WATER AND CITY
Guidelines of local governments for sustainability
CITIES AND NEW TECHNOLOGIES

Management and renewal of urban water infrastructure

Balvant Rajani and Yehuda Kleiner
National Research Council Canada

Zaragoza, 27 de junio, 2008
✓ Context – what is the problem?
✓ Should large and small diameter pipes be treated the same or differently?
✓ Need to collect data – why and what to collect?
✓ What can we do with data?
✓ How cathodic protection can be effective strategy to manage small diameter mains?
Urbanization begins …

✓ 1664 – Versailles, France uses cast iron mains…

✓ 1692 – Boston incorporates water works (wood pipe)…

✓ 1804 – Philadelphia uses cast iron mains…

✓ 1841 – Toronto has first private water supply system

✓ 1842 – NY completes Croton aqueduct for water supply
Bathtub curve of life cycle of buried pipe

- Burn-in phase
- In-usage phase
- Wear-out phase

Hazard rate vs. Time (years)

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Asbestos cement

Combined degradation / structural failure of asbestos cement pipe

Source: CSIRO
Cast iron

After sand blasting  
Before sand blasting

125 year-old pipe

Pit-cast pipe sample with casting voids

Source: Toronto, 2004

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Ductile iron

Source: Toronto, 2004

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Brittle fracture of PVC pipe

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Polyethylene pipes

Rupture of polyethylene pipe
Large diameter cast iron mains

Cleveland, 1926

Source: Cleveland, 2002

Hamilton, January 2003

Source: Hamilton, 2003

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Large diameter cast iron mains

CH2M G&S Ltd.

Ottawa, July 2000

Hamilton, January 2003

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Large diameter PCCP

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Calgary, Alberta
January, 2004

Temperature –31°C

PCCP 1200 mm

Repair costs: $700 K

Large diameter PCCP

No loss of life
No damage
Major arterial road

Source: AWWA Opflow

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Fort Lauderdale

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## Financial needs

### US

<table>
<thead>
<tr>
<th>Organization</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASCE</td>
<td>US $11 B / year</td>
</tr>
<tr>
<td>US EPA</td>
<td>US $83 B over 20 years</td>
</tr>
<tr>
<td>AWWA</td>
<td>US $250 B over next 30 years</td>
</tr>
<tr>
<td>WIN</td>
<td>US $460 B over next 20 years</td>
</tr>
</tbody>
</table>

### Canada

<table>
<thead>
<tr>
<th>Organization</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCM</td>
<td>Can $ 12 B over next 15 years</td>
</tr>
</tbody>
</table>

- Mains replacement value in North America US$ 400 B
- Only 0.5% replaced annually (expected life 200 years)

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Challenges to manage distribution systems

- Large majority of mains subject to corrosion
- Large systems – enormous ‘inertia’ – slow and difficult to change course
- Owners do not ‘depreciate’ assets
- Pro-active vs. reactive maintenance
- Distribution system self insured

...
## Transmission vs. Distribution Water Mains

<table>
<thead>
<tr>
<th>Mains</th>
<th>Transmission</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>PCCP, AC, steel, CI, DI</td>
<td>PVC, CI, DI</td>
</tr>
<tr>
<td>Pipe size</td>
<td>Large ( &gt; 300 mm)</td>
<td>Small ( &lt; 300 mm)</td>
</tr>
<tr>
<td>Consequences of failure</td>
<td>Severe</td>
<td>Moderate</td>
</tr>
<tr>
<td>Risk tolerance</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Repair / Renewal</td>
<td>Immediate</td>
<td>Risk / life cycle cost</td>
</tr>
<tr>
<td>Length in North America</td>
<td>65,000 km</td>
<td>1,500,000 km</td>
</tr>
<tr>
<td>Redundancy</td>
<td>Usually none</td>
<td>High</td>
</tr>
<tr>
<td>Non-intrusive condition assessment</td>
<td>Inspection of in-service Pipes</td>
<td>Deterioration modeling</td>
</tr>
</tbody>
</table>

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Distribution mains (small) – failure management

Failure frequency (#/km)

Cost (present value)

1 2 3 4

Total expected cost

min. cost

Failure risk

Cost of renewal

Time of renewal

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Transmission mains (large) – failure prevention

<table>
<thead>
<tr>
<th>Failure frequency (#/km)</th>
<th>Cost (present value)</th>
<th>min. cost</th>
<th>Total expected cost</th>
<th>Failure risk</th>
<th>Cost of renewal</th>
<th>Time of renewal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>2</td>
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<td>3</td>
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<tr>
<td>4</td>
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</tr>
</tbody>
</table>

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### Summary: Data requirements

<table>
<thead>
<tr>
<th>Pipe inventory</th>
<th>Operating conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Pipe diameter</td>
<td>✓ Operating conditions such as pressure</td>
</tr>
<tr>
<td>✓ Pipe length</td>
<td>✓ Traffic level</td>
</tr>
<tr>
<td>✓ Geographical coordinates (start and end nodes)</td>
<td>✓ Temperatures (soil, water)</td>
</tr>
<tr>
<td>✓ Pipe installation dates</td>
<td>✓ Soil moisture conditions</td>
</tr>
<tr>
<td>✓ Pipe material</td>
<td>✓ Cathodic protection</td>
</tr>
<tr>
<td>✓ Service connections</td>
<td></td>
</tr>
<tr>
<td>✓ Soil type, soil characteristics</td>
<td></td>
</tr>
</tbody>
</table>

### Static

<table>
<thead>
<tr>
<th>Pipe performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Pipe breakage history</td>
</tr>
<tr>
<td>✓ Location of failure along pipe length</td>
</tr>
</tbody>
</table>
Sacrificial Anode Cathodic Protection

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HS and Retrofit Cathodic
Protection

<table>
<thead>
<tr>
<th>Year</th>
<th>Breaks/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>0</td>
</tr>
<tr>
<td>1970</td>
<td>0.5</td>
</tr>
<tr>
<td>1980</td>
<td>1.5</td>
</tr>
<tr>
<td>1990</td>
<td>0.5</td>
</tr>
<tr>
<td>2000</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>0</td>
</tr>
</tbody>
</table>

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- Observed values
- Background ageing
- Time-dependent breakage rate
- Retrofit CP program
- HS CP program

Graph showing the increase and decrease in breaks/km over time with the retrofit CP program.
Pipe life - economic outcome of life-cycle costs

Cost (present value)

min. cost

total expected cost

cost of breakage repair

cost of renewal

Time of renewal

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Final remarks

- Treat large and small pipes differently:
  - Large mains: *failure prevention*.
  - Small mains: *failure management*.
- Collect data but must be good data!
- Without the right data → no analysis possible → rational decisions not possible.
- Use models to foresee possible problems.
- Use decision-making models to argue financial needs.
- Cathodic protection can help reduce performance of water distribution networks.
Our research has been supported by the National Research Council Canada, American Water Works Association Research Foundation (AwwaRF), and lots of in-kind support from water utilities in US, Canada, UK and Australia.
Thank you and I would be glad to answer any questions.

Visit us at:
http://irc.nrc-cnrc.gc.ca/ui/bu/index_e.html

URBAN INFRASTRUCTURE
Time line for iron pipe wall thickness ....

Pipe standard

Pressure rating 150 psi (10 bars)

Wall thickness (inches)

Wall thickness (mm)

Pit cast class D - 1908
Pit cast class 1 - 1957
Spun cast class 22 (18/40) - 1957
Spun cast class 21 (21/57) - 1957
Ductile iron thickness class 52 - 1965
Ductile iron pressure class 350 - 1991

150 mm
300 mm