# An Integrated Surface Runoff-Groundwater Model to Predict the Impact of Global Climate Change on Water Resources

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## 1. Introduction

The objective of this research by water research group of ICCAP is to assess the future possible changes in water resources due to global climate change. As an important tool for the assessment, a surface runoff model will be integrated with a groundwater flow model and applied to supposed field.

In this paper, basic concepts of a deterministic mathematical model named HYDROBEAM for simulating rainfall-runoff will be introduced first with an example applied to Yasu-river basin. Then two kinds of groundwater flow models will be introduced. Examples simulated by a quasi-three dimensional groundwater flow model for Shinano river basin and by a density flow model to deal with the problem of the impact of sea level rise caused by global climate change on salt water intrusion into coastal aquifers will be presented。

## 2. Hydrologic Cycle and a Rainfall-Runoff Model (HB)

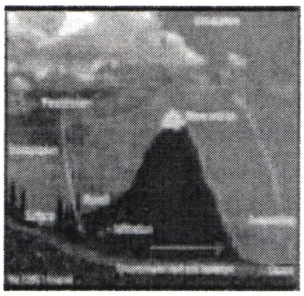

**Fig.1 Schematic diagram of hydrologic cycle**

Fig.1 presents a schematic diagram of hydrologic cycle. It will be possible to predict the amount of river runoff and overland flow by using the following rainfall-runoff model, which is described by the explicit finite difference method and is named HYDROBEAM.

$$q \approx \frac{\sqrt{\sin(\,)}}{n} w^{-2/3} A^{5/3}$$

$$\frac{{}_{(i,j)} - A_{(i,j-1)}}{\Delta t} + \alpha m \left[ \frac{A_{(i,j-1)} + A_{(i+1,j-1)}}{2} \right]^{(m-1)} \left[ \frac{A_{(i,j-1)} - A_{(i+1,j-1)}}{\Delta x} \right] = \bar{q} = \frac{q_{(i,j)} + q_{(i,j-1)}}{2}$$

$$\frac{{}_{(i,j)} - A_{(i,j-1)}}{\Delta t} + \alpha m \left[ \frac{A_{(i,j-1)} + A_{(i+1,j-1)}}{2} \right] \left[ \frac{A_{(i,j-1)} - A_{(i+1,j-1)}}{\Delta x} \right] = \bar{q} = \frac{q_{(i,j)} + q_{(i,j-1)}}{2}$$

R : hydraulic radius
P : wetted perimeter
$R = A/P \quad P = W + 2h$
$A = Wh$
$W \gg h$、$R \sim h$

## 3. Data Requirement for HYDROBEAM

The following are the list of data required for HYDROBEAM

**Weather :**

Precipitation :

*Locations of weather stations, Rainfall rate (hr/day/month/yr)*

Atmosphere:

*Temperature, Humidity, Pressure, Wind speed and direction, Evapo-transpiration*

**Land:**

<u>Land use:</u>

*Distribution and Activities of Agriculture, Forestry, etc.*

<u>Soil:</u>

*Distribution and characteristics*

<u>Surface conditions:</u>

*Roughness and Infiltration coefficients, Elevation with digital data for GIS*

**Rivers:**

<u>Observation stations:</u>

*Location, Dimensions (width, cross sections, slice gates and their specification), Rating curves, Water withdrawal with its locations*

<u>Hydro power stations:</u>

*Location, Capacity*

<u>Control sections, Reservoir, and Dams:</u>

*Release, Storage and Inflow(hr), Operation scenarios*

Given that the above data are provided, infiltration into subsurface can be calculated for groundwater flow models.

## 4. <u>An example obtained by using HYDROBEAM</u>

HYDROBEAM was applied to Yasu river basin shown in Fig.2 and the calculated river ronoff was compared with the obserbed in Fig.3.

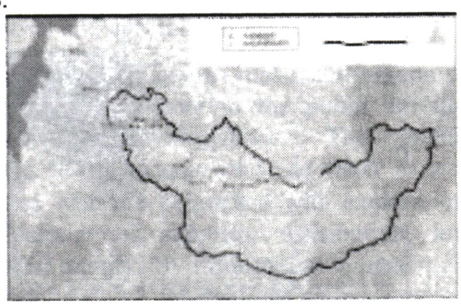

Fig2. Geographic map of Yasu river basin

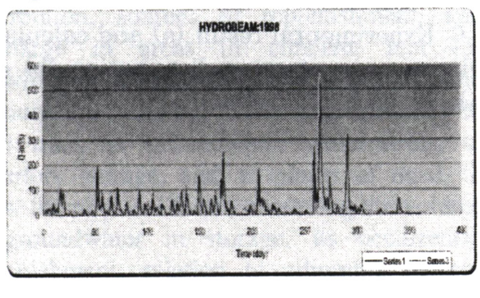

Fig.3 Observed and calculated runoff

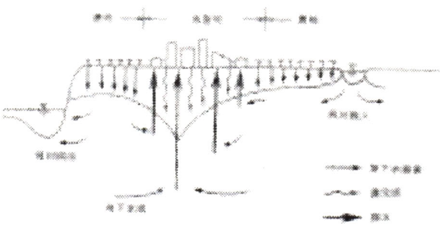

Fig.4 Schematic diagram of groundwater cycle

## 5. A Quasi-Three Dimensional Groundwater Flow Model and an example applied to Nagaoka Groundwater Basin

Fig.4 illustrates interaction between surface water and groundwater. By assuming that groundwater flows horizontally in relatively large groundwater basins, the governing equation for a quasi-three dimensional groundwater flow can be written as follows,

$$\frac{\partial}{\partial x}\{T(h)\}\frac{\partial h}{\partial x}+\frac{\partial}{\partial y}\{T(h)\}\frac{\partial h}{\partial y}+R-Q=n_e\frac{\partial h}{\partial t}$$

where $T$ is transmissivity expressed as a function of total head $h$ , and $R,Q,n_e$ are recharge, withdrawal, and effective porosity, respectively.

Fig.5 shows a finite element discretization together with porosity and hydraulic conductivity distribution for Nagaoka groundwater basin.

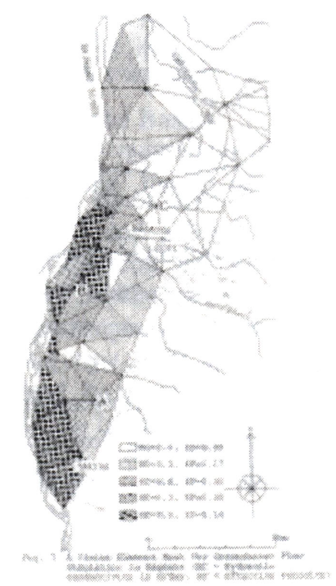

Fig.5 Finite element mesh and distribution of effective porosity and hydraulic conductivity for Nagaoka groundwater basin

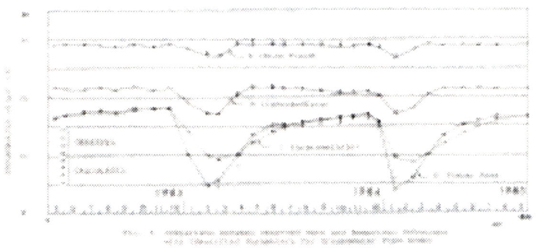

Fig.6 comparison between observed and calculated groundwater level.

Fig.6 shows the comparison between observed and calculated groundwater level.

## 6. A mathematical model for saltwater intrusion into coastal aquifers

Within a non-deformable porous media, the governing equation for flow of non-compressive fluids with variable density is given by

$$\nabla \cdot \rho K_f \left( \nabla h_f + \frac{\rho}{\rho_f} \nabla z \right) = \frac{\partial \rho}{\partial t}$$

where $\rho, \rho_f$ are the density of fluid and fresh water, $K_f, h_f$ are the hydraulic conductivity and the pressure head in terms of fresh water, and $z$ is the upward vertical coordinate.

The governing equation for transport of conservative mass is given by

$$\nabla \cdot D \nabla C - \mathbf{v} \cdot \nabla C = \frac{\partial C}{\partial t}$$

where $D$ is the dispersion coefficient, $C$ is the concentration of salt, and $\mathbf{v}$ is the fluid velocity vector

The above mentioned variable density flow model which couples a fluid flow equation with a mass transport equation was applied to numerically solve the saltwater intrusion problem. A finite element method was used to solve the fluid flow equation and a characteristic finite element method to mass transport. Fig.6 shows the Experimental and numerical results。

## 7. Data Requirement for groundwater models

The following are the list of data required for the above mentioned groundwater models.

**Groundwater flow:**

Geology: *Geological formation maps (Vertical, horizontal), stratigraphy, thickness of aquifers*

Geography: *Topological maps, surface water bodies*

Hydrogeology: *Hydraulic conductivity, effective porosity and specific storage, Pumping test results*

**Saltwater intrusion:**

Groundwater quality: *Distribution of salt concentration, Hydrodynamic dispersivity*

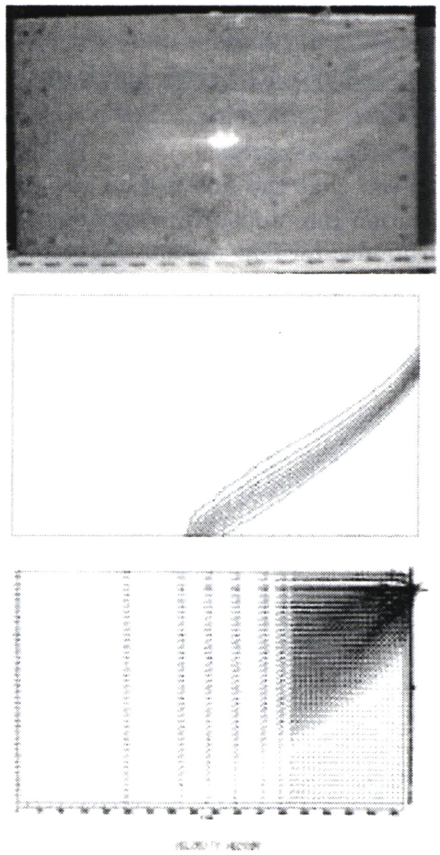

Fig. 6: Experimental result (a) and calculated relative concentration distribution (b) and velocity vector distribution (c).