TEVA-SPOT: DESIGNING CONTAMINATION WARNING SYSTEMS

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
Security and Contaminant Warning Systems
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National Homeland Security Research Center
Acknowledgements

• EPA Colleagues: Regan Murray & Terra Baranowski
• Collaborators:
  – Sandia National Laboratories
  – Argonne National Laboratory
  – University of Cincinnati
• American Water Works Association
• Partnering Water Utilities (TEVA Utilities)
Outline

• What is a Contamination Warning System
  ➢ Goals & design principles
• Motivation for developing TEVA-SPOT
• TEVA-SPOT Software Program
  ➢ Capabilities
  ➢ Platforms & Operation
  ➢ Quick look via screen shots
  ➢ Issues
  ➢ Release strategy for TEVA-SPOT
Contamination Warning Systems: Main Components

Water Quality Monitoring:
- Online monitoring
- Sampling and analysis

Consumer Complaint Surveillance

Enhanced Security Monitoring:
- Video
- Alarms
- Intelligence

Public Health Surveillance:
- 911 calls / EMS data
- ED visits
- OTC medication sales
Contamination Warning Systems

- **Contamination Warning System Goals**
  - To detect contamination events in drinking water distribution systems
  - To detect rapidly enough to allow for utility and public health intervention that reduces public health and economic impacts
  - Achieve multiple benefits to water utility

- **Design principles**
  - Spatial coverage:
    - Entire distribution system service area.
  - Contaminant coverage:
    - All contaminant classes posing a threat.
  - Timing of detection:
    - In sufficient time to allow for effective response.
  - System reliability:
    - Information sufficient to make response decisions.
  - Deployable at water utilities of all sizes and types
Motivation for TEVA-SPOT:
Understand Threats and Vulnerabilities

- We don’t know where contaminant releases can occur in the distribution system.
- We know health and economic impacts can vary widely depending on the release location.
- We know significant impacts can occur miles from the release location.
Motivation for TEVA-SPOT: Public Health and Economic Impacts Cont’d

- Economic Impacts:
  - Vary widely by scenario, i.e., contaminant, release location
  - Understanding how impacts are influenced by system design & operation, contaminant class, duration of upset, and other factors is critical to impact mitigation
Contaminant Consequence Features:

- Simulate contamination events in a distribution system
  - Single contamination events
  - Multi, simultaneous contamination events
- Define contamination event ensembles:
  - All nodes, non-zero demand nodes, or user defined
  - Nodes defined by diameter of pipes which they are connected to
- Select exposure and dose response model
- Results to quantitatively rank contamination scenarios, examine individual scenarios by receptors impacted, determine the timeline of exposure and health impacts

Impact:

- Assess contamination event consequences and timeline
- Support the optimal design of sensor networks
TEVA-SPOT features and impact

Sensor Network Design Features:
- Scalable solvers for large-scale problems
  - 10,000s junctions and pipes
- Solvers that can optimize many different objectives
- Flexible specification of performance constraints
- Fast solvers
- Methods for rigorously evaluating solver performance

Impact:
- Ability to design optimal sensor networks and evaluate alternative designs, e.g., expert designs or designs constrained to public facilities
- Results to quantitatively evaluate sensor network designs, including graphical plots depicting sensor coverage plots of contamination events
TEVA-SPOT PLATFORMS

• TEVA-SPOT Platforms:
  - Single machine version
    - Ensemble simulations, health impacts, and sensor placement routines running sequentially on a single computer. Windows or LINUX version of TEVA-SPOT for single computer available.
  - Distributed computing version
    - Windows or LINUX versions with each component (ensemble simulations, health impacts, and sensor placement routines) performed using distributed computing capabilities for greatly improved performance
Operation of TEVA-SPOT

• **Scenario** – A release or injection of a contaminant at a location (node) within a distribution system, specifying contaminant mass release rate (organisms or mass units per minute), injection duration (hours).
  – Injection definition
  – Node set definition

• **Ensemble** – Collection of one or more scenarios, using defined as “all nodes” or “all non-zero demand nodes” within the distribution system model.

• **Ensemble Analysis Mode** – TEVA-SPOT mode where contaminant vulnerability assessment and sensor network designs are performed.

• **Regret Analysis Mode** – TEVA-SPOT mode where multiple sensor designs are evaluated against different impacts to determine sensor network design(s) that perform best.
• Initial TEVA-SPOT window on startup:
  – Ensemble not yet created or loaded
  – Utility distribution network not yet loaded
  – One chooses “New” or “Load”

• Principal menus consist of:
  – Ensemble
  – File
  – Mode
  – Edit
EXECUTION PANEL

- **Green Check Mark** indicates that the module has been completed
- **Read Exclamation Mark** indicates a module has not been run or the data is not current
- Clicking EDIT buttons allows the User to edit the module data
Office of Research and Development
National Homeland Security Research Center

Scenarios – BaseEnsemble:
- Injection Definitions
- Node Set Definitions
- Node Injections
- Scenario Sets

Builds - Node Injections
Loaded into Scenario Set(s)
Sensor Design Parameters

- Solvers
- Sensor Set Sizes
- Objectives
- Dose Thresholds
- Response Time (minutes)
- Constraints
- Location Categories
- Costs – Currently not functional
- Detection Limits for contaminant detection
- Selection Methods – Currently not functional

EDIT commands open additional dialogue boxes to enter data or choose a particular option.

Edit opens above dialogue box.
Summary of some EPANET inp file parameters

Clicking faucet expands to this EPANET parameters window

Magnifying glass is ZOOM feature

Arrow is PAN feature

Text entry box to describe ensemble

Summary of some EPANET inp file parameters
REGRET ANALYSIS

A regret analysis or trade-off analysis evaluates how well a previously computed sensor network design meets an objective other than the one it was intended to optimize.

A regret analysis uses the impact data corresponding to alternate threats, response times, and/or objectives for the same network. The set of sensor designs and impact files which are evaluated are specified within the regret analysis.
Opening slide after switching to REGRET ANALYSIS MODE under “Mode”
Regret Analysis

• Evaluation of Sensor Design Performance
  – TEVA-SPOT outputs a table of impact results for each sensor network design and impact file evaluated.
  – Performance measures are used to provide a measure of the overall magnitude of the impacts for each sensor network design relative to the best design for each impact file evaluated.
### Table of Regret Analysis Results

- Sensor network designs across top
- Ensemble impact files along left
- 3 sensor network design performance measures provided
- Column highlighting lowest impact result which corresponds to “Best” sensor network design

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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</tbody>
</table>

- **Impact Ensemble**
- **Response Time**
- **Detection Limit**
- **No Sensors**

- **SPTests_Net2WithSensorsAugmentedID**
- **1440**
- **0.0**
- **399513.0**
- **351243.0**
- **365207.0**
- **366249.0**
- **261243.0**

- **SPTests_Net2WithSensorsSmall**
- **0**
- **0.0**
- **504016.0**
- **77715.6**
- **2:0204.0**
- **0.0**
- **0.0**

- **Performance Measure**
- **L2 Norm**
- **77715.6**
- **2:0241.38**
- **5006.0**
- **5006.0**

- **L1 Norm**
- **77715.6**
- **2:0204.0**
- **5006.0**
- **5006.0**

- **Execution**
  - Available Executions:
    - Regret Analysis
  - Status:
    - Done: 1 / 1 (100%)
    - Estimated Time Remaining: 00:00:00:00
    - Estimated Total Time: 00:00:00:30
    - Estimated Completion Time: 12/17/2007 04:23:11 PM
  - Options:
    - Execute
    - Terminate
Issues

• TEVA-SPOT relies on network distribution models
  – Currently does not support simulation of realistic water quality reactions
  – Uses only EPANET network distribution models, in the form of an *inp* file
  – Does not contain direct GIS interface

• Generally, current distribution system models are limited by:
  – Lack of data and understanding about parameter uncertainty and variability
  – Inability to automatically adapt models in real-time, based on system operation, hydraulic, and water quality SCADA data
  – Inefficient computational procedures
• TEVA-SPOT run times can be quite long
• Run times depend on:
  – Network model, simulation duration, hydraulic & water quality time steps
  – Number of scenarios
  – Options chosen in health impacts assessment
  – Sensor placement: # of sensor sets, objective/statistic, # of detection limits, and # of response delay times
• Memory utilization can be high for sensor placement
• Storage requirement for output data can be high, depends on network and # of scenarios, often a 1GB or more.
TEVA-SPOT OUTPUT: MAPS, CHARTS, & TABLES
INJECTION IMPACT PLOT

Adjustable scale to visually see where impacts occur above some threshold.

Details total fatalities by injection location.

Data are depicted at the single node where the injection occurs to provide a graphical representation of node ranking for production of health impacts.

Beware of these plots with more complicated simulation ensembles!
EXPOSURE IMPACT PLOT

Details source of release and receptor nodes which received impact (fatalities).

Source of Injection or Release

Adjustable scale to visually see where impacts occur above some threshold
Sensor network design identified by the title above.

Green stars denote sensor locations.
Scenario Event Detection Coverage Plot (nodes & links). Figure illustrates nodes & links covered by the identified sensor.

User can turn on either Links or Nodes or both.
Histogram-type plot of SCENARIO (x-axis) versus Estimated FATALITIES (y-axis) for all scenarios evaluated in the ensemble.

For example, there are 1,000 scenarios which result in 1,000 or less fatalities.

(Y-scale ranges from 0 to 15,000 fatalities)

(X-axis represents the total number of scenarios. In this case 1,621 scenarios were run.)
Infections, Diseased, and Fatalities by Time

Plot:
- Scenario specific
- Representative of contaminant’s latency and fatality times
- Shape of plot and impacts determined by injection location

Title specifies scenario, health impacts (fatalities), and injection location for scenario.
### Ensemble Percentiles Table

- **Percentile scenarios under Statistic**
- Average impact results of all scenarios in the ensemble: **Mean**
- Infected and Fatalities related by “Fatality Rate”
- Copy and paste to Excel, print under File Menu

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Max Concentration</th>
<th>Max Individual Dose</th>
<th>Number of Infected</th>
<th>Number of Fatalities</th>
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<tbody>
<tr>
<td>10th percentile</td>
<td>43,815,284</td>
<td>3,524,294,656</td>
<td>45.172</td>
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<td>25th percentile</td>
<td>160,614,112</td>
<td>9,464,930,304</td>
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<td>50th percentile</td>
<td>662,438,592</td>
<td>24,863,805,440</td>
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<td>75th percentile</td>
<td>2,069,381,632</td>
<td>75,628,470,272</td>
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<td>90th percentile</td>
<td>4,308,813,312</td>
<td>88,347,254,784</td>
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<td>100th percentile</td>
<td>2,982,847,447,040</td>
<td>203,939,233,792</td>
<td>48,683.121</td>
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<td><strong>Mean</strong></td>
<td>10,238,916,608</td>
<td>39,472,852,992</td>
<td>6,399.243</td>
<td>1,919.773</td>
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</table>
Ensemble Summary Table

- Complete compilation of ensemble results by scenario:
  - **Max concentration**: Maximum concentration observed at any corresponding receptor node.
  - **Max individual dose**: Maximum individual dose received at any receptor node for the scenario (injection node) identified.
  - **Number infected/fatalities**: Total number of individuals for the scenario, across all receptor nodes.
  - **Nodes for 90% fatalities**: Number of nodes required to obtain 90% of fatalities indicated for that scenario (measure of contaminant spread in network).
  - **Nodes with fatalities**: Number of nodes contributing fatalities to those indicated for the scenario.

<table>
<thead>
<tr>
<th>Injection Node</th>
<th>Max Concentration</th>
<th>Max Individual Dose</th>
<th>Number of Infected</th>
<th>Number of Fatalities</th>
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</table>
### Sensor Placement Summary Table

- Sensor network designs performance data
- Same data output by SPOT
TEVA-SPOT Release Strategy

- EPA is working with commercial vendors to incorporate the functionality of TEVA-SPOT into their modeling applications.
- EPA is also committed to supporting water utilities, including those involved in the Water Security Initiative, to perform contaminant vulnerability analyses and design CWSs by providing TEVA-SPOT when requested.
- For information or to request TEVA-SPOT, contact:
  
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  Water Infrastructure Protection Division
  U.S. EPA/NHSRC
  Mail Stop NG-16/NB21F
  26 West Martin Luther King Dr.
  Cincinnati, Ohio  45268
  Office Phone: 513-569-7160