Water Resource Cycle Simulation System

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OVERVIEW: Hitachi is collaborating with Geosphere Environmental Technology Corporation in the construction of a water resource cycle simulation system that can contribute to both water resource management as well as water disaster countermeasures. This simulation system makes it possible to analyze both surface water and groundwater in a unified manner, and includes visualization functions that enable the rapid and easy-to-understand display of a wide range of representations. These functions provide an accurate picture of the current conditions as well as future predictions of water resources and water disasters. Hitachi plans to use this simulation system to contribute to finding solutions to issues affecting the entire planet, including the securement of water resources and the resolution of various problems stemming from water disasters.

INTRODUCTION

THE world has been faced with a large number of increasingly serious problems in recent years due to issues such as global warming, rapid population growth, and societal developments, including a lack of industrial and drinking water, the growth of drought regions and corresponding crop failures, and flooding or inundation caused by torrential rain. A diverse range of complicated measures will be required in order to resolve these problems.

Japan faces threats such as a disorganized supply of water resources and frequent sudden torrential rains, all of which require solutions in the areas of water resource usage and water disaster countermeasures. In order to solve these problems, the “Emergency Measure Bill Regarding Regulating the Use of Groundwater” was submitted to the National Diet of Japan in January 2012 as lawmaker-initiated legislation intended to protect water resources. In addition, implementation of water measures is gaining momentum, including the installation of X-band multi-parameter radars that can observe regional rainfall amounts almost in realtime.

It is against this background that a need has arisen for functions that can correctly predict changes in water resource distribution both inside and outside the country, as well as the occurrence of water disasters, while supporting rapid and smooth decision-making regarding policies. To this end, Hitachi is collaborating with Geosphere Environmental Technology Corporation in order to help popularize the use of a water resource cycle simulation system.

This article discusses a water resource cycle simulation system that can contribute to water resource management and water disaster countermeasures, as well as the specific technologies that comprise this system.

NEEDS AND TECHNOLOGICAL ISSUES

Needs

Functions that support the decision-making that goes into solving various problems related to water resources and water disasters must meet the following two needs:

(1) Accurate understanding of the current conditions and future predictions

The ability to grasp the current amount and quality of groundwater resources that cannot actually be seen, and the ability to make predictions about the future based on the changing climate and human activities, are extremely important elements involved in the formulation of water resource plans. Accurate predictions about the future are also important when it comes to developing countermeasures for water disasters. Simulation technology must meet these needs.

(2) Ability to attach meaning to huge amounts of data and visualization functions

It is important that functions exist with the ability to systematically organize and easily attach meaning to the relationships between data and events based on huge amounts of data, including observational data and simulation results. In other words, a drawing function that utilizes the geospatial information system (GIS) is a key part of helping water policy decision-makers and local residents easily understand the data.

Technological Issues

Simulation issues

(1) Modeling interactions between surface water and groundwater

In the past, simulations of the water cycle were limited to specific areas based on objective, such as groundwater or flow analysis. For this reason, interactions between surface water and groundwater (river influent seepage, springs, and so on) were often not considered, making highly accurate analysis difficult.

(2) Analysis including material transfer

In order to enable quick and safe decision-making during the determination of a water policy or disaster response, it is necessary to analyze the transfer processes of materials such as nutrient salts and radioactive nuclides.

(3) High-speed calculation

Huge amounts of calculations must be performed in order to implement the consideration of surface water and groundwater and the analysis of the material transfer process as described in (1) and (2). Algorithms that can quickly execute these huge amounts of calculations are necessary to contribute to rapid decision-making.

Water resource cycle visualization issues

(1) Groundwater flow time series display

Easy-to-understand representations of water resource cycle simulation results that deal with surface water, groundwater, and how this water changes over time must display the conditions of surface and underground water flows in a time series format. In the past, GIS often lacked the ability to display underground conditions or time series data.

(2) Statistical processing of information distributed in three-dimensional space

Information distributed in three-dimensional space must be statistically processed so that the simulation results can be understood by the decision-makers.

(3) High-speed responsiveness

Information processing technology that can support rapid decision-making is necessary, including the ability to process and draw large amounts of data at high speed.

SIMULATION AND VISUALIZATION TECHNOLOGIES

Simulation Technology from a New Perspective

Calculations of water flow are generally executed by defining models of flow channels, such as river channels, drainage paths, pipeline networks, and others. The general purpose terrestrial fluid-flow simulator[1] (GETFLOWS*) system developed by Graduate School of Engineering, The University of Tokyo's Professor Hiroyuki Tosaka (Chairman of Geosphere Environmental Technology Corporation), on the other hand, can take terrain, the shape of strata, hydrological properties, precipitation conditions, and other information to automatically create models of natural river networks, lakes, and groundwater flow systems[2].

(1) Unified analysis of surface water and groundwater

By comprehensively analyzing the equations of motion that are derived from rivers, lakes, and other surface water, groundwater in the ground, and compressible fluids such as air, water cycle analysis can be used to unify surface water and groundwater in a manner that was not possible with previous simulations. This makes it possible to consider interactions between surface water and groundwater.

Fig. 1 shows an example of groundwater flow analysis. By analyzing surface water and groundwater in a unified manner, it is possible to derive the routes taken by rainwater that has seeped into mountainous terrain as it discharges in rivers or the ocean. This sample analysis shows how the system can contribute to decision-making with regards to water policies, such as excessive groundwater intake requires countermeasures to deal with ground subsidence, or the securement and regulation of water resources for use as agro-industrial water.

* GETFLOWS is a trademark of Geosphere Environmental Technology Corporation.

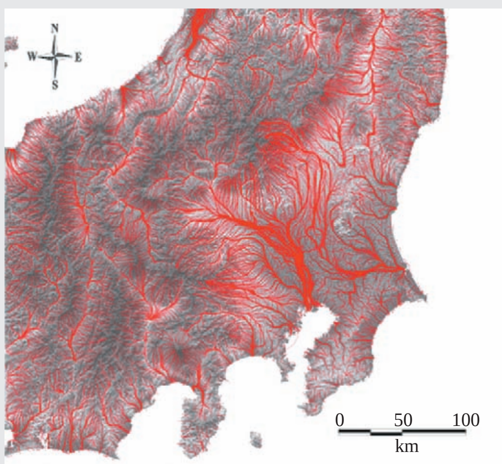

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Fig. 1—Groundwater Flow Analysis.
Groundwater flow analysis can be used to track the routes taken by rainwater that has seeped into a mountain as it discharges in a river or ocean.

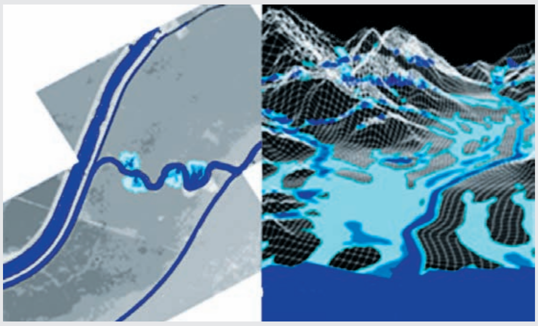

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Fig. 2—Flood Prediction.
Inundation calculations can give consideration given to the levee break point (left) and the moistness of the soil (right).

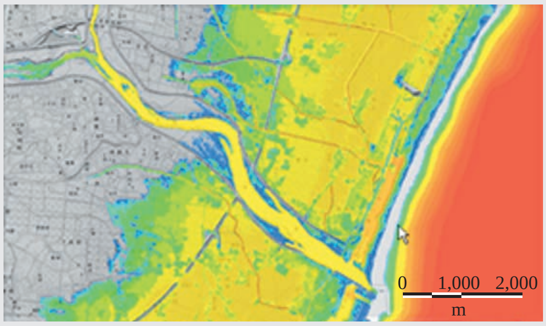

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Fig. 3—Simulation of Tsunami Flooding.
This figure shows the distribution of water depth three hours after a tsunami occurs.

A sample flood prediction analysis is shown in Fig. 2. The left side of this figure shows the flooding calculation with consideration given to the levee break point, and the right side shows an example of a flooding calculation that gives consideration to the moistness of the soil. This unified analysis of surface water and groundwater makes it possible to represent the rapid increase in the groundwater level during torrential rains together with inundation inside a levee, in order to predict the location where flooding will start, the flooded region, and the amount of flooding at a high level of accuracy.

(2) Analysis of material transfer processes

The system also offers the ability to consider kinetic changes in material that are caused by degradation and chemical reactions. The incorporation of material transfer processes such as river transportation, leakage of substances into the ground, sorption/desorption, and advection-dispersion make it possible, for instance, to analyze the behavior of radioactive nuclides.

Fig. 3 shows an example of a flooding simulation for three hours after a tsunami occurs. By inputting the tsunami waveform as it varies over time, it is possible to analyze the tsunami's dynamic behavior in coastal regions, including intrusion into rivers and inundation flows. The analysis can also simulate how salinity decreases due to factors such as rainfall in regions flooded by a tsunami, based on the soil characteristics of each land-use classification. This capability can be utilized during the consideration of a wide range of environment restoration effects, including salt removal planning during reconstruction projects.

Fig. 4 shows a simulation of nitrogen contamination in surface water and groundwater due to economic activities. The left side of the figure shows the results of an analysis of the total nitrogen concentration in surface water, and the right side shows the same for groundwater[3]. By analyzing the transportation and distribution of materials in this way, it is possible to follow the details of the material movement processes while tracing contaminant materials as they spread through surface water and groundwater, so that decontamination policies can be considered in case the contaminant material flows.

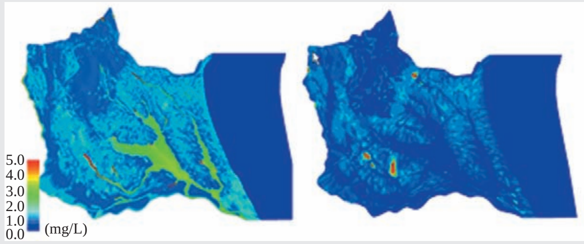

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Fig. 4—Simulation of Nitrogen Contamination of Surface Water and Groundwater Due to Economic Activities.
The left side of this figure shows the total nitrogen concentration in surface water, and the right side shows the same in groundwater.

(3) High-speed calculation using clusters of personal computers

Although the amount of data in high-speed calculation simulation results created using a cluster of personal computers (PCs) will depend on the size of the model, the results of simulating a grid of approximately 20 million points will require an output of around 1 Tbyte. For this reason, parallel calculation with a PC cluster is used to achieve high-capacity and high-speed computation in order to support rapid decision-making.

Characteristics of Visualization Technology

Hitachi is working to develop visualization technology that uses GIS as a means of visualizing groundwater, which usually cannot be seen directly. This technology offers the following three characteristics:

(1) Highly accurate display of surface, underground, and time series data

A map of the entire world is managed in a uniform manner using a geographical coordinate system, and a global model has been adopted that enables three-dimensional display so that both surface and underground can be included in a highly accurate, textured display. Furthermore, functions have been added to show underground structures that are ordinarily not visible. Also, by adding a time axis to the three-dimensional geospatial information, it is possible to display simulation results that vary over time, such as the conditions of a disaster.

Fig. 5 shows analysis results including the cross-section view of an underground grid covering areas including the watershed of the Sagami River in Kanagawa Prefecture, as well as a translucent satellite image[4]. The cross-section view of the underground grid makes it possible to represent both surface and underground. By overlaying the simulation results on the translucent satellite image, it is possible to intuitively understand the flow of surface water and groundwater.

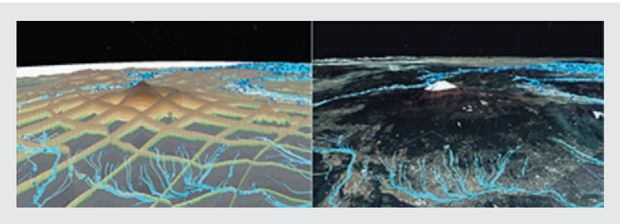

Fig. 5—Cross-section of Underground Grid and Translucent Satellite Image.
A cross-section of the underground grid is displayed over the flow of groundwater in a translucent satellite image to create an easy-to-understand representation.

Fig. 6 shows an example of animation. The flow routes of surface water and groundwater can be represented through animation, and by displaying this on top of three-dimensional geospatial information, it is possible to visualize dynamic changes in behavior over both space and time.

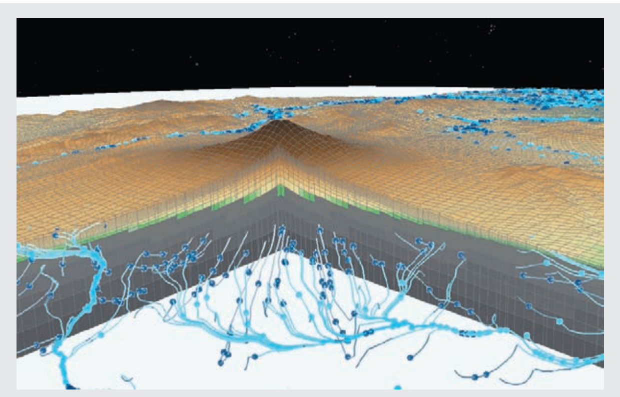

Fig. 6—Animation.
The flows of surface water and groundwater are animated for easy visualization.

(2) Spatial analysis functions

Spatial analysis functions make it possible to spatially summarize the results of governmental or watershed boundary simulations, in order to represent simulation results such as the amount of available groundwater resources in an easy-to-understand manner.

Fig. 7 shows a color-coded display of a summary of the distribution of water resources available underground based on spatial analysis[5]. The ability to understand the distribution of usable groundwater resources can contribute to the formulation of water resource usage plans.

(3) High-speed responsiveness

Although previous GIS systems would experience delays during rendering processes such as zooming in, this system improves rendering speed through means such as data culling based on scale reduction.

EXPECTATIONS FOR THE WATER RESOURCE CYCLE SIMULATION SYSTEM

Hitachi and Geosphere Environmental Technology Corporation are working to develop this water resource cycle simulation system as a product that combines data organization, simulation, spatial analysis,

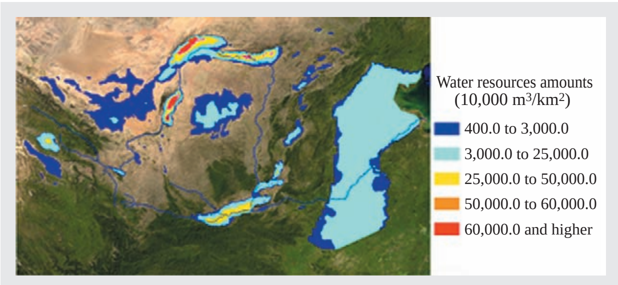

Fig. 7—Color-coded Distribution of Amount of Available Groundwater Resources Based on Spatial Analysis.
Amount of available groundwater resources are summarized and displayed with color codes corresponding to amounts.

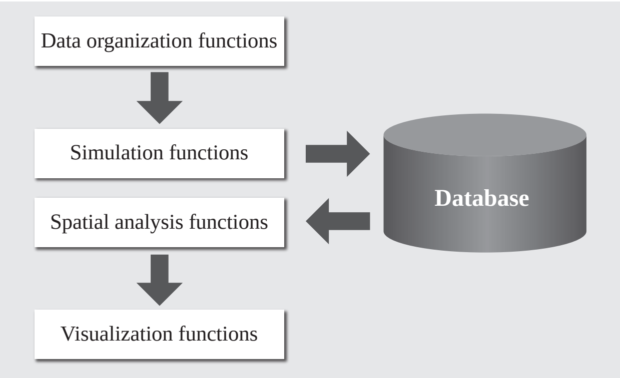

Fig. 8—System Functions and Flow.
This figure shows each function and a system flow chart. The data organization and simulation functions make use of water resource cycle simulation technologies, and the spatial analysis and visualization functions make use of visualization technologies based on the geospatial information system (GIS).

and visualization functions in a cloud service that can be used by a wide range of users (see Fig. 8). Further improvements in simulation accuracy and the provision of even faster and easier-to-understand visualized information to decision-makers will enable this system to support the correct management and prediction of water (the “oil of the 21st century”) while contributing to the achievement of a sustainable public infrastructure and a society that is safe and secure.

CONCLUSIONS

This article mainly focused on a water resource cycle simulation system that can contribute to water resource management and water disaster countermeasures, as well as the specific technologies that comprise this system. In summary, the water resource cycle simulation is a fusion of water resource cycle simulation technologies that unifies analyses of surface water and groundwater with visualization technology based on GIS. It is a tool that can rapidly provide easy-to-understand representations of the current conditions and future predictions of surface water and groundwater.

In a world faced by water resource shortages and water disasters, this water resource cycle simulation system is an exceedingly important tool. Hitachi will continue contributing to solutions to the various global problems related to water resources and water disasters.

REFERENCES

(1) H. Tosaka et al., “Fully Coupled Formulation of Surface Flow with 2-Phase Subsurface Flow for Hydrological Simulation,” Hydrological Processes **14**, pp. 449–464 (2000).
(2) Characteristics (Geosphere Environmental Technology Corporation), http://www.getc.co.jp/english/e-products/aboutgetf/feature/
(3) K. Mori et al., “A High Performance Full-3D Nutrient Transport Modeling based on the Surface Water and Groundwater Coupling Technique for the Water Quality Assessment: An Application to the Lake Kasumigaura, Japan,” International Symposium on Hydro Change 2008 in Kyoto.
(4) Y. Tawara et al., “Consideration of Restoration Possibilities for the Natural Water Cycle Behavior of the Kanagawa Expanded Basin Zone,” Japanese Association of Groundwater Hydrology (Nov. 2008) in Japanese.
(5) Project for Sustainable Coexistence of Human, Nature, and the Earth, “Development of a Model to Predict Changes in Water Resources due to Artificial and Natural Changes in the Asian Monsoon Region,” 2005 Research Results, RR2002 in Japanese.

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