Application of Water Quality Simulation for Water Safety Plan

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Agenda

• Introduction
• Background and Objective
  – Significance of Modeling Approach
  – Review of a Water Safety Plan
• Methodology
  – Model Framework and prioritized model
• Results and Discussion
  – Simulation Results for Present Status
  – Evaluation of Countermeasures
• Conclusion and Recommendation
Who We Are?

Nihon Suido Consultants Co., Ltd.

- Offering total solution for Water and Water Environment
- No.1 share in Japan domestic Water Supply Consultancy market
- Business experiences in over 50 countries

Our Business Field

- Planning
  - Project Appraisal and evaluation
  - Master Plan
  - Feasibility Study
  - Preliminary & Detailed Design
  - Construction Supervision
  - Training for Plant Operation & Maintenance
  - Training for Technology Transfer
  - Review of Existing Management Organization and Practices
- Designing
  - Environmental Impact Assessment
  - Water Quality Analysis & Assessment
  - Pollution Control Programs
- Construction
  - Leakage & NRW control Programs
- Operation
  - Data Mapping & GIS
  - Asset Management
Research Framework

- Collaborative research between NSC and University of Peradeniya for Water and Environment
- MoU formulation
- Joint Workshop

Background

- Emerging Water Environment Issues in Sri Lanka
  - Eutrophication, Agrochemicals
  - Water-related Diseases
  - Incidents by Wastewater Pollutions
  - Leachate from Waste Disposal Site

- Countermeasures to secure Safe Drinking Water
  - Water Safety Plan
    - Unknown likelihood and Significance of Risks
    - Need stakeholders involvement to control
Background and Objective

• Modeling and Simulation Approach

<table>
<thead>
<tr>
<th>Merits</th>
<th>Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Prospective Approach:</td>
<td>- Input / Verification data are not always available</td>
</tr>
<tr>
<td>Give scientific verification to policies, Evaluate Countermeasures</td>
<td>- Ad-hoc, Not replicable by practitioners</td>
</tr>
<tr>
<td>- Accountability:</td>
<td></td>
</tr>
<tr>
<td>Show visually to explain to the public</td>
<td></td>
</tr>
</tbody>
</table>

• Objectives
  – Review water resources problems from actual water safety plan
  – To establish the simulation model to evaluate the risks at water safety **under limited resource conditions**

Study Area: Mahaweli River Basin near Kandy

Greater Kandy
WTP:
72,000 m³/day
(Phase II, by 2014)
Population
Served:
400,000
WSP:
formulated on
July 2014
Review of Greater Kandy Water Safety Plan (1)

- “Very High” Risk Incidents focused at Source

<table>
<thead>
<tr>
<th>Location / Process step</th>
<th>Hazardous event</th>
<th>Hazard type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Pathogenic contamination from septic tanks and waste from Kandy city through</td>
<td>Physical/Chemical/microbiological</td>
</tr>
<tr>
<td></td>
<td>Middle canal (Meda-Ela)</td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>Leachate from Kandy city garbage dumping site entering intake</td>
<td>Physical/Chemical/microbiological</td>
</tr>
<tr>
<td>Source</td>
<td>Pollution by agrochemicals during spraying season</td>
<td>Chemical</td>
</tr>
<tr>
<td>Distribution chamber</td>
<td>Power failure at WTP</td>
<td>Chemical &amp; Microbial</td>
</tr>
<tr>
<td>Service reservoirs</td>
<td>Unauthorized personnel entering premises</td>
<td>Chemical &amp; Microbial</td>
</tr>
<tr>
<td>Pipe network</td>
<td>Contamination of treated water</td>
<td>Microbial</td>
</tr>
</tbody>
</table>
Review of Greater Kandy Water Safety Plan (2)

- Hazard identified at source (catchment)
  - WTP is near to Solid Waste Dumping Site at Gohagoda
  - There is some possibility for contamination from back flow of the Mahaweli River
  - **Major concern but difficult to evaluate its significance**

Methods(1) : **Overall Model Framework**

- **Catchment**
- **Reservoir or Lake**
  - Output
  - Input / Output

1. Kandy Lake Mid-canal
2. Mahaweli River
3. Gohagoda Dumping Site
4. Intake for Grater Kandy WTP
5. Intake for Kandy South WTP
6. Hydro Power
7. Intake for Polgolla WTP
8. Polgolla Reservoir
**Methods(2) : Catchment Model**

- **Catchment Model**
  - **Rainfall** *(Land-use)*
    - Forest
    - Paddy
    - Tea Garden etc.
    - Residential Population
    - Tourist Population
  - **Non-point Source Pollution Load**
    - Runoff Coefficient
  - **Point Source Pollution Load**
    - Runoff Coefficient
  - **Discharged Pollution Load**
    - Pollution Load

- **L = αQ^β**

**Methods(3) : Reservoir Model**

- **Vertical two dimensional Model**
  - **Hydraulic Model**
  - **Water Quality Model**
    - Density flow shall be analyzed in reservoir
    - Transfer pollution load according to advection & diffusion
Methods(4) : Detail of Reservoir Model

Hydraulic Model

- Flow velocity in flow and vertical direction
- Water level (water volume)
- Density

**Equation for Continuity**

\[
\frac{\partial \bar{u}}{\partial x} + \frac{\partial \bar{v}}{\partial y} = 0
\]

**Equation for Conservation of Momentum**

\[
\frac{\partial \bar{u}}{\partial t} + \frac{\partial}{\partial x} (\bar{u} \bar{u}) + \frac{\partial}{\partial y} (\bar{u} \bar{v}) = -\frac{\partial}{\partial x} \left( \frac{P}{\rho} \right) + \frac{\partial}{\partial x} \left( A_x \frac{\partial \bar{u}}{\partial x} \right) + \frac{\partial}{\partial y} \left( A_y \frac{\partial \bar{u}}{\partial y} \right)
\]

\[
\frac{\partial \rho}{\partial y} = -\rho g \quad \text{(Assumption of hydrostatic pressure distribution)}
\]

Methods(5) : Detail of Reservoir Model

Water Quality Model

**Equation for Temperature Balance**

\[
\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{\partial}{\partial x} \left( K_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_y \frac{\partial T}{\partial y} \right) + \frac{H}{\rho C_w}
\]

**Equation for Ecological Model**

\[
\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = \frac{\partial}{\partial x} \left( D_x \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y} \left( D_y \frac{\partial C}{\partial y} \right) + S
\]

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Methods (5): Scoping Target Water Quality Indicators

- **Background Water Quality** ¹)
  - Cd (3.9-21.5 μg/L)
- **Heavy Metals in Leachate** ²)
  - Cr, Fe, Ni, As, Cd, Se, Pb
- **Other Substances in Leachate** ³)
  - Mn, PO₄³⁻

⇒ Pb in leachate is higher than other substances.

Pb was selected as **model indicator** for simulation in this study.

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Required Input Data for Boundary Conditions

<table>
<thead>
<tr>
<th>Items</th>
<th>This Study</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment Framework</td>
<td>✔️</td>
<td>Provided by Uni.</td>
</tr>
<tr>
<td>River Profile</td>
<td>✔️</td>
<td>Provided by Uni.</td>
</tr>
<tr>
<td>Hydrology (Precipitation / Flow Volume)</td>
<td>✔️</td>
<td>Provided by Uni.</td>
</tr>
<tr>
<td>Water Quality</td>
<td>✔️</td>
<td>Literature</td>
</tr>
<tr>
<td>Meteorology</td>
<td>✔️</td>
<td>Literature</td>
</tr>
<tr>
<td>Dimension of Dam / Barrage</td>
<td>✔️</td>
<td></td>
</tr>
</tbody>
</table>
Polgolla Reservoir with total length of 7.5 km was divided into meshes at intervals of 0.5 km in flow direction and 1.0 m in vertical direction.

Inflow condition for Polgolla Reservoir was set according to the actual record of inflow volume in year 2014. Hydrological condition in 2014 corresponds to dry year in recent 7 years.
Meteorological Condition

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp(°C)</td>
<td>23.4</td>
<td>24.2</td>
<td>25.5</td>
<td>26.1</td>
<td>25.7</td>
<td>25.0</td>
<td>24.7</td>
<td>24.7</td>
<td>24.7</td>
<td>24.6</td>
<td>24.4</td>
<td>23.7</td>
</tr>
<tr>
<td>solar radiation (W/m²)</td>
<td>371</td>
<td>386</td>
<td>406</td>
<td>416</td>
<td>408</td>
<td>393</td>
<td>387</td>
<td>396</td>
<td>409</td>
<td>412</td>
<td>398</td>
<td>378</td>
</tr>
<tr>
<td>relative humidity(%)</td>
<td>83.8</td>
<td>79.0</td>
<td>76.5</td>
<td>82.5</td>
<td>83.5</td>
<td>83.4</td>
<td>82.0</td>
<td>81.0</td>
<td>81.2</td>
<td>85.2</td>
<td>87.8</td>
<td>86.8</td>
</tr>
<tr>
<td>wind speed(m/s)</td>
<td>0.8</td>
<td>0.6</td>
<td>0.3</td>
<td>0.2</td>
<td>0.8</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.5</td>
<td>0.8</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>cloud amount(-)</td>
<td>0.48</td>
<td>0.42</td>
<td>0.47</td>
<td>0.58</td>
<td>0.71</td>
<td>0.72</td>
<td>0.74</td>
<td>0.73</td>
<td>0.77</td>
<td>0.72</td>
<td>0.66</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Meteorological Condition is required to calculate water temperature for sunshine and heat balance in water surface in reservoir.

Water Quality Condition

<table>
<thead>
<tr>
<th></th>
<th>① Inflow from Kandy Lake</th>
<th>② Inflow from Mahaweli River</th>
<th>③ Leachate from Gohagoda Damping Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment Area (km²)</td>
<td>255</td>
<td>1063</td>
<td>0.06</td>
</tr>
<tr>
<td>Discharge Volume (m³/s)</td>
<td>13.1</td>
<td>54.6</td>
<td>0.006</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>22.4</td>
<td>8.0</td>
<td>700</td>
</tr>
<tr>
<td>T-N (mg/L)</td>
<td>5.9</td>
<td>1.9</td>
<td>700</td>
</tr>
<tr>
<td>T-P (mg/L)</td>
<td>1.1</td>
<td>0.4</td>
<td>8.0</td>
</tr>
<tr>
<td>Pb (mg/L)</td>
<td>0.005</td>
<td>0.005</td>
<td>12.9</td>
</tr>
<tr>
<td>Zn (mg/L)</td>
<td>0.145</td>
<td>0.145</td>
<td>700</td>
</tr>
</tbody>
</table>

Water quality condition was set according to discharged water quality calculated through the catchment model. Concentration of Pb was set according to the observed data.
The Simulation Model can configure input and output data on Microsoft Excel interface. Users can easily handle the simulation model (e.g., change of input data and evaluation of simulation results).

Results(1): **Simulation Results for Reservoir**

**Water Temperature**
February 15th, 2014

- **Water temperature**: between surface and bottom layer is different due to sunshine and low flow volume especially in dry season.
Results (2): Simulation Results for Reservoir

Water Temperature & Flow Velocity
February 15th, 2014

- **Flow Velocity**: Difference in temperature makes density flow (Fair current in middle layer and backflow in surface and bottom layer).

Results (3): Simulation Results for Intake Water Quality

Pb Concentration
February 15th, 2014

- **Backflow**: Substances in Leachate could flow back to upstream by approx. 2 km due to density flow.
• **Seasonal variation:** variation exists but not significant

Results(4): **Simulation Results for Intake Water Quality**

Results(5): **Control Measure Identification**

<table>
<thead>
<tr>
<th>Case</th>
<th>Control Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 01</td>
<td>Installation of fence in bottom layer</td>
</tr>
<tr>
<td>Case 02</td>
<td>Raw water Intake from surface layer</td>
</tr>
</tbody>
</table>

**Case 01:** Pb increased due to retention at bottom layer.

**Case 02:** Pb decreased, while Chl-a increase especially in dry season due to growth of phytoplankton.
As for Case 01, due to installation of fence, contaminated substances stay longer in bottom layer at intake and intake water quality of Pb increase.

As for Case 02, intake water quality of Pb decrease by intake from surface.
Results (8): **Control Measure Identification**

As for Case 02, intake of Chl-a increase especially in dry season due to growth of phytoplankton in surface.

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**Discussion: Model Flow of Simulation Application to WSP**

- Screening of Target WS
- Review of WSP
- Identification of Problems
- Determination of Model
- Data Collection
- Modeling
- Output Results
- Verification by Monitoring Data

Which System to be examined?
- Concern of Incidents
- Significant (Population)

Communication with Local Stakeholders

Involvement of Local Authorities

Collaboration for Data Acquisition
Conclusion (1)

- Water Safety Plan of Greater Kandy WTP indicated water source issues are identified as “Very High” risk because of unavailability of observed data.
- Water Quality Simulation model for Pollgolla Reservoir implied that;
  - Leachate contamination may flow back by 2km due to density flow*.
  - As countermeasure, fences at Intake (Case 01) may have adverse impact on water quality and Intake at surface (Case 02) is effective while Chl-a (phytoplankton) concern remains.

* Modeled substance (Pb) is below WHO guideline value

Conclusion (2)

- In this research, we could not reach quantitative re-risk assessment utilizing the results because the concentration of modelled substances (Pb) did not go beyond the WHO guideline level.
- More research is needed for identifying the possible harmful substances such as agro-chemicals, carcinogenic substances and other unknown substances.
- Application of water quality simulation model for water safety is effective to manage raw water quality and figure out likelihood and significance of risks for incidents.
Recommendations

• **Utilize simulation approach for public communication and policy making**
  – **Visualization** for communicating with stakeholders
  – Acceleration for Proactive Measures

• **Establish replicable simulation models/workflows considering limited resources**
  – **Data Availability** is the Key Factor
  – Improvement of usability is necessary

• **Monitoring**
  – Data Collection and Communication among institutions
  – Find Feasible, Expandable and Continuous methods