Urban Water Systems

Improving Sustainability and Developing Resilience

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Smart Cities Workshop - 18th and 19th May, 2017
1. Water Supply
   1. Present status and challenges
   2. Strategies for NRW reduction
2. Wastewater treatment – technology selection
3. Closing the loops: Nutrients and Water
Present Status of Water Distribution Systems in India

• Water supply in most of the Indian cities and towns, at present, is intermittent, normally 2-3 hours in morning and 1-2 hours in evening.

• As water is supplied for limited hours, peak factor sometimes rises to 10-12 or even more (Sashikumar et al., 2003).

• Due to empty reservoirs, end consumers do not get desired pressure and hence, there is inequitable distribution of water.

<table>
<thead>
<tr>
<th>Population</th>
<th>Peak factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 50000</td>
<td>3.0</td>
</tr>
<tr>
<td>50000 to 200000</td>
<td>2.5</td>
</tr>
<tr>
<td>Above 200000</td>
<td>2.0</td>
</tr>
</tbody>
</table>

CEPHEEO (1999)
Present status…. Contd…..

• There are no DMAs formed and water distribution systems emerging from all reservoirs are interconnected.

• Most of the systems are not metered

• Inequitable Distribution - Consumers residing near reservoirs & in low-level zones, get more pressure, consumers residing at tail end pockets do not get water as per minimum needs.

• It is practiced to divide city distribution in different zones by providing control valves and bifurcating supply timings

• Such attempt has no scientific standing and is based on experience of field staff.
Need For Rehabilitation

- Utility Life, Housing Connection? & Coverage?
  - Schemes more than 25 yrs. Distribution losses 25-40% & Coverage maximum 70%
  - Inadequate coverage and service standard of WSS

- Non Revenue Water & Unaccounted For Water (NRW & UFW)
  - Losses from Transmission till Distribution =30-55%
  - High UFW, NRW & Energy cost in Water System

- Sustainability - Running Cost & increasing expense?
  - Avg Energy Cost = 40%, Avg Salary & Wages = 50% O&M cost?
  - So Revenue from?
  - Inefficient O&M of WSS system

- Production Cost & More consumers with higher expectation?
  - No Tariff & Regulation but Human Right as UNO socio economic structure?
  - Low water tariff, poor billing & collection & Long Lead time

Percentage loss in Water Supply System – Standard \(\rightarrow\) Actual

<table>
<thead>
<tr>
<th>Source</th>
<th>Standard</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>98</td>
<td>80</td>
</tr>
<tr>
<td>Distribution</td>
<td>85</td>
<td>60</td>
</tr>
</tbody>
</table>
Non Revenue Water (NRW) is an important issue facing water utilities considering it has an estimated value of over $14 billion per year worldwide.

(Source: World Bank, 2006)

### Table 1: Estimates of Worldwide NRW Volumes

<table>
<thead>
<tr>
<th></th>
<th>Supplied population (millions, 2002)</th>
<th>System input (L/day)</th>
<th>Level of NRW (% of system input)</th>
<th>ESTIMATES OF NRW</th>
<th>Volume (billions of m³/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ratio</td>
<td>Physical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Physical losses</td>
<td>Com-mercial losses</td>
</tr>
<tr>
<td>Developed countries</td>
<td>744.8</td>
<td>300</td>
<td>15</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Eurasia (CIS)</td>
<td>178.0</td>
<td>500</td>
<td>30</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>Developing countries</td>
<td>837.2\textsuperscript{a}</td>
<td>250\textsuperscript{b}</td>
<td>35</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td></td>
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</tbody>
</table>

\textsuperscript{a} Calculated from the increase in population

\textsuperscript{b} Calculated from the increase in per capita demand

Source: World Bank, 2006
Maharashtra Sujal Nirmal Abhiyan (MSNA): A Government of Maharashtra initiative

|-----------------------------|-----------------------------|-----------------------------|
| • Consumer survey, detection of illegal connections  
• Bulk Flow Meters  
• Water audit  
• Energy audit  
• Hydraulic modeling  
• Geographic Information System (G.I.S.) mapping  
• Computerization of Billing  
• Measuring Existing Service Level Benchmark (SLB) | • 24 X 7 pilot project  
• Sustainable water source development  
• 80% Household Metering  
• 80% recovery of O&M cost  
• 80% collection efficiency  
• MIS at various level  
• Establish water tariff frame  
• Upgrading SLB to 80% | • Achieving 100 % of all Benchmark  
• City wide 24 X 7 water supply system  
• 100 % consumer metering  
• 100 % O & M cost recovery  
• 100 % Billing & collection efficiency |
Tools for Situational Analysis / Reforms

- GIS & Consumer Survey
  - Geography of the Project Area
  - Landbase & Utility Network Maps
  - Baseline Data Collection & Analysis

- Hydraulic Modeling
  - Steady State & EPS
  - Hydraulic Zoning
  - Recommendations for 24X7

- Flow Measurements & Water Audit

- Energy Audit
  - Energy Audit of all Electrical Equipments in WSS
  - TOD Tariff Utilization & Unity PF Achievement
  - Recommendations for Bill Reduction

- Computerized Billing Software
  - A System of HW & SW
  - Data Digitization
  - Customized Billing & Training

- FM Installation & DMA Isolation
- Domestic Metering & Water Audit
- Recommendations on improvisation of WSS & hence 24X7
GIS
A System which involves collecting/capturing, storing, processing, manipulating, analyzing, managing, retrieving and displaying data (information) which is, essentially, referenced to the real-world or the earth (i.e. geographically referenced)

**Property Survey**
- Baseline Data Generation
- Digitized satellite image
- Geo Coding of consumers
- Identify illegal / Suspicious connections
- Demand allocation
- Socio Economic information

**Water Network**
- Digital Mapping Of Water Supply System
- Attribute Collection for the Pipeline, Valves, etc.
- Road network, landmarks, Utilities and properties visible
- Contour Elevation
- Planning of Zones and DMAs
Analysis in GIS

- Add population and demand attributes to Ward Boundary Layer
- Check and rectify the attribute data

Base Data

- Population forecasting
- Estimation of Demand
- Estimation of ESR wise demand
- Creating pumping schedule

Analysis in HM Software

- Import Vector Data
- Validation and Calibration
- Zoning
- Demand Allocation
- Scenario Formulation
- SS / EPS Analysis

Data Transfer

Data

Base Data

Rehabilitation plan is prepared

Road map to 24 X 7 prepared

Hydraulic Modeling Report

Hydraulic Modelling (Kalbar et al., 2014)
# Standard Water Balance Chart (IWA, 2007)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System Input Volume</strong></td>
<td>Flow Meter Readings at Jack Well/ Raw Water Pump house Outlet or any other water source</td>
<td><strong>Authorized Consumption</strong> (Billed Authorized Consumption + Unbilled Authorized Consumption)</td>
<td><strong>Billed Authorized consumption</strong> (Billed Metered Consumption + Billed Un-metered Consumption)</td>
<td><strong>Billed Metered Consumption</strong> (Including water exported) Council's Water Meter Readings/ Billing Data</td>
</tr>
<tr>
<td><strong>Water Losses</strong> (System Input Volume – Authorized Consumption)</td>
<td><strong>Unbilled Authorized Consumption</strong> (Unbilled Metered Consumption + Unbilled Un-metered Consumption)</td>
<td><strong>Unbilled Metered Consumption</strong> Council's Water Meter Readings/ Billing Data Included unbilled connections like Stand-posts, Govt. Offices, Temples etc.</td>
<td><strong>Unbilled Un-metered Consumption</strong> Water Meter Readings/ Council's Billing Data Included unbilled connections like Stand-posts, Govt. Offices, Temples etc.</td>
<td><strong>Apparent Losses</strong> (Un-Authorized Consumption + Metering Inaccuracies)</td>
</tr>
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</table>

Pradip Kalbar
Methodology for Water Audit

Audit strategy

Supply side
- Source
- Raw and treated water transmission
- Treatment plants
- Sumps, MBRs and service reservoirs

Demand side
- Distribution network
- Consumer connections
- Metering-
  - which is a voluminous work
Typical Water Balance for Water Supply Scheme

\[
10-(10\times0.06)-(9.4\times0.02) = 9.212 \text{ MLD}
\]
Results of Water Audit for 38 Towns

(Source: Kulkarni et al. (2014))
Break-up of Revenue and Non-revenue Water

- Revenue Water 45.86%
- Non Revenue Water 54.14%
- Unbilled Authorised Consumption 4.16%
- Unauthorised consumption/Metering inaccuracy 1.63%
- Transmission loss 3.03%
- WTP loss 14.13%
- Reservoir & Distribution 31.18%

- Non Revenue Water is found to be 54.14 %
- What is the ground reality of this loss? Let's take a look at some actual site photographs.....
Visible Leakages & Water Loss

Valve Leakage On Transmission Main

Valve Leakage On Distribution Network
## Present Service Level Benchmarks (Audit Data)

<table>
<thead>
<tr>
<th>Key Performance Indicator</th>
<th>AVERAGE</th>
<th>STANDARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage of Water Supply Connections</td>
<td>50 to 76 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Per Capita Supply of Water (LPCD)</td>
<td>41 to 132</td>
<td>75 or 135</td>
</tr>
<tr>
<td>Extent of Metering of Water Connections</td>
<td>0 to 93%</td>
<td>100 %</td>
</tr>
<tr>
<td>Extent of Non-revenue Water</td>
<td>37 to 76%</td>
<td>17 to 20%</td>
</tr>
<tr>
<td>Continuity of Water Supply (hrs per day)</td>
<td>2 to 6</td>
<td>24</td>
</tr>
<tr>
<td>Cost Recovery in Water Supply Services</td>
<td>19 to 93 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Efficiency of collection in WSS Related Charges</td>
<td>60 to 95 %</td>
<td>100 %</td>
</tr>
</tbody>
</table>
Energy Audit

• Energy audit another important analysis required to make WSSs self sufficient economically
• Improves environmental performance of the system
• Typical Energy conservation measures
  – Time of day tariff
  – Power factor penalty and incentive
  – Replacement of pumps

<table>
<thead>
<tr>
<th>MSEB Tariff Hrs. of Operation</th>
<th>Zone</th>
<th>INR (Added with base tariff)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0600 to 0900 hours (6am to 9am)</td>
<td>B</td>
<td>0.00</td>
</tr>
<tr>
<td>0900 to 1200 hours (9am to 12 am)</td>
<td>C</td>
<td>0.80</td>
</tr>
<tr>
<td>1200 to 1800 hours (12pm to 6pm)</td>
<td>B</td>
<td>0.00</td>
</tr>
<tr>
<td>1800 to 2200 hours (6pm to 10pm)</td>
<td>D</td>
<td>1.10</td>
</tr>
<tr>
<td>2200 to 0600 hours (10pm to 6am)</td>
<td>A</td>
<td>-0.85</td>
</tr>
</tbody>
</table>
Results of Energy Audit of 25 Towns

(Source: Kulkarni et al. (2014))
Strategies for NRW Reduction
Leak Detection and Control

Four Main Approaches for Leakage Control

Source: IWA, 2007
Reaching to Consumer

• Present design practice is bigger size of storage reservoirs (e.g. 10 ML storage (not demand) which will serve about population 220,000 or 0.22 million)

• Have small storage tanks in the system
• For a city level 10,000 – 12,000 population on one storage tank and have multiple outlets with 2000-2500 population
• This will help maintaining influence zone of the tank
• This will mimic the situation of having the storage at the roof of the consumer – reaching the consumer is key
• This will help in dampening of the peak factor and hence will make optimized investment
• Making DMAs at field will never happen in India hence this solution is more logical
Pressure Management

<table>
<thead>
<tr>
<th>Technical performance category</th>
<th>ILIa</th>
<th>10 m</th>
<th>20 m</th>
<th>30 m</th>
<th>40 m</th>
<th>50 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed countries</td>
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<tr>
<td>Developed countries</td>
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<tr>
<td>1% reduction in pressure will reduce current leakage rate by between 0.55 and 1.5% and that most importantly, effective pressure management ensures full benefits from active leakage control (IWA, 2007)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Developing countries</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1–4</td>
<td>4–8</td>
<td>8–16</td>
<td>&gt; 16</td>
</tr>
<tr>
<td></td>
<td>&lt; 50</td>
<td>50–100</td>
<td>100–200</td>
<td>&gt; 200</td>
</tr>
<tr>
<td></td>
<td>&lt; 100</td>
<td>100–200</td>
<td>200–400</td>
<td>&gt; 400</td>
</tr>
<tr>
<td></td>
<td>&lt; 150</td>
<td>150–300</td>
<td>300–600</td>
<td>&gt; 600</td>
</tr>
<tr>
<td></td>
<td>&lt; 200</td>
<td>200–400</td>
<td>400–800</td>
<td>&gt; 800</td>
</tr>
<tr>
<td></td>
<td>&lt; 250</td>
<td>250–500</td>
<td>500–1,000</td>
<td>&gt; 1,000</td>
</tr>
</tbody>
</table>

Source: Roland Liemberger.

m = meters

a. The Infrastructure Leakage Index (ILI), a leakage benchmarking indicator developed by the IWA, is the ratio between the present volume of physical losses to the minimum achievable volume at the present pressure. (It was used to develop this table, but is not discussed in this report.)
Pressure Management Summary

- PRV (cost & maintenance)
- Masterpieces (multiple masterpieces in series rather than one long masterpiece)
- Changing inlet to DMA
- Separate outlets for areas with difference in elevations (one of the best strategy)
- Introduction of BPT at the outlet of Storage Tank
Flow Measurement and Automation

• Consumer Metering
• Leakage detection system
• Automatic ESR management system
• Ultrasonic meters.
Summary – Water Supply

• Improving water supply service is a step-by-step process with a defined direction

• Making supply equal to the demand is an operator skill

• Reaching to consumer, peak factor dampening, pressure management and leak control is key (data is needed)

• It is necessary to undertake reform works for rehabilitation of WSSs

• Reform works gives an opportunity to ULBs to understand their WSSs better, both technically and financially
Selection of Appropriate Technology for Wastewater Treatment: Life Cycle Approach
## Status of Water Supply and Sewage Generation in Indian Cities

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Class I cities and Metros (population &gt; 1,00,000)</th>
<th>Class II cities (population 50,000 to 99,000)</th>
<th>Mumbai</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Cities</td>
<td>498</td>
<td>410</td>
<td>--</td>
</tr>
<tr>
<td>Population (million)</td>
<td>227.6</td>
<td>30</td>
<td>14</td>
</tr>
<tr>
<td>Water Supply (MLD)</td>
<td>44,769</td>
<td>3,324</td>
<td>3,000</td>
</tr>
<tr>
<td>Water Supply (LPCD)</td>
<td>179</td>
<td>120</td>
<td>204</td>
</tr>
<tr>
<td>Wastewater Generated (MLD)</td>
<td>35,558</td>
<td>2,696</td>
<td>2,400</td>
</tr>
<tr>
<td>Wastewater Generation (LPCD)</td>
<td>156</td>
<td>90</td>
<td>163</td>
</tr>
<tr>
<td>Wastewater Treated (MLD)</td>
<td>11,553 (32.5%)</td>
<td>2,244 (8.7%)</td>
<td>2,130 (80%)</td>
</tr>
<tr>
<td>Wastewater Untreated (MLD)</td>
<td>24,005 (67.5%)</td>
<td>2,472 (91.7%)</td>
<td>270 (20%)</td>
</tr>
</tbody>
</table>

(Source: CPCB, 2009)
Introduction

• Wastewater treatment technology / alternative selection is a multidimensional problem [involves end-user community, Urban Local Bodies (ULBs), technology providers, Decision Makers (DMs) etc.]

• Many technological alternatives are available in the market (ASP, SBR, UASB, MBR)

• Each of the technology providers have their own justification for the technology

• Natural Treatment Systems (NTSs) are neglected technologies due to non-commercialization – although has huge potential of application in India
Alternatives in wastewater treatment and reuse

(Source: Arceivala and Asolekar, 2007)
For Building Scale in Dense Urban Areas
Process Flow Diagram of Building Scale STP based on MBR
Building Scale Solution in Sub-Urban Area
Selection of Appropriate Wastewater Treatment Alternative

Data Collection and Analysis

Identification of Criteria and Indicators

Multiple Attribute Decision Making

Ranking of Alternatives

Life Cycle Costing
3. Net Present Worth (NPW)

Life Cycle Assessment
1. Global warming potential
2. Eutrophication potential

Robustness of the System
6. Reliability
7. Durability
8. Flexibility

Sustainability Criteria
9. Acceptability
10. Participation
11. Replicability
12. Promotion of Sustainable Behavior

4. Land Requirement
5. Manpower Requirement

Framework for Selection of Appropriate Wastewater Treatment Alternative

(a) Activated Sludge Process (ASP)
(b) UASB–FAL
UASB-FAL (78 MLD)
(c) Constructed Wetlands (CWs)
• 21 constructed wetland tanks with Phragmites karka

• Four saplings were planted per m² of area with a harvesting time of 6 months.

• Each CW tank is 65 m in length and 20 m in width (1300 m² area) and is designed to handle a flow of 371.4 m³/day.

**Constructed tanks of the 7.8 MLD CWs plant at Jaipur**
(d) Sequencing Batch Reactor
## Criteria and Indicators

### Quantitative

<table>
<thead>
<tr>
<th>Sr No.</th>
<th>Criteria</th>
<th>Indicator</th>
<th>ASP</th>
<th>SBR</th>
<th>UASB -FAL</th>
<th>CWs</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Global warming</td>
<td>Global warming potential (kg CO₂ Eq./ p.e.-year)</td>
<td>18.20</td>
<td>31.97</td>
<td>7.67</td>
<td>-3.86</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Eutrophication</td>
<td>Eutrophication potential (kg PO₄ Eq./ p.e.-year)</td>
<td>3.76</td>
<td>1.38</td>
<td>5.85</td>
<td>3.40</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>Life cycle costs</td>
<td>Net Present Worth (Rs. Lakh / MLD)</td>
<td>137</td>
<td>127</td>
<td>103</td>
<td>242</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>Land requirement</td>
<td>Land requirement (m² / MLD)</td>
<td>1400</td>
<td>353</td>
<td>1123</td>
<td>8500</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>Manpower requirement for operation&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Number for operation of medium scale plant</td>
<td>10</td>
<td>6</td>
<td>14</td>
<td>4</td>
<td>10</td>
</tr>
</tbody>
</table>
Criteria and Indicators
Qualitative

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Criteria</th>
<th>Indicator</th>
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<th>SBR</th>
<th>UAS B-FAL</th>
<th>CWs</th>
<th>Weights</th>
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<tbody>
<tr>
<td>6</td>
<td>Robustness of the System*</td>
<td>Reliability(^a)</td>
<td>80</td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>60</td>
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<tr>
<td></td>
<td></td>
<td>Durability(^a)</td>
<td>80</td>
<td>60</td>
<td>60</td>
<td>40</td>
<td>60</td>
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<tr>
<td></td>
<td></td>
<td>Flexibility(^a)</td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acceptability(^a)</td>
<td>30</td>
<td>30</td>
<td>50</td>
<td>90</td>
<td>10</td>
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<tr>
<td>7</td>
<td>Sustainability*</td>
<td>Participation(^a)</td>
<td>30</td>
<td>30</td>
<td>50</td>
<td>80</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Replicability(^a)</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Promotion of Sustainable Behavior(^a)</td>
<td>40</td>
<td>40</td>
<td>60</td>
<td>90</td>
<td>10</td>
</tr>
</tbody>
</table>

\(^a\)These indicators do not have units as they quantify qualitative sustainability stock. Instead they are rated between 0 and 100 with 0 being the worst score and 100 the best score.

\(\ast\) (Mels et al., 1999; Ashley et al., 1999; Foxon et al., 2002; Balkema et al., 2002; Palme et al., 2005; Arceivala and Asolekar, 2007; Mokroppulos et al., 2008; and Singhirunnusorn and Stenstrom, 2009)
## Scenario Based Decision Making

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Scenario I</th>
<th>Scenario II</th>
<th>Scenario III</th>
<th>Scenario IV</th>
<th>Scenario V</th>
<th>Scenario VI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Urban Area / Land Constraint / Disposal to Surface Water Body</td>
<td>Urban Area / Land Constraint / Treated Water for Reuse</td>
<td>Sub-urban Area / No Land Constraint / Disposal to Surface Water Body</td>
<td>Sub-urban Area / No Land Constraint / Treated Water for Reuse</td>
<td>Rural Area / No Land Constraint / Disposal to Surface Water Body</td>
<td>Rural Area / No Land Constraint / Treated Water for Reuse</td>
</tr>
<tr>
<td>Global warming potential (kg)</td>
<td>20 cost</td>
<td>20 cost</td>
<td>20 cost</td>
<td>20 cost</td>
<td>20 cost</td>
<td>20 cost</td>
</tr>
<tr>
<td>Eutrophication potential (kg)</td>
<td>20 cost</td>
<td>80 cost</td>
<td>30 cost</td>
<td>80 cost</td>
<td>30 cost</td>
<td>80 cost</td>
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<tr>
<td>Net Present Worth (Rs. Lakh)</td>
<td>20 cost</td>
<td>20 cost</td>
<td>60 cost</td>
<td>90 cost</td>
<td>90 cost</td>
<td>90 cost</td>
</tr>
<tr>
<td>Land requirement (m²)</td>
<td>80 cost</td>
<td>80 cost</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>80 benefit</td>
<td>80 benefit</td>
</tr>
<tr>
<td>Number</td>
<td>10 cost</td>
<td>10 cost</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>80 benefit</td>
<td>80 benefit</td>
</tr>
<tr>
<td>Reliability</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
</tr>
<tr>
<td>Durability</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
</tr>
<tr>
<td>Flexibility/Adaptability</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
</tr>
<tr>
<td>Acceptability/Simplicity</td>
<td>10 benefit</td>
<td>10 benefit</td>
<td>30 benefit</td>
<td>30 benefit</td>
<td>80 benefit</td>
<td>80 benefit</td>
</tr>
<tr>
<td>Participation/Responsibility</td>
<td>10 benefit</td>
<td>10 benefit</td>
<td>30 benefit</td>
<td>30 benefit</td>
<td>80 benefit</td>
<td>80 benefit</td>
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<tr>
<td>Replicability</td>
<td>20 benefit</td>
<td>20 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>80 benefit</td>
<td>80 benefit</td>
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<tr>
<td>Promotion of Sustainable behavior</td>
<td>10 benefit</td>
<td>10 benefit</td>
<td>40 benefit</td>
<td>40 benefit</td>
<td>80 benefit</td>
<td>80 benefit</td>
</tr>
</tbody>
</table>
Relative distance metric for each scenario and rank of each alternative in particular scenario

<table>
<thead>
<tr>
<th>ALT</th>
<th>No Scenario</th>
<th>Scenario I</th>
<th>Scenario II</th>
<th>Scenario III</th>
<th>Scenario IV</th>
<th>Scenario V</th>
<th>Scenario VI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equal Weights to Indicators</td>
<td>Urban Area / Land Constraint / Disposal to Surface Water Body</td>
<td>Urban Area / Land Constraint / Treated Water for Reuse</td>
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<td>Rural Area / No Land Constraint / Treated Water for Reuse</td>
</tr>
<tr>
<td>Score</td>
<td>Rank</td>
<td>Score</td>
<td>Rank</td>
<td>Score</td>
<td>Rank</td>
<td>Score</td>
<td>Rank</td>
</tr>
<tr>
<td>ASP</td>
<td>0.5066</td>
<td>4</td>
<td>0.7857</td>
<td>1</td>
<td>0.7081</td>
<td>2</td>
<td>0.4277</td>
</tr>
<tr>
<td>SBR</td>
<td>0.5087</td>
<td>2</td>
<td>0.7789</td>
<td>2</td>
<td>0.8017</td>
<td>1</td>
<td>0.3715</td>
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<tr>
<td>UASB</td>
<td>0.5083</td>
<td>3</td>
<td>0.7404</td>
<td>3</td>
<td>0.5816</td>
<td>3</td>
<td>0.4452</td>
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<tr>
<td>CWS</td>
<td>0.5271</td>
<td>1</td>
<td>0.2127</td>
<td>4</td>
<td>0.2822</td>
<td>4</td>
<td>0.5506</td>
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</tbody>
</table>
Technology Selection Summary

• Sustainability of urban areas can be improved through selection of appropriate wastewater treatment technologies.

• The incorporation of sustainability criteria in the technology assessment will clearly identify technologies appropriate for a particular situation.

• It is also essential to incorporate the experts' opinion in the decision making process.

• Finally, to evaluate the alternatives, a suitable MADM method has to be used which will provide final ranking.
Closing the loops:
Nutrients and Water
The Circular Economy (CE) aims to decouple economic growth from resource constraints by maximizing use of residuals. (Ellen McArthur Foundation – EMF- 2013)

→ provides multiple value creation mechanisms that are decoupled from the consumption of finite resources.
The “butterfly” diagram by the EMF

**Biological cycle:** materials meant to be returned to the soil (composting/anaerobic digestion)

**Technical cycle:** materials are designed to be recovered refreshed or upgraded

Circular Economy for Water Cycle

• Water is important resource and wastewater generated is more important resource!

• **Extracting cascaded value** - process of extracting value at a series of stages beginning with high value products such as specialist chemicals, followed by fertilisers, energy, water and bio-solid

• Closed loop water systems can be full or partial and work at all scales:
  – **City scale** – 30% of Singapore’s water demand is provided by recycled sewage
  – **Industry scale** – the Pearl gas-to-liquid plant in Qatar recycles 450,000m³ of water a day, equivalent to 50% of the total demand of the country.
  – **Building scale** – the Solaire building in New York recycles 750,000 litres per day of its wastewater. This reduces water demand by 50%, water discharge volume by 60% and significantly lowers the building’s energy demand.
  – **Product scale** – Aquafresco, a Boston-based start-up has created an appendage to a washing machine that recycles **95% of its water** and detergent

(Source: http://circulatenews.org/2017/01/applying-the-circular-economy-lens-to-water/)
P Cycle – Nashik Case

- P content in the Indian consumed diet increased from 545 g P/cap/year in 1988 to 597 g P/cap/year in 2011 (Keil et al., 2017)
- About 10% leaves as food (solid) waste
- Total food P consumed in Nashik is 1,076 t P/year

(Source: Cornel and Schaum, 2009)
Substance Flow Analysis – Base case

Nashik, 2017

Import: 1,610.2 t/a

dStock: 167.0 t/a

Export: 1,443.3 t/a

Detergents

Food

Household consumption

Wastewater

Centralized wastewater treatment

Agriculture

Sludge

Erosion and leaching

Effluent

(Source: Sanderbo and Kalbar, 2017)
Substance Flow Analysis – P Circular Economy

Nashik, 2017

Import: 2,093.2 t/a  
dStock: 1,177.0 t/a  
Export: 916.2 t/a

I  694.4
Detergents

I  1,398.8
Food

Wastewater (previous losses)  220.6

Household consumption

1,389.6
Wastewater

30% increased wastewater flow

Building scale treatment (CW)

Decentralized treatment (ASP + CW)

116.8
Sludge

366.2
Effluent

483.0
Effluent

Local agriculture and gardening

453.3
Sludge

453.3
Struvite

Agriculture

+825.2

814
Erosion and leaching

483.0
Effluent

351.8
Erosion and leaching

+351.8
Summary

• Water Supply Systems in India are facing numerous challenges such as reducing NRW and improving sustainability

• Wastewater treatment capacity needs to be enhanced with appropriate and sustainable technologies (rather solutions)

• Focus on resource recovery from wastewater will enable ULBs to transit to Circular Economy

• Mix of strategies are needed to develop resilience in the Urban Water Systems
Thank You

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Questions??