Improving efficiency of water systems: practical examples

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Water Industry Sales Director EMEA

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Agenda

1. Bentley at a Glance
2. Water Solutions Overview
3. Improving efficiency thru:
   1. Active Leakage Management (finding leakage hot-spots)
   2. Lifecycle Asset Management (leakage and break records analysis)
   3. Pumping scheduling and pressure optimization (saving water and energy)
4. Demo
5. Contact Information
Bentley: Sustaining Infrastructure

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

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

Global Business:
- Over 3,000 colleagues in 45 countries
- $500M revenues
Water Industry Solution Offerings

- Industry Framework
  - sisNET Water (Bentley Water)
  - Expert Designer
- Modelling Framework
  - SewerGEMS / CAD
  - CivilStorm / PondPack
  - WaterGEMS / CAD
  - Hammer
  - StormCAD / HEC-Pack
  - GasAnalysis
- Modelling products
- GIS products
  - MicroStation
  - AutoCAD
  - ArcGIS
  - Web clients
  - Web Publishing
- GeoSpatial Server & ProjectWise
- Enterprise Connectors
- Interoperability Connectors
- Data Files
- Data Files w/ Database Linkages
- Spatial Databases
- Web Services
- Spatial Documents
- Business Documents
- Ancillary Files w/ RDBWS
- Proprietary GIS Databases
- Enterprise Data Stores
- SCADA & Loggers

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Bentley Haestad Product Line

**WATER**

- **WaterGEMS.** Water distribution modeling with geospatial integration
- **WaterCAD.** Water distribution modeling and design
  - **Darwin Designer.** Network design automation
  - **Darwin Calibrator.** Model calibration optimization
  - **Darwin Scheduler.** Energy efficiency optimizer
  - **Pipe Renewal Planner.** Asset investment planning tool
- **HAMMER.** Transient flow analysis and modeling
- **SCADACheck.** Supervisory and control data integration

**SEWER**

- **SewerGEMS.** Urban sewer modeling with GIS integration
- **SewerCAD.** Sanitary sewer design and modeling
- **CivilStorm.** Stormwater management and dynamic modeling
- **StormCAD.** Storm sewer design and modeling
- **PondPack.** Detention pond design and analysis
- **HEC-Pack.** River basin modeling, reservoir optimization
- **CulvertMaster.** Culvert design and analysis
- **FlowMaster.** Hydraulics calculator
- **AquaSAFE.** Real-time reporting & operational platform
- **WaterObjects.** .Net development environment
- **Mohid.** 2D / 3D Catchment and coastal modeling solution

27 years
130,000 users
170 countries
Water & Wastewater Industry Drivers

- **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
1) Water Loss

Leakage Reduction by pressure management, hydraulic modelling, measured data and optimization techniques
Remediating Water Loss is Complex

- It’s impossible to find and fix all leaks (economic level of leakage)
- 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 2010

(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>Unbilled Authorized Consumption</th>
<th>Billed Metered Consumption</th>
<th>Billed Unmetered Consumption</th>
<th>Unbilled Metered Consumption</th>
<th>Unbilled Unmetered Consumption</th>
<th>Revenue Water</th>
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<tr>
<td>Water Losses</td>
<td>Apparent Losses</td>
<td>Unauthorized Consumption</td>
<td>Unmetered Consumption</td>
<td>Non Revenue Water</td>
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<td></td>
<td>Real Losses</td>
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</tr>
</tbody>
</table>

- **Apparent Losses**
- **Real Losses**
- **Customer Meter Inaccuracies**
- **Leakage on Transmission & Distribution Mains**
- **Leakage and Overflows at Reservoirs**
- **Leakage on Service Connections up to metering point**
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

- Active Leakage Control
  - Detecting and fixing leaks
  - Replacing/installing meters (DMAs)

- Risk-based asset management for maximum return

- Infrastructure Management

- Unavoidable Real Loss
  - Economic Level Real Loss
  - Current Annual Real Loss Volume

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

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Bentley's Integrated Water Solution Covers the Full Range of Problems

Bentley solutions complement existing solutions
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 (how detailed)
   - Use hydraulic model for PRVs including pumps optimisation
   - Install PRVs to manage MNF

3. **Active Leakage Detection**
   - Sounding for leaks
   - Step-testing
   - Acoustic loggers (noise correlators)
   - Smart balls
   - Use hydraulic model and measured (Scada) data
Leakage Detection using Mathematical Optimization Techniques

Search for:
\[ \vec{X} = (LN^n_i, K^n_i); \quad LN^n_i \in J^n; n = 1, \ldots, N; \quad i = 1, \ldots, LK^n \]

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

Subject to:
\[ 0 \leq K^n_i \leq K^n_{\text{max}} \]

Leakage Nodes:
\[ nL = \sum_{n=1}^{N} LK^n \]

Where:
- \( LN^n_i \) is the index for leakage node \( i \) in group \( n \)
- \( K^n_i \) is the 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 the number of leakage nodes in group \( n \)
- \( K^n_{\text{max}} \) is the max emitter coefficient for demand group \( n \)
Integrated Framework: Leakage Detection & Model Calibration

WaterGEMS (Darwin Calibrator)
Case I: system conditions

- DMA system model owned by UUW
- 20 km pipelines
- 400 properties
- 5 pressure loggers and one flow meter
Case Study I: previously detection

Burst A

Burst B

KEY
- DMA Boundary
- Posi-tect prediction
- Leak located

<table>
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<tr>
<th>BURST A</th>
<th>BURST B</th>
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<td>Distance from prediction</td>
<td>Distance from prediction</td>
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<tr>
<td>&lt;50m</td>
<td>150m</td>
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<tr>
<td>Mains Material</td>
<td>Mains Material</td>
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<tr>
<td>Ductile Iron</td>
<td>8” Cast Iron</td>
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</tbody>
</table>
Case I: results comparison (sensitivity)
Case I: savings

Saving > 210,000 Euro / year

30m³/hr reduction
Case Study I: flow comparison

Graph - flow comparison

- Inflow without leakage
- Observed inflow
- Simulated inflow of one predicted leakage solution
Video: WaterGEMS leakage detection
Essential Requirements

- Build hydraulic model
- Use existing (Scada data) or collect field data (e.g. flows and pressures)
- Prepare and import data
- Perform leakage detection runs
- Analyze results with sensitivity analysis
- Look for consistent predicted leakage hotspots
- Go to the field: check the identified locations and take a proper action
2) Pipe Renewal Planning

Water Mains Asset Management
(leakage and break records geospatial analysis)
Bentley Utility Products

- Built on Bentley Map (GIS solution)
- Include
  - Bentley Water
  - Bentley WasteWater
  - Bentley Gas
  - Bentley Electric
  - Bentley Fiber
  - Bentley sisNET (multi-utility solution)
  - ...
- Learn one – learn them all
Example: Pipe Renewal Planning

1. Asset Inventory/Leak History
2. Bentley WaterGEMS
3. Cost Estimate
4. AssetWise (eB) / GWP

Manage records, Report, Visualize, Schedule
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
Cluster Thematically Bad Pipes
# Analyze Patterns

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<th>Diameter, in.</th>
<th>Breaks</th>
<th>Break Rate, break/yr/km</th>
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# Look for Relationships

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<th>Corrosion holes</th>
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<tr>
<td>Steel</td>
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<td>1</td>
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</table>
Thematic Maps & Reports
Workflow

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:

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<th>ID</th>
<th>Label</th>
<th>Pipe Score</th>
<th>Raw Score (Pipe Break)</th>
<th>Score (Criticality)</th>
<th>Raw Score (Capacity)</th>
<th>Score (Capacity)</th>
<th>Diameter (in)</th>
<th>Length (ft)</th>
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</table>
eB – Report, Visualize, Schedule Renewals

- Customizable Dashboard
- None Technical Presentation
- Easy to read, easy to use
- Integrated Spatial Map
- Integrate with Enterprise Workflows
- Visualize and Approve
Or Publish with GWP
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) Pumping Scheduling

Optimizing Pumps Operation for Minimum Energy Usage in Water Systems
Typical Water System

Sources → Gravity or Pump → WTW → Pump → Distribution → Pump → End Use

WTW / PUMPING STATION / BOOSTER

WTW

BOREHOLE

STORAGE RESERVOIR
Energy Consumption

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

Carbon Intensity (in pound)

<table>
<thead>
<tr>
<th></th>
<th>U.S. Electric Grid (per kWh)</th>
<th>Natural Gas (per cubic foot)</th>
<th>Fuel Oil (per gallon)</th>
<th>Liquefield Pedro Gas (per gallon)</th>
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<td>2050</td>
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National Energy Consumption Projections for Public Water Supply

Which pump is wasting energy?
Overall (wire-to-water) Efficiency = Water Power/Input Power

Pump Efficiency = Water Power/Motor Power
Pump Power and Efficiency

Water Power (hp) = \( Q \times h \times S \div \text{efficiency} \)

Wire-to-Water Efficiency = Pump x Motor x Drive Efficiency
Pump Characteristics Curves

Head Characteristic Curve

System Head Curves

Operating Points

Efficiency Characteristics Curve

Best Efficiency Point (BEP)
Reduce Energy by Optimal Pump Scheduling

• What to schedule
  ■ Which pump is on duty
  ■ When pump is on duty
  ■ What speed is on duty
  ■ Which Tanks to utilise

• Goal
  ■ Minimize energy consumption
  ■ Minimize total energy cost

• Supply requirements
  ■ Water demand and hydraulics
  ■ Manage pressure constraints (water loss)
  ■ Deliver 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: 
  \[ h_{\min} \leq h_{i,t} \leq h_{\max} \]
  \[ v_{\min} \leq v_{j,t} \leq v_{\max} \]
  \[ \omega_{\min} \leq \omega_p \leq \omega_{\max} \]

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,
- \( h_{\min} \) and \( h_{\max} \) are the minimum required and maximum allowed hydraulic head,
- \( v_{\min} \) and \( v_{\max} \) are the minimum required and maximum allowed flow velocities.
## Energy Cost Analysis Tool

### Energy Pricing

**Scenario:** F-1

**Daily Cost:** $75.00

**Usage Cost:** $150.00

**Overall Energy Used:** 964.4059 kWh/MG

**Overall Unit Energy Cost:** $132.6812/MG

### Results

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## Darwin Scheduler

### Energy Costs

**Scenario:** F-1

- **Daily Cost:** 75.0 $
- **Usage Cost:** 150.0 $
- **Overall Energy Used:** 964.4059 kWh/MG
- **Overall Unit Energy Cost:** 132.6812 $/MG

### Results

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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
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 requirements at PRVs and critical points

- Results converted to control rules, e.g.

  Rule 100
  IF  SYSTEM CLOCKTIME  <=  8:00  AM
  OR  SYSTEM CLOCKTIME  >=  10:00  PM
  AND  TANK  BUTa2  LEVEL BELOW  5.73
  THEN  PUMP  PILWTH  STATUS IS  OPEN
  ELSE  PUMP  PILWTH  STATUS IS  CLOSED
## Energy Cost Comparison

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

- Pressure points and Tank levels
- Pump flows and controls
Summary

- Improving Efficiency is a part of a lifecycle asset management practice in Water Utilities and Consulting Ecosystem

- Integrated Geospatial, hydraulic modeling and optimization technology can help:
  - Detecting leakage hotspots
  - Pipe renewal planning process
  - Pumping scheduling and optimal pressure and energy management (including CO2 footprint)

- From ‘dull pipes’ towards Smart Water Networks for real-time modelling, decision making and emergency response
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Thank You for Your Attention

A SUSTAINABLE BUILT ENVIRONMENT

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