Numerical study on dispersion of turbid overland flow in stratified waters

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Introduction

- Coastal Area
  - Very important area for human
  - A part of water circulation
  - Watershed management is important

http://www.omsolar.net/en/system_z/index.html
- Steep stream gradient
- To prevent flooding, provide a stable water supply and electric power generation

=> 2868 dams were constructed in Japan

=> It is very important in the watershed management to consider dam

- Environmental Problem caused by dam
  - Disjuncture of eco-region
  - Decrease of sediment transport to coastal area
  - Continuous turbid water runoff
Continuous turbid water runoff from dam

- **Generation mechanism**
  1. Heavy rain generated high-turbidity water by erosion of bottom (land and/or riverbed) suspended solids.
  2. High-turbidity water was transported to dam and widespread to limited water depth because it is stratified.
  3. Influent high-turbidity water pumped out to river gradually and continuous turbid water runoff from dam was occurred.
Environmental impact of continuous turbid water runoff to river

- Decreasing attached algae in downstream
  - Decrease of feed for Japanese trout
- Spoil a view

- Environment change in near future
  - Increasing drought phenomenon
  - Decreasing forest area
- Environmental impact of turbid water become more serious
- Water quality management of runoff from dam become important
How to manage an effluent quality?

a. Remove a deposited sand in upstream

b. Tailwater control method
   - Selective intake facility
   - Silt protector
   - Prediction of dispersion of turbid water in dam is needed for effective operation


http://www.cbr.mlit.go.jp/yahagi/03-match/envi_control/index.html
Objectives

• Develop a numerical model to evaluate an advantage of tailwater control method

A) Field observation
  • Actual phenomena of dam and inflowing rivers were evaluated

B) Numerical Simulation
  • Two tailwater control method were evaluated
A) Field Observation

- A Dam located at center area of Japan
  - Two river inflow, one intake point

- River discharge rate(Q), SS concentration @ St6,7
- Vertical SS concentration @ St.1 to 5
Volume balance from Aug. 8 to Oct 10.

176m³/s on Sept. 16
• High-Turbidity water widespread to downstream
• High-Turbidity water disappeared 23 days later
Almost all SS sink to bottom
**Fine sand**(>d=5um) : settled
**Silt** (<d=5um): suspended
Consideration of various grain diameters is effective for improve reproducibility of numerical simulation
• Periodical River temperature variation weaken during a flood
• The water temperature of the river is different respectively
B) Numerical Simulation

- An existing quasi 3D baroclinic flow model was applied
  - No need to make new model to predict phenomena in hydrographic basin
  - Dam with complex topography
  - Density flow was dominated in dam

- Accuracy was evaluated by hindcast simulation

- Two tailwater control methods were evaluated
Quasi 3-D Baroclinic Flow Model -- ODEM

- by Nakatuji (1987)
- Boussinesq assumption
- Hydrostatic approximation

Turbulent coefficients
- Horizontal: Sub-Grid Scale (SGS)
- Vertical

\[
\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - v \frac{\partial u}{\partial y} - w \frac{\partial u}{\partial z} + f v - \frac{1}{\rho_0} \frac{\partial p}{\partial x} + A_M \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) + \frac{\partial}{\partial z} \left( K_M \frac{\partial u}{\partial z} \right)
\]

\[
\frac{\partial v}{\partial t} = -u \frac{\partial v}{\partial x} - v \frac{\partial v}{\partial y} - w \frac{\partial v}{\partial z} - f u - \frac{1}{\rho_0} \frac{\partial p}{\partial y} + A_M \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) + \frac{\partial}{\partial z} \left( K_M \frac{\partial v}{\partial z} \right)
\]

\[0 = -\frac{1}{\rho} \frac{\partial p}{\partial z} - g\]

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

\[A_v = A_{v_0} \left( 1 + 5.2 R_i \right)\]

\[K_v = A_v \left( 1 + 10 R_i \right) \frac{3^{3/2}}{3^{1/2}}\]

Ri: Richardson number
Transport model for SS

\[
\frac{\partial C}{\partial t} + \frac{\partial (UC)}{\partial x} + \frac{\partial (VC)}{\partial y} + \frac{\partial (W - W_s C)}{\partial z} = \frac{\partial}{\partial x} \left( K_H \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_H \frac{\partial C}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_v \frac{\partial C}{\partial z} \right) + q_e - q_d
\]

\( W_s \) : Settling velocity (by Rubey's law)

\( q_e \) : Sediment erosion flux on the bottom

\( q_d \) : Sediment deposition flux on the bottom
ODEM need to be improved for large water level elevation

- Model was modified to keep an accuracy near surface.
- Dry and Wet function was added
Arrangement for Numerical Simulation

Target period
July 14, 2006 – Sept 11, 2006

Area 4.1km x 2.9km
Horizontal grid size: 50m
Vertical grid size: 1m
Numerical condition

Initial vertical profile of temperature

* Grain size distribution for numerical simulation

<table>
<thead>
<tr>
<th>Diameter of particle</th>
<th>2 μm</th>
<th>6 μm</th>
<th>10 μm</th>
<th>16 μm</th>
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</thead>
<tbody>
<tr>
<td>Normal situation(%)</td>
<td>60</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Flood situation(%)</td>
<td>25</td>
<td>25</td>
<td>30</td>
<td>20</td>
</tr>
</tbody>
</table>
## Simulation Condition

<table>
<thead>
<tr>
<th>Case</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case1</td>
<td>Hindcast (for verification)</td>
</tr>
<tr>
<td>Case2</td>
<td>Surface intake(surface to -5m)</td>
</tr>
<tr>
<td>Case3</td>
<td>Surface intake(surface to -10m)</td>
</tr>
<tr>
<td>Case4</td>
<td>Silt protector(Surface to 20m)</td>
</tr>
<tr>
<td>Case5</td>
<td>Silt protector(Surface to 10m)</td>
</tr>
<tr>
<td>Case6</td>
<td>Case2 + Case4</td>
</tr>
</tbody>
</table>
Turbidity of Tailwater from Jul. 22 to Sept. 10 (50 days)

- Case1 (Hindcast): Turbidity variation of tailwater well
- Case2 & 3 (Surface intake): Turdibity become very low. Sedimentation become serious
- Case4 (Large Silt Protector): Continuous turbid water runoff become prolong
- Case5 (Small Silt Protector): Smaller than Case 1 only early phase
- Case6 (Case2 + Case4): Similar with Case2

Silt Protector is not effective and surface water intake is effective but ....
Conclusion

A) Field observation
   • Consideration of various grain diameters is needed to improve reproducibility of numerical simulation
   • Periodical River temperature variation weaken during a flood
   • The water temperature of the river is different respectively

B) Numerical Simulation
   • Quasi 3D Coastal model applied to stratified dam
   • SS transport mode and dry and wet function was added for big water level change
   • Model result of turbidity of tailwater represented observed one
   • According to numerical test of tailwater control method, Surface intake was effective for reduction of turbidity of tailwater
Future work

• Next step is consideration of First Flash Flood
Temporal Variation of Vertical Profile of T and Turbidity

- Hight-turbidity water was observed after Sept. 19.
Relationship between Q and SS

Equation for Q-SS is needed every river
ODEM

**Boundary condition**

- SSH (Tide)
- Dist. of T and S
- Geostrophic current
- Wind velocity
- Atmospheric pressure
- Topography
- River discharge

**ODEM**

- Flow velocity
- Temperature
- Salinity
- SSH
- SS

**SWAN**

- Wave height
- Wave direction
- Wave period

**Sediment model**

- **Bed friction velocity** of the combined wave and current flow
- Sediment erosion and deposition flux on the sea bed
- Transport model for SS
Distribution of SS in Vertical Plane
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