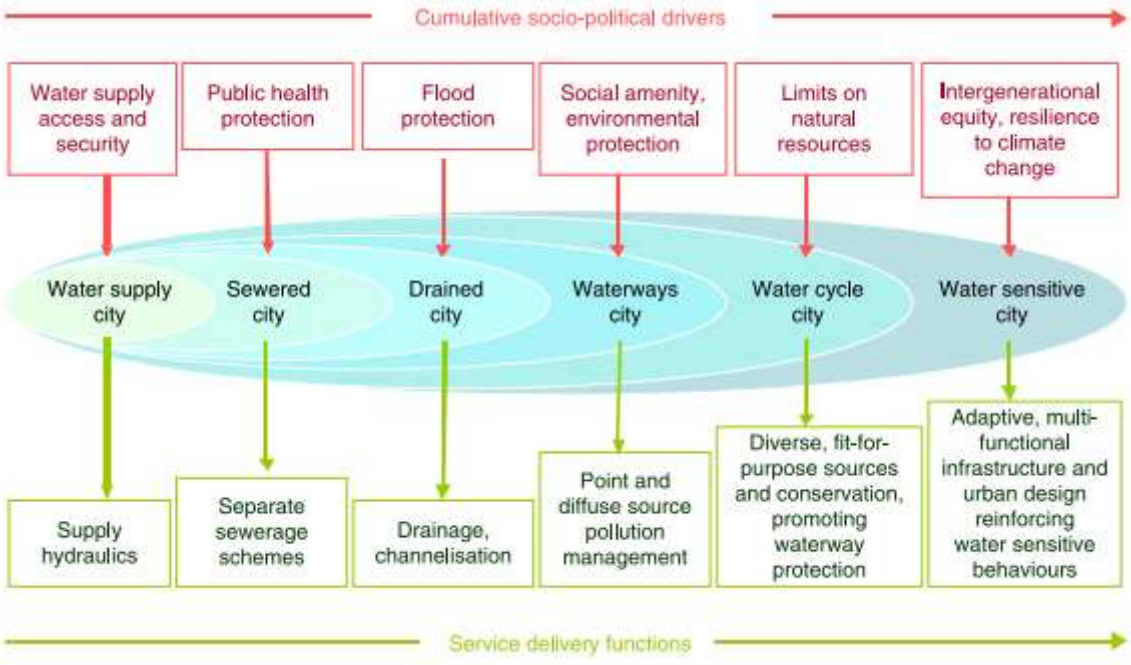
two completely different mindsets. What comes to our mind when we talk about profit or loss? 99.99% of the time out mind will be filled with the image of money. However, the word leak or leakage naturally makes us think about something that is fluid, a flowing liquid that is running away from a place where it is supposed to stay. We subconsciously align ourselves with the flow when we think of a leak or leakage

Some of the paradigmatic questions that we engineers can ask ourselves are: Why is fixing all leaks necessary for a 24x7 supply? Why cannot we give 24x7 supply and shift the responsibility of water conservation behaviour to the urban citizens? Why don't we promote the idea of 24x7 water supply as the real freedom or liberation among the urban citizen and challenge them to exercise it? Might sound crazy and strange but this needs a "Let go" mindset and the will to face the backlash from various quarters. Can we change from command and control paradigm to accept and attend paradigm? Can we "Let go" the system, like a newly walking or cycling child who does not needs support but supervision? We can draw inspiration from a child or from humongous systems such as United Nations that frame the rules and best practices and let the member nations to follow, but is always on standby to support. The SDGs are a good example what a change in paradigm can do to complex systems. For example this Tailor made Training is based on the paradigm that water loss management goes beyond the engineering aspects and should encompass social, political and cultural aspects as well. Although it is hard to change the mindset, mindset has the utmost influence on system creation.

- ***Reflection exercise: Has my urban water system undergone any paradigmatic change? What kind of paradigmatic change can my urban system needs? What change of mind set can be sustained in my urban water systems? What are the changes that cannot be sustained in my urban system?***

1. This too will change. Change of mindset are like big clouds. They can bring a lot of rain but they will also drift away and keep changing. One can predict and get ready for the onset of change but cannot stick on to a change for long time. Though this might appear a philosophical it is the hard reality. Paradigms keep changing and history is replete with examples of such systems. We never thought fifty years ago that we will all be communicating with each other through our mobile phone and attending online classes sitting at homes in India conducted by someone in Netherlands with IT support from someone sitting in Croatia. Things keep changing and systems keep changing because of the changes that happens within and outside the systems. Systems creates change and changes create systems as well. We, the people, created culture and culture shapes us and is continuously evolving. What was relevant in the past may be relevant today or may not be relevant today and in the future? There is no point in arguing that this is how things were done in the past, this is how it is being done now and this is how it will be done in the future. Urban water systems have undergone paradigm shift from time immemorial, transitioning from a water supply city to water sensitive cities.

In the present context, the adoption of SDGS into our everyday urban water supply practice can help us handle the change better. Who knows, things might change in 2030 again when the SDGS would be nearing their end of lifetime and could be reborn as something else, as SDGs themselves are the reincarnation of MDGs. Flexibility with respect to mindset, practices and protocols are necessary to handle change. As engineers we know that every leak is unique and no protocols or standard operating procedures work when we come in contact with a leak. Being creative & pragmatic is the key to plug the leaks or to let them leak.



Urban Water management transitions (Brown et.al, 2009)

- ***Reflection exercise: What is the next change in What change of mind set can be sustained in my urban water systems? What are the changes that cannot be sustained in my urban system***

Systems thinking in a nut shell

Ancient Wisdom

"எப்பொருள் யார்யார்வாய்க் கேட்பினும் அப்பொருள்

மெய்ப்பொருள் காண்ப தறிவு"

Verse 423, (Thiruvalluar 31 BC)

"Wisdom is listening to others thoughts and from them drawing

lessons to blend with one`s own to make its subtle laws"

Translation based on Gopalkrishna Gandhi (2015)

"நோய்நாடி நோய்முதல் நாடி அதுதணிக்கும்

வாய்நாடி வாய்ப்பச் செயல்"

Verse 948 (Thiruvalluar 31 BC)

Only when of the disease, its cause and likely cure you have insight

Then and then alone go about setting it right

Translation based on Gopalkrishna Gandhi (2015)

"வெள்ளத் தனைய மலர்நீட்டம் மாந்தர்தம்

உள்ளத் தனையது உயர்வு"

Verse 595 (Thiruvalluar 31 BC)

"With rising flood the rising lotus flower its stem unwinds;

The dignity of men is measured by their minds."

Translation based on Pope et al. (1886)

These three Thriukkural verses more or less summarises systems thinking and its application in urban water systems. Before we dive in to the essential technical and economic aspects of water loss let us all once again reiterate and remember that "Systems cannot be controlled they can only be designed and redesigned; trained and regulated". The phrase "control system" is an oxymoron. Urban water system is an organised chaos. It is a little India, a system with diverse self-organising subsystems like our human body. We have to trust ourselves, trust the system and let go!!!

Systems thinking in a nut shell

Modern outlook for living in the world of systems

Donella Meadows (2008)

1. Get the beat of the system
2. Expose your mental models to the light of day (Discuss and don't be shy)
3. Honour, respect and distribute information
4. Use language with care and enrich it with system concepts
5. Pay attention to what is important and not just what is quantifiable
6. Make feedback policies for feedback systems
7. Go for the good of the whole
8. Listen to the wisdom of the system
9. Locate responsibility in the system
10. Stay humble – stay a learner
11. Celebrate complexity
12. Expand time horizons
13. Defy disciplines
14. Expand the boundary of caring
15. Do not erode the goal of goodness

6. *Creating utility specific water loss management and asset management plans*

For a change let us begin this lesson with a reflection 😊

Reflection exercise: What did I learn from the Asset management lessons in the NRW module in BEWOP learning platform? Is that relevant or applicable in my water utility? Are the physical condition and the financial condition of my water utility the deciding factors in my context? I am thinking about asset management action from a short-term perspective or from a long-term perspective? How long is long in a long-term perspective?

If the reflection based on the earlier modules on asset management prompted you to answer 'yes' and to opt for short term asset management, then it is time to broaden our knowledge on contextual utility specific asset management plans.

6.1 Think Globally act locally

Cities, especially urban water utilities, tend to suffer due to the swing between extremities of paucity and in plenty, be it water, money or authority. This can be attributed to the lack of long term, as well as, emergency management that cannot cope with the disruption when there is too less water or too much water. The events surprise us as we do not pay attention to the trends or have not thought enough about how the disruption might travel across our systems. As a parent we don't feel overtly concerned about our kids playing hide and seek, but we are concerned about where and when they play hide and seek, not in the darkness

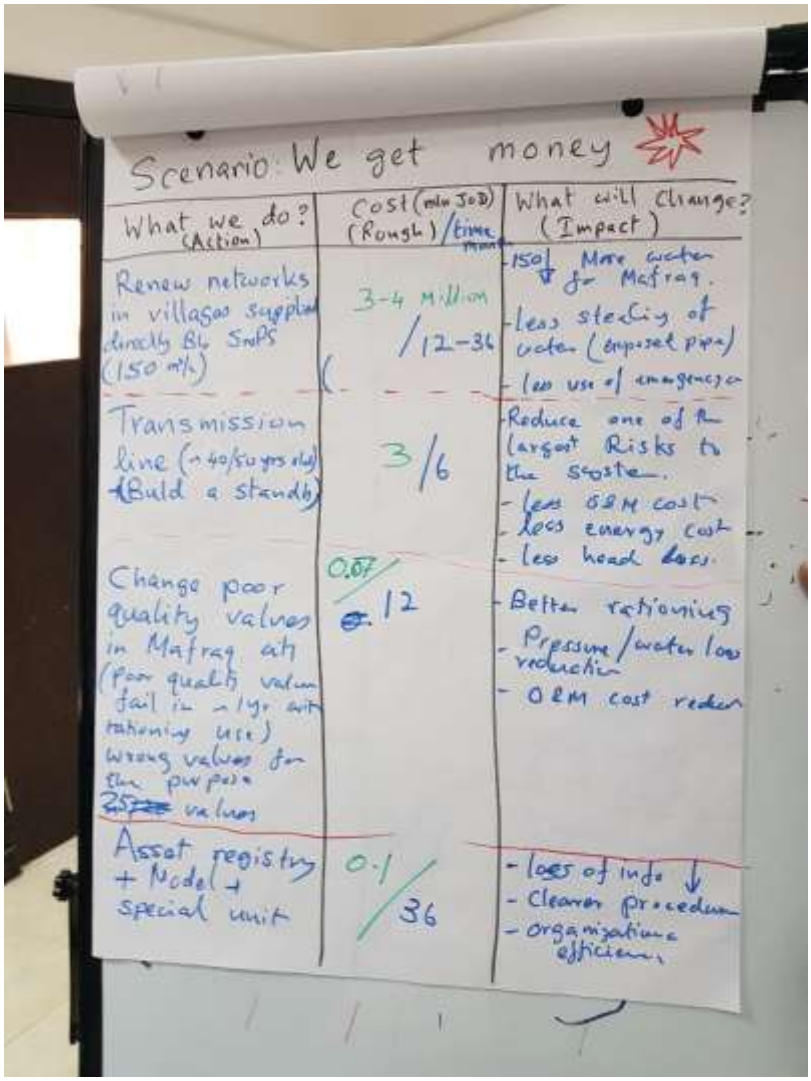
and definitely not hiding in the washing machine. For example, Chennai and the monsoon always play hide and seek with each other. The Chennai 2017 floods were attributed to the "save as much you can" mentality from the past drought experiences which clouded the judgement of the engineers and mangers in spite of the heavy rainfall projections in the coming days. The operation and management of the primary water reservoir was a trigger that could have been managed prudently if such scenarios were anticipated and strict operating protocols put in place that are devoid of administrative or political interference. This can be said about the other urban utilities as well, where the buildings comes first without even thinking about roads, water supply, sewerage and drains. These local developments happen, with some kind of local self-organised, without the systems hierarchical coordination between utilities and across levels leading into suboptimal performances and failures. The thinking and action become too local without looking the big picture at the city level, river basin or district or state or country level. Even when resources are available under a state or country level programme, the local context is window dressed to give it the required appearance of the programme objective to get the resources. We engineers are good at firefighting as and when the problems arise, but is it not wise to thing about preventing these fires erupting in first place? This is what thinking in systems lead to you. We need to understand the context where our system is operating and why it behaves the way it behaves. An engineer as an asset manager should start thinking about the following question before learning sophisticated GIS based asset management tools or real data acquisition and processing systems: What is my context? What are my boundaries and what my drivers? How does my water system (including staff and urban citizens) behave or react during normal times and during extremities? Let us remember that we are urban citizens first and utility engineers next. There is no point in comparing the water loss percentages of Chennai and Pune to prove our performance superiority or indulging in blame game, when Pune is not Chennai. Cities in Australia learned it through a hard way after the millennium droughts that conventional thinking on design, construction, operation and management of assets are not good enough for the changing urban and climate scenario. Some of the water augmentation infrastructure such as seawater desalination plants are dead investment and white elephants, draining the exchequer of the Australian commonwealth.

Asset management in a process which not only helps the engineers and managers to maintain the urban utilities in mint conditions but also help them achieve the overall system goal. As we all know that the systems goals change with the change of mindset or change of objectives such as Millennium development goals or Sustainable development goals at the global levels; or Swachh Bharat or Total Sanitation Campaign at the National level. The change in political objectives every five or year at the national and state level is the most certain thing that happens. How can we engineers keep over asset management process flexible and fit to change or the transition smoothly to that top down changing political objectives without causing a shock in that system? What if the Ministry of Climate Change and Environment comes with a Bench marking for urban water utilities on their environmental compliance, how they mitigate climate change and actions taken to adopt climate change? Although management of municipal assets alone does not address these challenges, it would address

a major part of climate action challenges. Stocking enough water buffer at source to demand management practices at citizen end to usage of energy efficient pumps, all these actions are strongly linked to management of assets. If you are interested in knowing more about the how to understand the local context from a global perspective you can find two interesting infographic videos and research publications relevant to urban adaptation in following blog [Urban adaptation – Secondary cities of Global South](#).

6.2 Questioning asset management

Understanding the context in which the assets are managed gives us the opportunity to critically analyse the long-term needs and short term needs, which also gives us the opportunity to explore how we can address both the short and long term objectives. This leads us through a completely different process of asset management that not only looks at the conditions of assets and their performance at present, but also about their behaviour in the changing future. Generally, Asset management comprises four questions, separate from those related to SP: (i) What we have?—Asset inventory; (ii) What is the condition of assets?—Condition assessment; (iii) What is the importance of assets?—Identifying assets important for service provision and continuity of services; (iv) What to fix first?—Risk-based prioritization of O&M and renewal. However, analysed from long term systems perspective, i.e., the asset management process at three levels—system functioning, network functioning, and object functioning, suitable answers are to be found for the following five questions as well : (i) What are the required long-term service levels? Additionally, in which environment must this service level be delivered?; (ii) What is the current state of the assets? What will be the future performance of the infrastructure system?; (iii)Which assets are critical for achieving the long-term service levels?; (iv) What are the best minimum lifecycle cost continuous improvement programs and operation and maintenance strategies?; and, (v) What is the best long-term funding strategy? Hence asset management is strongly coupled with strategic planning, where strategic planning sets the context or



the play field for asset management and asset management provides the inputs from the playground for planning the objectives. A contextual fit-for-purpose infrastructure asset management framework is necessary to address the multiple challenges of (a) minimizing the risk of current service levels from deterioration due to internal causes like ageing systems, as well as external causes such as limited water resources, climate change impacts, and rapid population growth; (b) addressing the critical shortfalls in the current service levels by system improvement ; and (c) prioritizing investments and measures of operation and maintenance.

Read the peer reviewed article "Fit-for-Purpose Infrastructure Asset Management Framework for Water Utilities Facing High Uncertainties" to know more about framing critical questions about the local context in asset management before embarking on the exercise on asset management. Understanding how the systems would behave in various scenarios in the future can help us think about actions that can ensure the required performance across the various scenarios or select actions that can lead to a smooth transition with minimal disruption. We can sequence the present asset management, utility and service management actions in a such a way that it can transition us towards multiple plausible futures. If you want to read more about how this can be done read the peer reviewed article " Capturing the changing dynamics between governmental actions across plausible future scenarios in urban water systems" , where the local context has been analysed and actions presented that leads to different water quality in various future scenarios is a tourist village in China. The dynamics between the asset management actions can be easily done by you by performing a SWOT (Strength, Weakness, Opportunities and Threat) analysis of these actions with you team. *Think about the SWOT of your day to day actions and your planed actions in the upcoming budgetary cycles and see how can they play with each other and their dynamics change*. May be your prioritisation of your asset management actions based on risk analysis might change after you had done a SWOT analysis of the action with your team.

If you are interested in understanding asset management from a Flood risk management perspective have a look at FAIR – Asset management of flood infrastructure , a free online course at IHE Delft's open courseware platform.

6.3 System thinking outcomes in an integrated asset management system

Whether it is water supply asset management or flood risk asset management, domain specific understanding at system, network and object assets is important as it leads to better identification of problems and opportunities within and across these domains. Upon assessing these domains in the water supply systems of emerging economies the MSc students of asset management course at IHE Delft identified a number of challenges which is presented in the figure.

Asset management challenges in SCGS

Object level	Network level	System level
	Every day operational issues	Service inequalities
	Reactive maintenance	Skewed planning
Shortage of infrastructure		Lack of political continuity or clarity
	Epidemic breakout and contingency measures	
Vandalism		Immigration (refugee influx)
	Illegal connections	
Weak enforcement and regulation		Lack of policy
Lack of integration across departments		
Inappropriate solutions Lack of multiple perspectives Lack of knowledge, awareness and willingness Mindset rooted in past practices Lack of information about assets and their behavior Encroachments or illegal settlements		

From the drawing we can infer that such an analysis based on a whole systems approach can improve the understanding of system and drivers on the system in specific domain or across domains. This can be witnessed from the broad range of challenges ranging from refugee influx to reactive maintenance to shortage of infrastructure.

Reflection exercise:

- *Challenge yourself and try to elucidate answers at object level, network level and system level asset management challenges in your urban water systems context.*
- *How can I make utility specific asset management plans based on the following concepts*
  - *a) Fit-for-Purpose Infrastructure Asset Management Framework for Water Utilities Facing High Uncertainties*
  - *b) Asset management software tool*
  - *c) Urban adaptation – Secondary cities of Global South*
  - d) *Capturing the changing dynamics between governmental actions across plausible future scenarios in urban water systems*

- Is it possible to analyse or reinterpret IWA water balance method using systems thinking? Can such an interpretation be applicable in my urban water systems context? Will it help me in identifying the most effective leverage in my urban water system to bring about change in the system? Will my order of prioritisation of water loss reduction actions change when analysed through systems thinking lens? What kind of changes can I anticipate in my system based on a Systems thinking water balance understanding? Is it worth the effort?
- *What are the system leverages that can be studied in detail using the water distribution system modelling tools? Is it with resect to understanding the flows, behaviour of flows? Can we understand the way the urban water system is structured? What are the balancing loops and runoff loops that can be identified or Can you use the hydraulic model to understand the interconnections and rules? Can the model be used to check the resilience of the network? Can urban water system models be used to prioritise actions that can maximise the change of behaviour in urban water systems?*

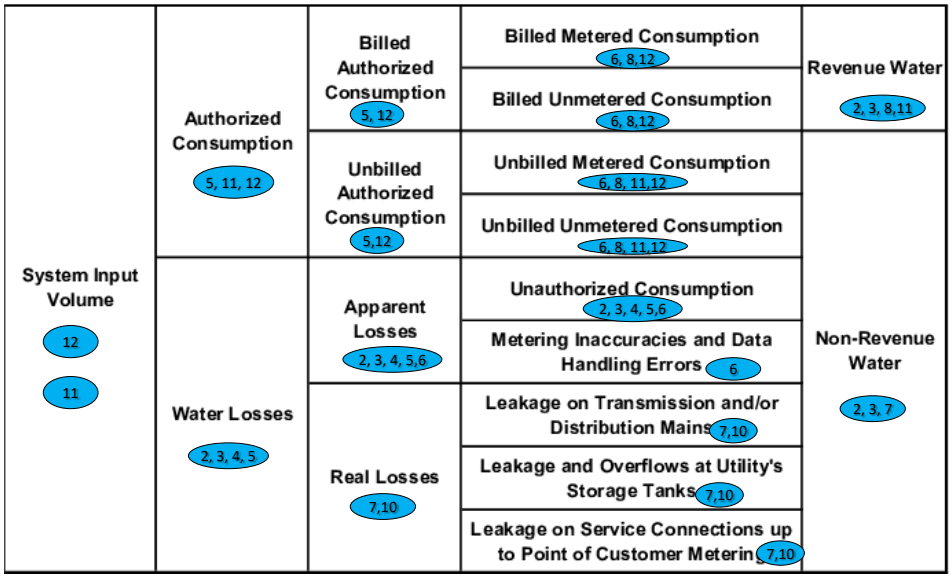
7. The way forward: Thinking in water systems

This guidance literature on water loss attempted to introduce the multiple perspectives of urban water loss using the systems thinking. The intention behind this approach was to enable our municipal water supply engineers to prioritise reasoning over numbers. Why is water lost should be the first question to be asked and answered and not how much is lost, which can always be approximated. Thinking first about why is water lost enables the municipal engineer to critically examine the systems from various perspectives and understand the system.

7.1 Systems leverage mapping of IWA water balance

Actions that are taken after understanding the system behaviour and the underlying structure can result in sustainable outcomes. Also understanding the systems enables the identification of leverage points in the urban water system or the urban system where change can be affected to maximise its effect. The diagram below is an outcome of an analysis of the IWA water balance table using systems thinking to identify the leverage points. This is a generic analysis and it will vary from context to context.

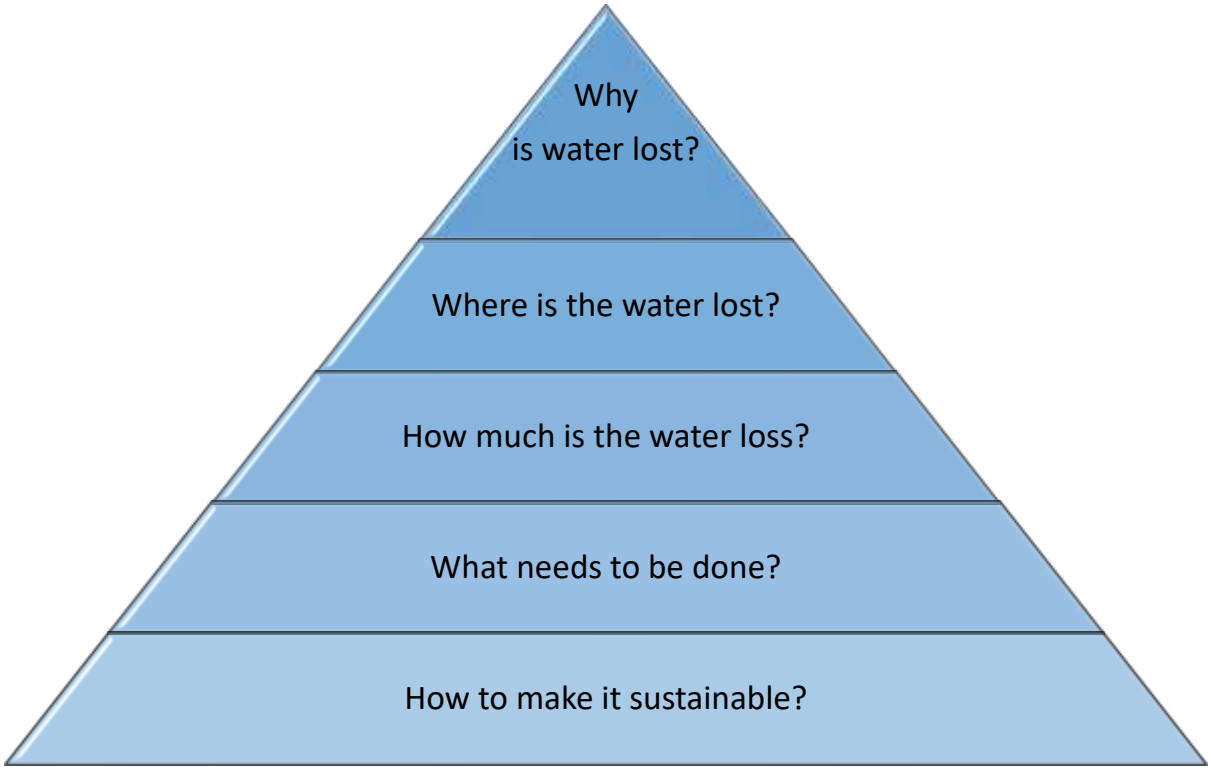
# Rank	System Leverage
1	Changing mindset
2	Mindset
3	Goal
4	Resilience
5	Rules
6	Information
7	Runaway loop
8	Balancing loop
9	Delays
10	System structure
11	Buffer
12	Flows



The system input was given #12 and #11 as the flows and buffers do not influence the systems behaviour to the greater extent. Real loss components were assigned the ranks #7 and #10 as they pertain to structural changes and prevention of physical leaks that disrupts the runaway loop. Water losses, Revenue water and Non-Revenue water were accorded higher ranks such as #2, #3 and #4 as it is the goal and engineering economic mindset that makes us focus on the revenue aspect of water lost. This table is actually a revenue balance table not a water balance table, which is based on the revenue maximisation goal arising out of the engineering-economic mindset. The table can be redrawn with any typical mindset which we look at the urban water systems, based on which we can reclassify the water streams. Don't you think if the goal was about maximising Equitable water or Clean energy water, the

classifications would result in a completely different water balance table? IWA water balance table should be seen as a precedence or a trendsetter for classification of urban water streams based on a goal and mindset and should not be seen as the classic or the only process to analyse and address water loss in urban water systems. If it is possible to classify urban water streams as revenue and non-revenue streams, it is also possible to classify them based on some other goal from a different mindset. Try to redraw the water balance table based on a goal which you think is appropriate for your city or town. *A change in mindset can lead to reclassification of the components in the water balance table.*

The pioneer in leak detections and management *Allan Lambert* always emphasis that the leak management and asset management is about pressure management. Nowadays there is plenty of effort put in by water utilities to manage pressure in the network to reduce leaks and to maintain their assets. There is even a movement in the direction towards differential pressure zoning or point of pressurisation, such as fire hydrants, to avoid pressurising the entire system with high pressures. This is a change of goal or a change of mindset on the operators or managers that lead to the transition from leak management to asset management to pressure management over the decades. This can be interpreted as the shift in focus from "How much water is lost?" to "What needs to be done?", which gives hope that the focus can be diverted to why water is lost? Prioritising reasoning over quantification can be achieved by putting why is water lost on top and how to make the systems more sustainable as the foundation of the reasoning pyramid. The quantity lost will be an outcome of why water is lost, which in turn would be the driving force for finding out how we can reduce losses sustainably.



7.2 What is lost?

In addition to water and revenue, trust is the most important buffer in urban water systems. The most important and fragile link in most of the Indian urban water systems is the trust that urban citizens have on system. Trust is a two-way street between the water utility and the urban citizens both trusting each other, the former trusting the latter on paying for services and conserving water, whereas the later trusts the former in the provision of services. Managing and maintaining trust of the people on urban water supply systems in difficult than managing the water and revenue leaks as trust is fragile and takes a longer time to build and short time to break. Letting down the people with poor water services is a breach of trust and is an equivalent of a heartbreak. It is a soft spot and weak link in the urban water systems. The strength of the chain lies in its weakest link. How do we strengthen the weak link, in addition to improvement of services and paying the bill in time? Many be technology can help. These days, information and technology specialists talk a lot about blockchain. It is believed that blockchain is a medium for exchange or verification of trust among people, like the internet which is the medium for exchange of information. Block chain is promoted as the internet for trust and internet of trust. I neither understand this technology nor its way of functioning. If trust is the most important buffer in our water supply systems why not explore and seek the help of blockchain in building it. Be it a child that is after a chocolate or the Pharaohs who built the mighty pyramids or our water engineers who create mighty canals, all the systems arise out of a mindset and are inspired by some kind of trust in their actual reality or in an imaginary afterlife. In a cash-strapped urban utility context, the need for stable revenue inflows and outflows is bound to cloud our perception and decision-making. May be a little bit of reflection based on ancient wisdom might be of little help to seek the appropriate leverage of sustainable change in our urban water systems. *When revenue is lost nothing is lost, when water is lost something is lost, when trust is lost everything is lost. So, what have we been losing through our urban water systems? What is lost? Only, you have the answer.*