Bringing Together Treatment, Storage and Conveyance for System-Wide, Continuous Real Time Operation

Timothy Ruggaber, PE
EmNet

June 29, 2016
Why Dynamic Control?

- Spatial and temporal rainfall distribution
- Long travel times
- Different permeability coefficients
Real Time Control

Software: Optimization Algorithm
In-Line Storage
Automatically control
An Approach to:

- Consolidate knowledge
- Provide guidance
- Extend the WWTP to the CS
Market Based Control: A swarm intelligence approach to optimization

Interceptor: “I’ve got capacity at $3 per gallon”

CSO 30: “Wait, I’ll pay you $4 a gallon!”

CSO 22: “I’ll buy it!”

Storage Tank: “I’ve got capacity at $3.50 per gallon”
Market Based Control: Concept

- Agent-Based control
- Network nodes trade capacity
- Downstream nodes are suppliers
- Upstream nodes are consumers

Local Optimization
Minimize cost
Compete for WWTP
Market Based Control: An example

\[ Q_{trunk} \rightarrow Q_{diverted} \rightarrow Q_{WWTP} \]

\[ Q_{overflow} \]

\[ \text{min}(Q_{overflow}) \text{ subject to } Q_{WWTP} \leq \overline{Q}_{WWTP} \]
Virtual Cost: Plant

![Graph showing the relationship between virtual cost/gallon and capacity, labeled with $Q_{WWTP}$ as the capacity point.](image)
Virtual Cost: Overflow

![Graph showing virtual cost per gallon vs. overflow]

- Virtual cost per gallon: 1
Virtual Cost: Trading

- **Virtual Cost/gallon**: $\frac{Q_{WWTP}}{\text{capacity}}$

Diagram:
- **WET WEATHER 2**
- **Control Valve**
- **WWTP**
- **Overflow**
Market-Based Control

- Two step optimization:
  - “design time” optimization of supply curves
  - “run time” optimization of agents trading
- Highly optimized rules are easy to capture and explain
- Easy to implement in SWMM and SCADA
- No centralized control means robust operation to degraded modes.
Columbus, OH

- 300,000 acres service area
- 2,800 miles combined and separated sewers
- Jackson Pike WWTP: 150MGD
- Southerly WWTP: 330MGD
- Plans for: CEPT (110MGD), OARS (55MG)
Objectives

Objective:

• Reduce overflows according to service levels.
• Maintain or reduce HGL

<table>
<thead>
<tr>
<th>Overflow Location</th>
<th>Level of Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jackson Pike Gravity Bypass</td>
<td>10 yrs.</td>
</tr>
<tr>
<td>Jackson Pike Mechanical Bypass</td>
<td>10 yrs.</td>
</tr>
<tr>
<td>All DSRs</td>
<td>10 yrs.</td>
</tr>
<tr>
<td>Downtown CSOs</td>
<td>10 yrs.</td>
</tr>
<tr>
<td>Southerly Gravity Bypass</td>
<td>1.4 yrs.</td>
</tr>
<tr>
<td>Alum Creek Storm Tanks</td>
<td>1 yr.</td>
</tr>
<tr>
<td>Whitter Street Storm Tanks</td>
<td>1 yr.</td>
</tr>
<tr>
<td>OARS</td>
<td>3 mo</td>
</tr>
</tbody>
</table>
Objectives

Objective:

- Minimize impact of overflows
- Level of Service Requirements
- Level of Treatment at outfall
- Legality
- Receiving Stream Designation
- Discharge Location

Overflow Impact Factor = (Level of Service Factor) x (Level of Treatment Factor) x (Receiving Stream Designation Factor) x (Receiving Stream Location Factor) x (Legality Factor)
General Methodology
Control Relationships
Need for Predictive SWWTP

SMR

JPWWTP

travel time: 2.5hrs

Flow Monitor

SWWTP
Predictive Widget
SWMM Widget Concept

\[ \frac{dQ_{out}(t)}{dt} = kQ_{in}(t) \]

\[ H_{out}(t + T) \approx \tilde{H}_{out}(t) \]
\[ Q_{out}(t + T) \approx \tilde{Q}_{out}(t) \]
SWMM Widget Implementation

\[
\min_{k>1, tank} \sum (H_{out}(t) - \tilde{H}_{out}(t))^2
\]

Interconnector Pump (West)

BWO Pump (East)

Southerly WWTP

Southerly Prediction Widget
SWMM Widget Results

Actual Vs. Predicted Inflow to Southerly WWTP

Flow (MGD)

May-81 May-81 May-81 May-81 May-81 May-81 June-81 June-81

- Actual Southerly Inflow
- Predicted Southerly Inflow
Multi Objective Control: SMR

Overflow Location | Level of Service
--- | ---
Jackson Pike Bypass | Never
Southerly Bypass | 1.4 yrs
OARS | 3 mo
Multi Objective Control: SMR
Multi Objective Control: SMR

Southerly Agent Cost

Max Cost

So Bypass Structure Level

Cost
Simplified SMR Control Rules

RULE CLOSESMR
IF COST(So) > COST(JP) THEN
SMR SETTING = SMR SETTING − 0.2

RULE OPENSMSR
IF COST(So) < COST(JP) THEN
SMR SETTING = SMR SETTING + 0.1
SWMM Control Options

RULE MC1
IF NODE N2 DEPTH \( \geq 0 \)
THEN WEIR W25 SETTING = CURVE C25

RULE MC2
IF SIMULATION TIME > 0
THEN PUMP P12 SETTING = TIMESERIES TS101

RULE MC3
IF LINK L33 FLOW \( \neq \) 1.6
THEN ORIFICE O12 SETTING = PID 0.1 0.0 0.0 0.0
Reverse Polish Notation in SWMM

RULE OPENSMLR

<table>
<thead>
<tr>
<th>Condition</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF SIMULATION TIME &gt; 0</td>
<td>;;;do always</td>
</tr>
<tr>
<td>AND NODE JPWW DEPTH [ENTER]</td>
<td>---</td>
</tr>
<tr>
<td>AND STACK OP [ENTER] 0.03</td>
<td>;;;calculate Jackson Pike cost</td>
</tr>
<tr>
<td>AND STACK OP [*]</td>
<td>---</td>
</tr>
<tr>
<td>AND NODE SOWW DEPTH [ENTER]</td>
<td>---</td>
</tr>
<tr>
<td>AND STACK OP [ENTER] 0.02</td>
<td>;;;calculate Southerly cost</td>
</tr>
<tr>
<td>AND STACK OP [*]</td>
<td>---</td>
</tr>
<tr>
<td>AND STACK OP [X&lt;Y]</td>
<td>;;;compare!</td>
</tr>
<tr>
<td>AND ORIFICE SMR SETTING [ENTER]</td>
<td>---</td>
</tr>
<tr>
<td>AND STACK OP [ENTER] 0.1</td>
<td>;;;calculate new orifice setting</td>
</tr>
<tr>
<td>AND STACK OP [+]</td>
<td>---</td>
</tr>
</tbody>
</table>

THEN ORIFICE SMR SETTING = STACK RESULT ;;;apply if true!
Control Dashboard

- SMR: 33%
- Weather: 0.2 in/hr
- IPS (2.3hrs): 20 ft
- IPS (now): 15 ft
- SWWTP (2.3hrs): 320 mgd
- SWWTP (now): 280 mgd
- Rainfall: 2 in/hr
RT-DSS Dashboard (Sample)
Risk Based Control

No need for CEPT

CEPT is required

Pr(Total Precipitation < X)

Prob = 1

Prob = P_{max}

Threshold Precipitation

Precipitation = X
Real Time Decision Support System

- Interactive (human-in-the-loop).
- Operator-centric.
- Utilizes glass-box concepts for easy transfer of knowledge.
- Combines real time data with real time modeling.

“Operate the collection system as an extension of the treatment plant.”