Validation of Groundwater Flow Simulation Model by the Committee

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JAPAN ATOMIC ENERGY AGENCY
Aim & action

● Aim
To validate the groundwater (GW) flow model, which has been constructed by the committee on countermeasures for contaminated water treatment.

● Action
✓ Additional GW flow analysis has been performed by JAEA to estimate GW flow condition before and after implementation of the countermeasures.
✓ The consistency of analytical results from committee and JAEA models has been confirmed.
Contents

- Area setting for the modeling
- Geological modeling
- Hydrogeological modeling (Modeling the hydraulic conductivity field)
- GW flow analysis (3-D steady state analysis under saturated and unsaturated conditions)
  - Before implementation of countermeasures
  - After implementation of countermeasures
- Comparison between the analytical results from Committee and JAEA models
Area setting

Abukuma Mountains

Abukuma Mountains

Regional area

Futaba Fault

Site area

Committee model

Model | Focused GW flow system
---|---
Committee model | Shallow GW flow
JAEA nested model* | Site model
Regional model | Shallow to deep GW flow

*To confirm an influence of regional GW flow on GW flow on 1F site

Futaba Fault

Elevation (m)

Site area

Model

Focused GW flow system

Site model

Regional model

East (m)

90500 92500 94500 96500 98500 100500 102500 104500 106500

-500 -300 -100 100 300 500 700
Geological modeling

Geological model was constructed based on the data provided by TEPCO.
Geological modeling

A-A’ cross section through Unit #1 building

B-B’ cross section through Unit #4 building

C-C’ cross section

Legend

- Quaternary
  - Alluvium
  - Terrace deposit
- Pliocene/Tomioka stratum
  - Sandstone stratum
  - Mudstone stratum
  - Alternate stratum
  - Tomioka stratum ---T2
Geological modeling

A-A' cross section through Unit #1 building

Legend
- Quaternary
- Terrace deposit
- Sandstone stratum
- Mudstone stratum
- Alternate stratum
- Tomioka stratum
- Tomioka stratum (T2)

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In 1F site, unconfined and confined aquifers are distributed, and divided by low permeable mudstone stratum.

GW in unconfined aquifer mainly affects inflow volume into the underground facilities (UFs).

Origins of GW in unconfined and confined aquifers are estimated to be precipitation in 1F site.
Hydrogeological modeling

- Hydrogeological model was constructed based on the geological model using integrated system for geological modelling and GW flow simulation (GEOMASS system; Ohyama and Saegusa, 2008)

- Spatial discretization
  - Whole of the model: 50m×50m×20m
  - Area containing the unit 1-4 buildings(2km×3.5km): 25m×25m×20m
  - Ground surface to EL -30m: 1m thickness to model continuity the aquifers

Hydraulic conductivity (Log[K] (m/s))

Number of grids: 658,092

Hydrogeological model
Hydrogeological modeling  -Hydraulic parameters-

- Hydraulic parameters were assigned as same as Committee model
- K of Tomioka stratum was assigned based on literature information

<table>
<thead>
<tr>
<th>Geological units</th>
<th>Hydraulic conductivity (Log[K] (m/s))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal</td>
</tr>
<tr>
<td>Terrace deposit</td>
<td>-4.52</td>
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<tr>
<td>Alluvium</td>
<td>-5.00</td>
</tr>
<tr>
<td>Medium-grained sandstone stratum</td>
<td>-4.52</td>
</tr>
<tr>
<td>Medium-grained sandstone stratum (south area and upper part)</td>
<td>-6.00</td>
</tr>
<tr>
<td>Mudstone stratum</td>
<td>-7.96</td>
</tr>
<tr>
<td>Medium-grained sandstone stratum (south area and lower part)</td>
<td>-6.00</td>
</tr>
<tr>
<td>Mudstone stratum</td>
<td>-7.96</td>
</tr>
<tr>
<td>Alternative stratum</td>
<td>-5.00</td>
</tr>
<tr>
<td>Mudstone stratum</td>
<td>-7.96</td>
</tr>
<tr>
<td>Fine-grained sandstone stratum</td>
<td>-4.64</td>
</tr>
<tr>
<td>Mudstone stratum</td>
<td>-7.96</td>
</tr>
<tr>
<td>Coarse-grained sandstone stratum</td>
<td>-4.70</td>
</tr>
<tr>
<td>Mudstone stratum</td>
<td>-7.96</td>
</tr>
<tr>
<td>Tomioka stratum (T2)</td>
<td>-6.10</td>
</tr>
</tbody>
</table>

Major Aquifer / Impermeable stratum

Hydraulic parameters were assigned as same as Committee model. K of Tomioka stratum was assigned based on literature information.
Hydrogeological modeling - underground facility -

- UF's, where GW inflow are occurred, were modeled
- UF's were modeled as quadrangular prism with equivalent area with actual area
- Boundary conditions of walls of UF's: seepage condition

※Skin effect factor “α” was applied to be taken into account concrete wall of the UF

\[ K_{wall} = K_{rock} \times \alpha \]
Boundary conditions

- Recharge rate: 55% of annual precipitation (1,545mm/year)

- Top boundary (land area); constant recharge rate (850mm/year)

- Top and side boundaries (sea area); constant head (Head: 0m)

- Bottom boundary; No-flow

- Side boundaries (land area); constant head from result of GW flow analysis on regional area

- Same condition as Committee model

- Different condition from Committee model

Head dist. from GW flow analysis on regional area
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### Procedure for GW flow analysis

**GW flow analysis before implementation of countermeasures**

1. Assignment of hydraulic parameters
2. Adjusting of the skin effect factors
3. Assignment of boundary conditions
4. GW flow analysis

- Comparison between measured and modeled inflow rate into UFs
  - Good
- Comparison between measured and modeled GW level
  - Good

**GW flow analysis after implementation of countermeasures**

1. Re-assignment of hydraulic parameters and boundary conditions taking into account the countermeasures
2. GW flow analysis
3. Calculation of inflow rate into UFs with countermeasures
4. Estimation of effectiveness of the countermeasures

**Image of GW flow analysis**

- GW table
  - Before
  - After
- GW table is to be calculated based on the K field and water balance among recharge, discharge and inflow into UFs

**Items for model comparison**
Comparison items

- GW flow analysis before implementation of countermeasures
  - GW table:
    To validate the hydrogeological model (K field) and boundary conditions

- GW flow analysis after implementation of countermeasures
  - Rate of reduction of inflow rate into UFs:
    To validate result of estimation of effectiveness of the countermeasures
Results of GW flow analysis (before)

Inflow rate into UFs

“Others” contains Heat incinerator and Process building

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Results of GW flow analysis (before)

- JAEA model could simulate GW table distribution before implementation of countermeasures

- Results from Committee and JAEA models are consistent
Results of GW flow analysis (before)

GW flow is affected by detail topographic undulation

GW flow is affected by regional topography (from west to east)
Results of GW flow analysis (before)

- Major GW flowing through around UFs recharges at terrace located west of UFs and discharges at coastal line.

[Diagram showing head distribution, cross sections, and geological strata]
### JAEA model cases

<table>
<thead>
<tr>
<th>Case ID for JAEA model</th>
<th>Land-side frozen soil impermeable walls around buildings (Units #1 to #4)</th>
<th>Sea-side impermeable walls</th>
<th>Pumping up GW from wells near buildings (sub-drain)</th>
<th>Pumping up GW on the mountain side of the buildings (GW bypassing)</th>
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</thead>
<tbody>
<tr>
<td>Case A</td>
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<tr>
<td>Case B-1</td>
<td>○</td>
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<td>Case B-2</td>
<td>○</td>
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<tr>
<td>Countermeasures</td>
<td>Modeling method</td>
<td></td>
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<td>--------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
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<tr>
<td>Land-side frozen soil impermeable walls around buildings</td>
<td>Installing walls from ground-surface to EL.-25m (covering aquifers) log[K(m/s)]=-20 (No-flow)</td>
<td></td>
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<tr>
<td>Sea-side impermeable walls</td>
<td>Installing walls from ground-surface to EL.-25m (covering aquifers) log[K(m/s)]=-7</td>
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<tr>
<td>Pumping up GW from wells near buildings (sub-drain)</td>
<td>Constant head boundary at 51 sub-drains Head = bottom of sub-drain</td>
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</tr>
<tr>
<td>Pumping up GW on the mountain side of the buildings (GW bypassing)</td>
<td>Constant head boundary at 12 wells Head = bottom of wells</td>
<td></td>
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</tr>
</tbody>
</table>
Effectiveness of the countermeasures

Case B-1

- Rate of reduction of inflow rate into UF (%)
- Units #1-#4:
  - Committee model: 91
  - JAEA model: 86
- Others:
  - Committee model: 69
  - JAEA model: 65
- Total:
  - Committee model: 100
  - JAEA model: 98

Increasing inflow into the building outside of land-side impermeable walls

“Others” contains Heat incinerator and Process building

Case B-2

- Rate of reduction of inflow rate into UF (%)
- Units #1-#4:
  - Committee model: 100
  - JAEA model: 98
- Others:
  - Committee model: 16
  - JAEA model: 23
- Total:
  - Committee model: 81
  - JAEA model: 82
Results of GW flow analysis (after)

Case A

Case B-1

- GW flow around buildings is much inhibited by land-side wall
- GW flow direction is changed to upward inside of land-side wall (possibility of contaminated shallow GW flowing downward is not to be considered)

Case B-2

- After installing sea-side wall, GW flowing toward sea is inhibited and GW flows upward around coastal line
Conclusion

• The analytical results from Committee model are consistent with JAEA’s results, although...
  ✓ larger region is considered to implement an alternative boundary conditions and,
  ✓ different numerical modeling and solving method is applied.

• The confidence of Committee’s analytical results can be presented.
JAEA’s additional contribution

- Development of methodology for sequential flow modeling from GW to sea water

GW discharge distribution, which is output from GW flow analysis, is to be input to numerical analysis of sea water flow inside port

Example of GW discharge distribution