Improving Efficiency of Water Systems: practical examples

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Water Industry Director EMEA
Agenda

1. Bentley at a Glance
2. Water Solutions Overview
3. Trends in the Water Industry
4. Practical Cases:
   1. Active Leakage Management
   2. Lifecycle Asset Management
   3. Energy Efficiency Improvement
5. Contact Information & Resources
Bentley at a glance

World's leading provider of software for infrastructure design, construction and operations:

- #1 in Building Performance
- #1 in Structural Engineering
- #1 in Water Modelling
- #1 in Roads and Transit Design
- #1 in Bridge Engineering
- #1 in GIS for Utilities

Global Business:
- Over 3,000 colleagues in 45 countries
- $500M revenues
The World of Water

- Rural water systems
- Urban water systems
- Estuaries and coastal water systems
Water Industry Solutions

GIS products

- sisNET Water (Bentley Water)
- Expert Designer
- MicroStation

Modeling products

- SewerGEMS / CAD
- Hammer
- StormCAD / HEC-Pack
- CivilStorm / PondPack
- WaterGEMS / CAD
- GasAnalysis

Web Publishing

- Web clients
- Business Documents
- Ancillary Files w/ RDBWS
- Spatial Documents
- Spatial Databases
- Web Services

Data Files

- Data Files w/ Database Linkages
- Proprietary GIS Databases
- Enterprise Data Stores
- SCADA & Loggers

Interoperability Connectors

- Bentley
Water & Wastewater Industry Challenges

• Regulatory Compliance
  – Adequate Supply & Treatment capacity
  – Protecting Water Quality
  – Business performance
  – Improving efficiency

• Reliability
  – Consistently achieving target levels of services
  – Maintaining aging infrastructure
  – Avoiding failure

• Budget
  – Reducing costs while improving services
  – Asset investment planning for aging infrastructure
  – Aging workforce
The Evolution of Smart Water Networks

<table>
<thead>
<tr>
<th>AGE</th>
<th>CONDITION</th>
<th>COMMON FRAMEWORK</th>
<th>STABLE SERVICEABILITY</th>
<th>REAL TIME</th>
</tr>
</thead>
</table>
The Smart Water Network - Integration

**Hydraulic Models**

**Online model**

**Planning and Demand forecasting**

**SCADA system**

**Enterprise GIS system**

**CRM, WO Call Centre**
1) Leakage Reduction Case Studies by pressure management, hydraulic modelling, measured data and optimization techniques
A Worldwide Problem: Controlling and Remediating Water Loss Is Complex

- It’s impossible to find and fix all leaks
- Partial implementation of a water loss plan is highly likely to fail
- Coordination between all components of a water loss program is required

"Many practitioners make common mistakes- they may have the false impression that each time a leak is repaired, physical loss is reduced by the volume saved..."

Vermersch and Rizzo
Source: IWA’s Water21 Magazine, April 2008

(Courtesy Dr. Thomas Walski)
# IWA Standard Water Balance

<table>
<thead>
<tr>
<th>System Input Volume</th>
<th>Authorized Consumption</th>
<th>Billed Authorized Consumption</th>
<th>Billed Metered Consumption</th>
<th>Billed Unmetered Consumption</th>
<th>Unbilled Authorized Consumption</th>
<th>Unbilled Metered Consumption</th>
<th>Revenue Water</th>
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<tbody>
<tr>
<td>Water Losses</td>
<td>Apparent Losses</td>
<td>Unauthorized Consumption</td>
<td>Customer Meter Inaccuracies</td>
<td></td>
<td></td>
<td></td>
<td>Non Revenue Water</td>
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<tr>
<td></td>
<td>Real Losses</td>
<td>Leakage on Transmission &amp; Distribution Mains</td>
<td>Leakage and Overflows at Reservoirs</td>
<td>Leakage on Service Connections up to metering point</td>
<td></td>
<td></td>
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</table>
Leakage Types

- **Background leakage**
  - Small flow rates, run continuously but not economically recoverable

- **Reported leaks and bursts**
  - High flow, reported by customers and get fixed quickly

- **Unreported leaks and bursts**
  - Medium flow rates, longest duration and only located by active leakage detection

Implement IWA best / good practices

- Speed and Quality of Repairs: Replacing pipes with least impact on customers
- Unavoidable Real Loss
- Economic Level Real Loss: Current Annual Real Loss Volume
- Active Leakage Control: Detecting and fixing leaks, Replacing/installing meters (DMAs)
- Pressure Management
- Risk-based asset management for maximum return

Source: The “4 Component” diagram promoted by IWA’s Water Losses Task Force
**Current Practice**

1. **Assessment**
   - water balance or water auditing based upon water infrastructures’ physical data and some statistics

2. **Pressure Management**
   - Divide the network in Pressure Zones and DMAs
   - Use hydraulic model for PRVs
   - Install PRVs to manage MNF

3. **Active Leakage Detection**
   - Sounding for leaks
   - Step-testing, smart balls
   - Acoustic loggers (noise correlators)
   - Smart balls
   - Use hydraulic model and measured (Scada) data
Pressure Management (Case Study in Cyprus)
Water Board of Lemesos

- Established in 1951
- Semi-government, non-profit organisation
- Supply of potable water
- Number of employees: 110
- Area served: 100 km²
- Population Served: 170 000
- Annual water needs: 14 million m³
- Number of consumers: 78 000
- Length of pipework: 850 km
Pressure Management Considerations

Pressure range:
- Between 20m and 40m
- Minimum of 15 m if conditions allowed

Pressure control achieved through:
- Pressure reducing valves
- Pressure regulating valves

Types of pressure control:
- Fixed outlet
- Two point control (Time or Flow)
- Flow / Time modulation
- Critical point control
Pressure Management Objectives

- Reduce the flow rates (MNF) of all leaks
- Reduce surges and excess pressures
- Reduce burst rates and background leakage, cut repair costs
- Reduce some components of consumption
- Effects of change can be hydraulically modelled and predicted
DMAs - Pressure Management

**DMA categories**
- Small : <1000 properties
- Medium : 1000 – 3000 properties
- Large : 3000 – 5000 properties

**Factors considered in DMAs (re)-design**
- Use Hydraulic Model (WaterCAD)
- Minimum variation in ground level
- Single entry point into the DMA
- Well defined DMA boundaries
- Area meters correctly sized and located
- Continuous monitoring
Possible pressure reduction of about 0.5 bar

**DMA 232**
Graph of 24-hour pressure measurements at AZP Point and Critical point, compared to Minimum Standard of Service before pressure reduction.

Possible pressure reduction of about 0.5 bar

**Time of Day**
- Critical Point
- Minimum Standard of Service
- Average Zone Point AZP
Pressure Reduction (2/3)

**DMA 232**

Graph of 24-hour pressure measurements at AZP Point and Critical point, compared to Minimum Standard of Service

**after pressure reduction**

Reduction in **AZP** from **39 m** to **32 m** resulted in reduction in **MNF** from **5.2 m³/hr** to **4.3 m³/hr**
Pressure Reduction (3/3)

District 225

Before pressure reduction

After pressure reduction

Reduction in MNF
## Minimum Night Flow Summary Results

<table>
<thead>
<tr>
<th>DMA (Sector 2)</th>
<th>AZNP (m)</th>
<th>Actual MNF (m³/hr)</th>
<th>Background losses (m³/hr)</th>
<th>Locatable losses (m³/hr)</th>
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<tr>
<td></td>
<td>before</td>
<td>after</td>
<td>before</td>
<td>after</td>
</tr>
<tr>
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<td>3.96</td>
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<td>234</td>
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<td>Total before</td>
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<tr>
<td>Total after</td>
<td></td>
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<td>87.96</td>
<td>27.09</td>
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</table>
Leakage Detection using Models and Data
Mathematical Optimization Techniques

Search for: \( \vec{X} = (LN_i^n, K_i^n) \); \( LN_i^n \in J^n; n=1,\ldots,N; i=1,\ldots,LK^n \)

Minimize: \( F(\vec{X}) \)

Subject to: \( 0 \leq K_i^n \leq K_{\text{max}}^n \)

Leakage Nodes: \( nL = \sum_{n=1}^{N} LK^n \)

Where:
- \( LN_i^n \) is the index for leakage node \( i \) in group \( n \)
- \( K_i^n \) is emitter coefficient at leakage node \( i \) in group \( n \)
- \( J^n \) is the set of junctions in demand group \( n \)
- \( N \) is the number of demand groups
- \( nL \) is the total number of leakage nodes
- \( LK^n \) is number of leakage nodes in group \( n \)
- \( K_{\text{max}}^n \) is the max emitter coefficient for demand group \( n \)
Integrated Framework — Leakage Detection & Model Calibration

WaterGEMS (Darwin Calibrator)
Case I: system conditions (United Utilities)

- DMA system model
- 12 km pipelines
- 1000 properties
- 5 pressure loggers and one flow meter
Case Study I: previously detection

<table>
<thead>
<tr>
<th>KEY</th>
</tr>
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<tbody>
<tr>
<td>DMA Boundary</td>
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<tr>
<td>Leak located</td>
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<table>
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<tr>
<th>BURST A</th>
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<tr>
<td>Distance from prediction</td>
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<tr>
<td>&lt;50m</td>
</tr>
<tr>
<td>Mains diam</td>
</tr>
<tr>
<td>150mm</td>
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<table>
<thead>
<tr>
<th>BURST B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from prediction</td>
</tr>
<tr>
<td>150m</td>
</tr>
<tr>
<td>Mains diam</td>
</tr>
<tr>
<td>8&quot;</td>
</tr>
</tbody>
</table>
Case I: results comparison
Case I: savings

Saving > 210,000 Euro / year

30m³/hr reduction
Case Study I: flow comparison (after)
Case II: another DMA

Field survey

Leakage spots identified with WaterGEMS Leakage Calibrator

15 m³/hr reduction
Savings of 115,000 Euro / year
Important: Check Risk on Transients!
Essential Requirements

- Build hydraulic model
- Collect field data (e.g. flows and pressures)
- Prepare and import data
- Calibrate the model and make leakage detection runs
- Analyze results
- Look for consistent predicted leakage hotspots
- Go to the filed: check the identified locations and take a proper action
2) GIS-based AM using Bentley Water
Bentley Utility Products

• Built on Bentley Map

• Include
  – Bentley Water
  – Bentley WasteWater
  – Bentley Gas
  – Bentley Electric
  – Bentley Fiber
  – Bentley sisNET (multi-utility solution)
  – ...

• Learn one – learn them all
What Does Bentley Water Do?

- Water GIS product with CAD power/precision
- Built on Bentley Map / MicroStation
- Manages & maps water infrastructure assets for mapping, inventory and analysis
- Customized for water networks
- Dozens of elements w/predefined properties
- Can define your own elements
- Can attach any kind of data/files
Bentley Water Features

- Customizable data model
  - Water has its own data model
  - Can define/remove new types of elements
  - Can define/remove properties of elements
- Compatible with Oracle Spatial or DGN/RDBMS
- Ensures connectivity
- Network tracing
  - Segments for shutdown
  - Pressure zone management
  - Define your own “stop” conditions
- Leakage and breaks analysis, thematic GIS mapping
- Native export to WaterGEMS / EPANET for hydraulic modeling, optimization and analysis
Example of IZSU: Izmir Water Utility in Turkey

- City with 4,000,000 population at the Aegean Cost of Turkey
- Total water customer served by IZSU is 1,200,000
- Water/Waste Water/Storm network in 5000 km road network
- All structures related within City Limits
  - 619 Resorvoirs (Dam, Pond and Wells)
  - 426 Tanks
  - 135 Pumps
  - 11,000 Valve
- 10% of the data was in papers
- 90% of the data was in different digital formats (ncz, plt, dxf, dwg, dgn)
Mapping: Thin client
Mapping: Web client
Manage Leak Records:

- Most utilities keep leak records
- Many forms
  - Paper records
  - Databases
  - Spreadsheets
  - Shapefiles
  - Work orders
- Import to Bentley Water
- Need x-y coordinates (georeference)
Spatially View Leak Locations:
Find Bad Pipes:
## Analyze Patterns

<table>
<thead>
<tr>
<th>Diameter, in.</th>
<th>Breaks</th>
<th>Break Rate, break/yr/km</th>
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<tbody>
<tr>
<td>6</td>
<td>25</td>
<td>0.105</td>
</tr>
<tr>
<td>8</td>
<td>15</td>
<td>0.082</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
<td>0.062</td>
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<tr>
<td>16</td>
<td>2</td>
<td>0.041</td>
</tr>
<tr>
<td>24</td>
<td>3</td>
<td>0.056</td>
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Look for Relationships

<table>
<thead>
<tr>
<th>Material</th>
<th>Circumferential breaks</th>
<th>Longitudinal breaks</th>
<th>Corrosion holes</th>
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<tbody>
<tr>
<td>Cast Iron</td>
<td>73</td>
<td>7</td>
<td>4</td>
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<tr>
<td>Ductile iron</td>
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<td>2</td>
<td>5</td>
</tr>
<tr>
<td>PVC</td>
<td>23</td>
<td>17</td>
<td>0</td>
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<tr>
<td>Steel</td>
<td>2</td>
<td>1</td>
<td>12</td>
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</table>
Pipe Renewal Planner Workflow

Pipe Score

System Inventory

Pipe Break History

Break Analysis

Normalized Break Score

Model

Fire Flow Analysis

Normalized Fire Score

Criticality Analysis

Normalized Criticality Score

Other Property Of Interest

Analysis

Normalized Score

Weighting

Overall Score
Pipe Renewal Planner Results

<table>
<thead>
<tr>
<th>ID</th>
<th>Label</th>
<th>Pipe Score (Break)</th>
<th>Raw Score (%ile)</th>
<th>Score (Criticality)</th>
<th>Score (Capacity)</th>
<th>Raw Score (Cft/yr)</th>
<th>Score (Capacity)</th>
<th>Diameter (in)</th>
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<tbody>
<tr>
<td>366: P-131</td>
<td>366 P-131</td>
<td>62</td>
<td>0.082</td>
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<td>87</td>
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Part of risk-based Asset Management

- Pipe break and leak history feeds into asset management decision making
- Rational, quantifiable basis for investment planning decisions
- Thematic graphical displays
3) Optimizing Pump Operations for Minimum Energy Cost in Water Distribution Systems
Typical Water System

Sources

Gravity or Pump

WTW

Pump

Distribution

Pump

End Use

WTW / Pumping Station / Booster

Storage Reservoir

Boreshole

WWW.BENTLEY.COM
Energy Consumption

- Water is pumped throughout the system
- Adequate pressure is maintained by pumping
- Pumping results in high energy consumption

Why Pump Scheduling

- Many benefits for saving pump energy
  - Reduce cost
  - Improve water service efficiency
  - Reduce carbon footprint
  - Improve sustainability

- Many ways to save pump energy
  - Regularly maintain pumps
  - Keep pump operated at best efficiency point
  - Make sure electricity bills are correct
  - Improve pipelines to reduce head losses
  - More...

- Many pumps operated by experience
  - Nothing bad or wrong
  - Represent good opportunity to improve
Pump Scheduling

- **What to schedule**
  - Which pump is on duty
  - When pump is on duty
  - What speed is on duty

- **Goal**
  - Minimize energy consumption
  - Minimize total energy cost

- **Supply requirement**
  - Hydraulics
  - Manage pressure (water loss)
  - Water quality
Formulation (mathematical optimization)

- Search for: \[ \vec{H} = (h_{i,t}) \quad i = 1,2,\ldots,N_{ps}, \quad t = 1,\ldots,T \]
- Minimize: \[ C = \sum_{p=1}^{N_p} C_p \]
- Subject to:
  \[ h_{\text{min}} \leq h_{i,t} \leq h_{\text{max}} \]
  \[ v_{\text{min}} \leq v_{j,t} \leq v_{\text{max}} \]
  \[ \omega_{\text{min}} \leq \omega_p \leq \omega_{\text{max}} \]

Where
- \( h_{i,t} \) is the target hydraulic head of pump station \( i \) at time \( t \)
- \( v_{j,t} \) is the flow velocity of pipe \( j \) at time \( t \)
- \( \omega_p \) is the relative speed factor for pump \( p \)
- \( N_{ps} \) is the number of pump stations,
- \( C_p \) is the energy cost of pump \( p \),
- \( N_p \) is the number of pumps,
- \( C \) is the total energy cost of the pumps,
- \( h_{\text{min}} \) and \( h_{\text{max}} \) are the minimum required and maximum allowed hydraulic head,
- \( v_{\text{min}} \) and \( v_{\text{max}} \) are the minimum required and maximum allowed flow velocities
CSP Case Study (Water Utility in UK)

- DMZ system
- 57 Ml/day
- 11 pump stations and 9 tanks
- Energy cost: £330K/year
- Recorded daily energy cost: £912
- Modeled daily energy cost: £923
Electricity Tariff Pattern

Time

Price Pattern Factor

0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00 0:00
Pump Characteristics

- Pump curve

- Efficiency curve
Conventional Controls

- Control rules: if...then; if...then...else...
- Pumps are triggered by clock time
- Pumps are triggered by nodal pressure or HGL
- Pumps are triggered by metered flow
- Pumps are triggered by tank level
- Conventional wisdom
  - Turned ON when below a low tank level
  - Turned OFF when above a high tank level
  - Keep pump operation in a large range of tank levels
Pump Scheduling Optimization

- Optimization criteria
  - One hour control interval
  - Tank minimum level is set to 20% of depth
  - Tank maximum level is set to 90% of depth
  - Meet minimum pressure requirement

- Results converted to control rules, e.g.
  Rule 100
  \[
  \text{IF} \quad \text{SYSTEM CLOCKTIME} \quad \leq \quad 8:00 \quad \text{AM} \\
  \text{OR} \quad \text{SYSTEM CLOCKTIME} \quad \geq \quad 10:00 \quad \text{PM} \\
  \text{AND} \quad \text{TANK BUTa2 LEVEL BELOW} \quad 5.73 \\
  \text{THEN} \quad \text{PUMP PILWTHSTATUS IS} \quad \text{OPEN} \\
  \text{ELSE} \quad \text{PUMP PILWTHSTATUS IS} \quad \text{CLOSED}
  \]
## Energy Cost comparison

<table>
<thead>
<tr>
<th>Pump ID</th>
<th>Existing controls</th>
<th>Optimized controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pump utilization (%)</td>
<td>Daily cost (£)</td>
</tr>
<tr>
<td>X2420052_</td>
<td>100</td>
<td>181.99</td>
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<tr>
<td>X2420014_</td>
<td>40</td>
<td>142.11</td>
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<td>X2420075_</td>
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<td>201.95</td>
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<tr>
<td>X2410361_</td>
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<td>X2419963_</td>
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<td>X241998C_</td>
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<td>7.92</td>
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<tr>
<td>X2450024_</td>
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<tr>
<td>PILWTH</td>
<td>82</td>
<td>236.19</td>
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<tr>
<td>NEWMRKT</td>
<td>23</td>
<td>111.63</td>
</tr>
<tr>
<td>Total cost (£)</td>
<td>983.12</td>
<td></td>
</tr>
</tbody>
</table>

- Immediate saving is 100,000 £ (29% of original energy cost)
- By optimizing pumping hours and better supply from storage sources
Optimized Pump Controls

- Tank levels
- Pump flows
Models and Scada data integration in AquaSafe real-time platform

- ScadaConnector
- Existing Scada Server
- DB Historic Data
- Aquasafe Client/Server
  - User Interface, Configuration, Alarms, Data Flow Management
  - Flow Analysis and Leakage Alarm
  - Operational Data Management
  - Demand Estimation and Forecasting
- WaterGEMS Operational Modeling
- Darwin Calibrator Optimized Leakage Detection
- Darwin Scheduler Optimized Pumping
- Operational Data Management
  - Models and Scada data integration in AquaSafe real-time platform
Bentley Real-time Platform (ex. SABESP)
Summary

- Improving Efficiency is a part of a lifecycle asset management practice in Water Utilities and Consulting Ecosystem
- Real-time data streams, hydraulic modeling and optimization technology can help:
  - Reducing Water Loss and Detecting leakage hotspots
  - Pipe Renewal process as part of AM
  - Pumping scheduling and optimal pressure and energy management (including CO2 footprint)
- From ‘dull pipes’ towards Smart Water Networks for real-time modelling, decision making, asset management and emergency response
EXPO Stand F10
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Tank You for Your Attention

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