[Form 2 (to be reported to Committee on Countermeasures for Contaminated Water Treatment
and to be disclosed to public)

Technology Information	
Area	6 (Select the number from "Areas of Technologies Requested")
Title	**ENHANCED DATA-MODEL INTEGRATION FOR DEDICATED MONITORING AND ADAPTIVE CONTROL OF GROUNDWATER FLOW AROUND FUKUSHIMA DAIICHI NUCLEAR POWER PLANT**
Submitted by	Deltares (the Netherlands)

1. Overview of Technologies (features, specification, functions, owners, etc.)

TECHNOLOGIES FOR ENHANCED DATA-MODEL INTEGRATION

The advantages of enhanced data-model integration are that the effort in continued data-collection can be limited with regards to frequency and spatial resolution, focusing on instances and locations where environmental risks and/or model uncertainty are highest. Where possible remotely controlled data-collection/logging is applied. Conversely, all data collected are used to their highest value, as they are fed back into the model, to optimize and refine the model based understanding of groundwater flow and fate and transport of the radioactive contamination. Furthermore, enhanced data-model integration enables *a priori* assessment of the effectiveness of intervention measures and operational forecasting for adaptive management.

Deltares can provide the following specific technologies/products and related expertise to facilitate:

- a better understanding of groundwater flow and of the spread of radioactive contamination in both groundwater and coastal marine area
- optimal design of dedicated monitoring strategies,
- prediction and evaluation of the effect of intervention measures and scenarios,
- the tailored design of hydrological intervention measures (see Appendix 1 for example).

Groundwater:

a. Regional geological and geohydrological schematization

This schematization will be a 3-D digital model representation of the subsurface, showing the geologic architecture and related hydraulic properties. It will be built using iMOD (Figure 1, see also under b), based on existing information (Digital Elevation Model, geological maps and profiles, borehole information, etc.) that should be made available for free by the Japanese parties responsible. The 3-D schematization will cover a wider region than just the Fukushima Daiichi Nuclear plant location and tank storage area, to provide the necessary geohydrological context and boundary conditions for the modeling workflow under b. The schematization will be set up by Deltares, in cooperation with relevant Japanese parties, for example AIST, as the main responsible for geological information.

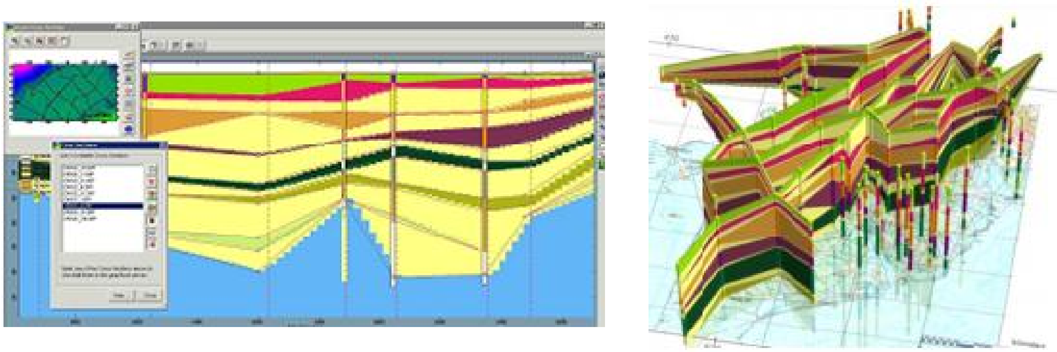

Figure 1: Examples of the 3D solid tool in iMOD

b. iMOD based groundwater-flow-and-transport modeling work flow

Interactive MODeling (iMOD) will provide an easy-to-use, transparent and flexible modeling environment for active groundwater management at the location of the Fukushima Daiichi Nuclear Power Plants and surroundings. The most relevant iMOD features are its easy to use graphical interface, capabilities for interactive geologic schematization (see under a), flexibility to updating when new data become available, great visualization options in support of communicative processes (see Figure 2), possibilities to zoom in or out to focus on local or regional aspects, and specifically the ease to create and quickly run scenarios (in the order of just a few minutes computation time for 10^9 model nodes). Through running scenarios, the effectiveness of planned measures can be probed in advance, and various alternatives tested. iMOD thereby avoids endless copying and modification of model input. Instead, its Scenario Tool offers a way to define areal polygons for which parameters should be perturbed, without copying and/or adjusting the original model input files. iMOD has been developed by Deltares, and will be Open Access as of January 2014. It is MODFLOW based and incorporates MT3D/RT3D functionality for reactive transport, as well as SEAWAT that takes variable-density groundwater flow and coupled salt transport into account. MODFLOW has been chosen because it is used throughout the world and accessible by the wider hydrologic modeling community. Deltares will set up the basic model environment in cooperation with relevant Japanese parties, and provide training and advice on its subsequent use during the project and in preparation of the handing over process.

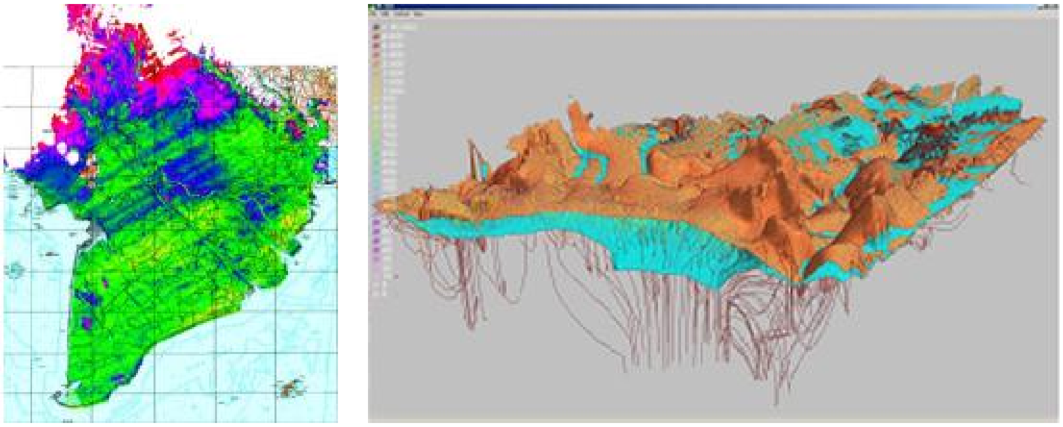

Figure 2: Visualization of simulated phreatic heads (left) and surface elevation, hydraulic head and flow lines (right)

c. Smart monitoring network design

A basic requirement for smart monitoring at Fukushima Daiichi is that the time spent in the field for sampling and monitoring is kept to a minimum. This can be achieved by focusing the monitoring effort on locations and instances where environmental risks and/or model uncertainty are highest. The design procedure will be based on the outcomes of the groundwater model as described under b. A Monte Carlo approach is used to assess model uncertainty. Depending on the model complexity and subsequent computing requirements, this will be fully performed within iMOD, or the iMOD functionalities for particle tracking and visualization of flow lines -in profiles that also show the subsurface characteristics- will be used to feed a stream-tube based reactive transport model. Calculations will take into account -amongst others- sorption-desorption, density driven flow caused by variation in salinity, and preferential flow through high permeability layers/subsurface features. In the Monte Carlo approach, a large number of scenarios are calculated in which the values of uncertain or sensitive model parameters are varied based on their probability distribution. Model outcomes, in terms of radioactivity levels and fluxes, are also returned in terms of probability distributions. Monitoring can then be steered towards collecting those data that will lower the model uncertainty and thereby, in combination with the model results, provide insight into the contaminant spread and contaminant levels at the required level of certainty. The stream-tube and risk/uncertainty based model approach have been developed by Deltares.

d. Remote geophysical data collection

The above approach is expected to be largely implemented based on already existing information. Where additional information on the structure of the subsurface and/or groundwater flow is required, a number of geophysically based techniques that only require limited human involvement are under development at Deltares:

- ***autonomous geophysical mapping robot***

  This robotical system consists of an unmanned, remotely controlled vehicle that can be equipped with various geophysical instruments (geo-electrical, electromagnetic, seismic, georadar, …) that vary in vertical reach. They can provide information on the depth of the groundwater table, presence of a salt-fresh water interface, detailed layering down to 10 m below surface, or the deeper geologic structure.

- ***remote in-well measurement of flow velocity***

  In combination with the modeling outcomes under b, a recently developed technique by Deltares for high resolution temperature measurements in boreholes can provide in situ measurement of vertical and temporal variation in groundwater flow velocity. This can be further developed towards in-well measurement of groundwater flow directions.

Additionally/alternatively, Deltares has access to and expertise in airborne geophysical methods for which short-duration helicopter flights could be used (in cooperation with other partners).

Coastal marine environment:

e. Tracking contaminated water flows in the coastal zone

The spread of radioactive contamination in the coastal zone can be tracked using Deltares' state-of-the-art, widely used open-source modelling suite Delft3d (www.delft3d.nl). The FLOW module of Delft3D simulates the local flow patterns, under the influence of the local coastline and bathymetry, tidal currents, wind driven currents and other relevant oceanographic phenomena. The WAQ module of Delft3D simulates the resulting radioactive contamination patterns, optionally taking into account the interaction of radioactive substances with sediment movement in the coastal zone. The modelling will focus on the area of primary interest, presumably the direct vicinity of the installation. It is common that such detail models derive their open sea boundary conditions from larger scale regional models, set up on the basis of public domain oceanographic databases. Model results will be presented in the form of animations, contour maps and time series plots, optionally projected on Google Earth images (Figure 3).

The contamination tracks will be variable, due to variable inputs from the ground water, due to variable meteorological and oceanographic conditions and maybe due to variable biochemical processes. Analogous to the case of the groundwater, we propose to take this into account by performing probabilistic modelling using a Monte-Carlo approach (repeated simulations with variable inputs). The results will be post-processed to obtain concentration probability maps, so that best possible insight in the magnitude of the risk and the geographic variability thereof can be obtained. Should alternative management decisions need to be evaluated, we can further enhance the usability of the modelling results by developing a rapid assessment decision support tool that allows direct insight in the consequences of specific decisions for the coastal ecosystem and ecosystem services.

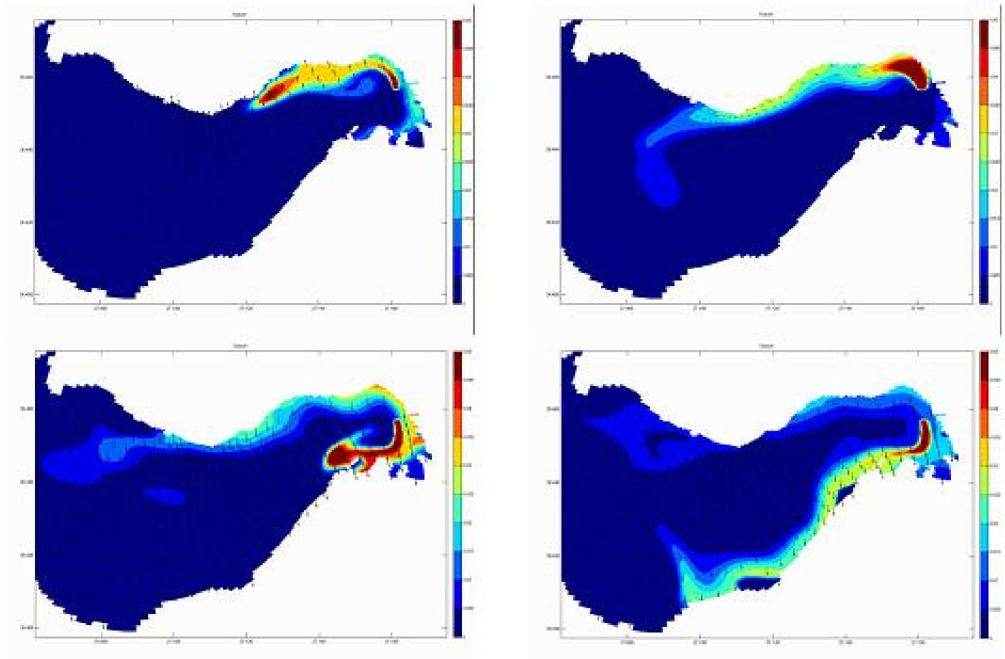

Figure 3. Snap shots of contaminant concentrations as a result of a continuous discharge, obtained from Delft3D FLOW and WAQ simulations. The arrows represent the wind direction, which is in this example the predominant driving force for contaminant transport.

2. Notes (Please provide following information if possible.)
- Technology readiness level (including cases of application, not limited to nuclear industry, time line for application)

The proposed integration of modeling and monitoring is already well developed within Deltares, and has been used in support of controlling groundwater flow and groundwater pollution in coastal aquifers, groundwater and soil remediation technologies, uncertainty and risk analysis, artificial infiltration, freshwater/salt water interfaces in aquifers, monitoring and real time control of well fields - extraction wells and infiltration wells. Analysis of the local and regional groundwater situation and formulation of remediation strategies is our key expertise. Modeling and advising on groundwater flows to prevent or reduce seepage or to prevent dispersion of plumes of polluted groundwater is our daily work.

Deltares has been active in this field of work in Europe, Canada and the United States. Deltares for example analysed the groundwater protection risks under a nuclear power plant in the Netherlands, designed and is still supervising a Geohydrological Containment System (GCS) for a large industrial pollution site in the Netherlands, developed a Mega-Site Approach for groundwater pollution for the Port of Rotterdam, worked on regional groundwater modelling in Alberta (Canada) and leads a large European research project on brownfield regeneration (www.zerobrownfields.eu). More information on these examples is provided in the Annexes to this Form 2.

Our integrative approach not only addresses the combination of modelling and monitoring, but also water quantity with water quality, terrestrial with marine environment, and specifically also the integration of human measures with the natural system. This integrative thinking has been at the base of the establishment of our institute by the Netherlands government in 2008, as an independent, institute for applied delta-technology research (water, subsurface and infrastructure with a main focus on deltas, coastal regions and river basins). Our main role in the Netherlands is as specialist adviser for our national, regional and local authorities, working closely together with businesses, other research institutes and universities. Deltares is experienced in multi-stakeholder projects and facilitating in- and external communication. Yet, we also have management procedures in place that can guarantee confidentiality of data storage and information when required (see Appendix 1-B for example of project).

Depending on the basic data/information being easily available, and depending on the intensity of the modeling effort, development of a fully functional iMOD based model (a+b) will take in the order of a few months. The design of smart monitoring guidelines (c) would require one or more additional months. A similar (parallel) timeframe is foreseen for the coastal zone model.
Regarding the autonomous geophysical mapping robot (d), all the constituent parts are proven technology, with wide experience especially in bathymetry. A prototype of the unmanned vehicle for use on land has already been successfully applied in the detection of unexploded ordnance (UXO) in the US. To have a robust and tailored fitted robot ready for use at Fukushima Daiichi, a development period of 6 months to about a year is envisaged.
For the in-well measurement of flow velocity, it is expected that the necessary tests for calibration and proper linking with the iMOD model could be completed within 6 months.

- Challenges

The main challenges for the model-based parts lies in the ready availability of existing geohydrological and hydrological data. Cooperation with TEPCO and other Japanese parties like

METI and AIST is essential. Sufficient attention should also be given to bridge any language barrier. Of course the limited access to the site will need to be taken into account in the work process. For the remote data collection, aspects of robustness and low-and-easy maintenance will need to be specifically addressed.

- Others (referential information on patent if any)

Annexes to Form 2:

Annex 1. iMOD – interactive modeling

Annex2. Groundwater modeling for the Mekong Delta using iMOD

Annex 3. Utilization of Interactive MODeling (iMOD) to Facilitate Stakeholder Engagement in Model Development Using a Sustainable Approach with Fast, Flexible and Consistent Sub-Domain Modeling Techniques

Annex 4. Fresh-saline groundwater in deltaic and coastal areas

Annex 5. Megasite approach of the Rotterdam Harbour area

Annex 6. Reference project: Design of a complex Geohydrological Containment System (GCS) at an industrial site in the Netherlands

Annex 7. Research and advice for water quality management and policy

Annex 8. Water Quality Modelling Seas and Bays

【Areas of Technologies Requested】

a. Accumulation of contaminated water (Storage Tanks, etc.)
b. Treatment of contaminated water (Tritium, etc.)
c. Removal of radioactive materials from the seawater in the harbor
d. Management of contaminated water inside the buildings
e. Management measures to block groundwater from flowing into the site
f. Understanding the groundwater flow