Integrated Water Resources Modeling for River Basin: the Case of the Yasu River

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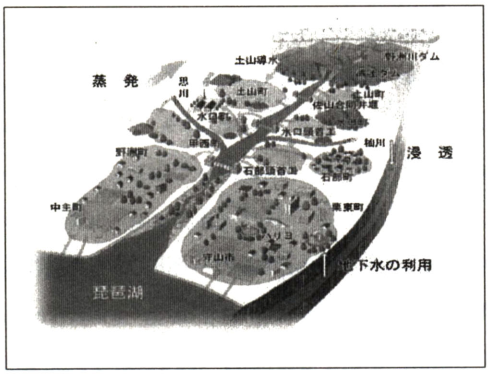
Abstract

A method for applying the multi-layer mesh typed runoff model approach using Hydro-BEAM (Hydrological Basin Environmental Assessment Model) to river basins is presented. The Yasu River basin in Japan is investigated as a case study illustrating the method, and Hydro-BEAM is updated for application to the Seyhan River Basin in Turkey. The spatial and temporal characteristics for both water quantity and quality are calculated using the kinematic wave model, and a multi-media model, which includes transformation of parent products of a pollutant. The formulation of the reservoir is evaluated using the basin divide approach (upstream and downstream of the reservoir). Human utilization of land is also evaluated using the dynamics of land use approach. Ten years of hydrological data and average pollutant release data are provided. A preliminary combination of these approaches gives promising simulation results for this ongoing project.

Introduction

The Yasu River is located in Shiga prefecture, Japan, and is one of the main sources of water for Lake Biwa, which supplies more than 14 million people in Kyoto, Kobe, and Osaka regions. Averaged annual precipitation for the regions ranges from 1550 - 2050 mm for the lower and upper catchments, respectively. There are four distinct seasons. The area of the basin is 445 km^2 (see Fig. 1) and the length of the river channel is 95 km. The total population is approximately 220,000. Small river flows and draw-down of the groundwater table in the lower catchment and conservation of the water quality are the main concerns in the Yasu River Basin.



Integrated hydrological modeling of various basin scenarios using Hydro-BEAM allows for objective-orientated decision making to achieve efficient basin management. The impact of each decision can therefore be formulated mathematically as an objective function (Bear,*et..al,*1987).

Methodologies

The hydrological cycle involves complicated interactions between the atmosphere, surface water, and groundwater. A large-scale model was developed by Jennifer (2001) for areas with a shallow groundwater table, and it was found that 5-20% of the groundwater is evaporated from the basin each year. The three-layer model has mathematical and physical constraints due to different residence times of water within each layer.

One approach is to include the interactions between each model using a statically-linked coding of input data with Hydro-BEAM, by using averages of the output of the other models (Kojiri,*et..al*,2000). Another approach is to use a dynamically-linked coding with Hydro-BEAM. For the case study of the Yasu River Basin, the first approach is used. Each mesh is modeled using n layers, with the surface layer (see Fig.2) using the kinematic wave model for unsteady one-dimensional flow, as illustrated by the following equations:

$$\frac{\partial A}{\partial t}+\frac{\partial q}{\partial x}=r(t,x) \qquad (1)$$

$$q=f(x,A)=\alpha A^{m} \qquad (2)$$

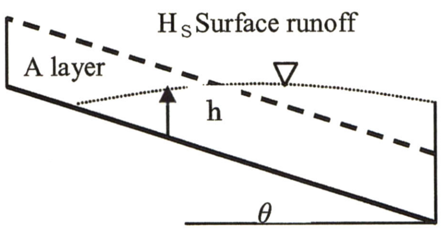
A: cross-sectional area (m^2), q: discharge (m^3/sec)

r: lateral flow (m^3/m.sec)

$$\text{Manning flow: } q=\frac{\sqrt{\sin(\theta)}}{n}AR^{2/3} \qquad (3)$$

θ : average slope (rad), n : roughness coefficient, R : hydraulic radius (m).

α and m in equation (2) are computed according to the cross section of the flow and parameters of land use of each mesh. The linear storage model is used for the 2nd – n^{th} layer to calculate the flow for each layer.



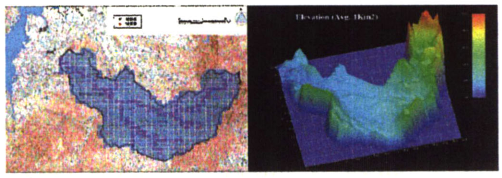
$h=\gamma \cdot H_A+H_S, A=w \cdot h$

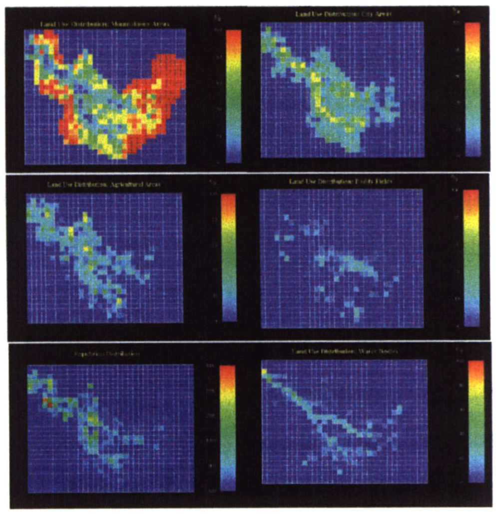
w : width (m), k: permeability (m/sec)、

γ : effective thickness of layer A

Fig. 2: Water profile for the surface layer

Case Study: Yasu River Basin. In order to calculate the spatial and temporal distributions of the simulation results, the basin is divided into one kilometer by one kilometer square meshes (see Fig.3). A digital elevation map is shown in Fig. 4. Land uses are classified into five types as follows: 1) mountains, forests; 2) paddy fields; 3) farms; 4) urban areas; 5) water bodies. (see Fig. 5) shows the land use and population distribution.





Two dams are located in the Yasu River basin. The Yasu Dam is used to supply water for irrigation when shortages occur in the downstream area, and to control floods, and it has a capacity of 7.8 - 10 Mcum. The Aoto Dam is used to supply domestic water (0.080 m^3/sec) and to satisfy industrial water demand (0.533 m^3/sec). The monitored operational value at Yokoda Bridge is 1.68 m^3/sec.

The basin decomposition approach was used in order to model the operation of the Aoto Dam, and therefore the runoffs from the upper and lower catchments are calculated separately. The river discharges at point 1 and 2 are fed back to the Aoto Dam mesh (see Fig.6) to modify the release for the next time step of simulation.

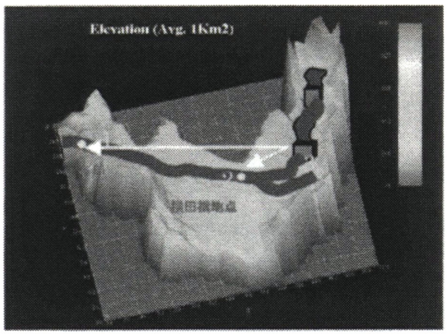
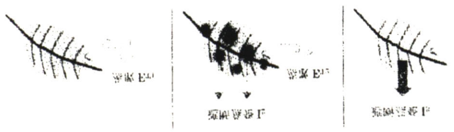


Fig. 6: Operation of Aoto Dam

The dynamics of land uses approach is used in order to simulate the seasonal behavior of the basin vegetation. Fig. 7 shows an example for estimating the interception.



No rain	Showers of rain	Heavy rain
Evap. only	Evap. + Interc.	Interc. Only
E=ET1	E=ET2+I2	E=I3
β =0.1~0.26	β =0.1~0.26	β =1.0

Fig. 7: Interception of vegetation

The groundwater table in the Yasu River basin is highly affected by heavy rainfall in summertime, and is also affected by the seasonally increasing demands of water for agricultural production. There has been a clear draw-down of the water table over the past 30 years as shown in Fig. 8 (Kimaro,*et..al*,2002). There are many causes for this trend, such as growing demands, urbanization, dynamics of land uses, and climate change. Hydro-BEAM is capable of considering most of these causes in simulating distributed rainfall-runoff. Groundwater modeling with Hydro-BEAM is achieved using the linear storage model for ground layers. Improvements are currently being made to Hydro-BEAM in order to allow simulation of the nonlinear nature of the groundwater level.

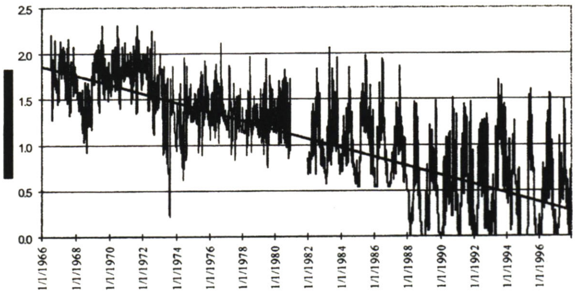


Fig. 8: Groundwater level at Otsukubo St.

Water quality model

For environment assessment, COD, BOD, SS, T-N, and T-P are handled, the pollution loads in the atmosphere are discharged to the river by the rainfall, and runoff pollution loads are calculated through the approach of pollutant ratio and non-point source (Kojiri,*et..al*,2000). The transformation products are also handled. These products ($x_1, x_2, .., x_n$) can be more toxic, more soluble, more persistent, or more bioacumlated than the parent compound. There are many obstacles in considering the transformation compounds because many of these compounds are poorly characterized, and the setting of the boundary conditions of the model illustrates some of the unique problems for simulating the interactions between hydrological layers while the contribution of the neighboring areas is hardly evaluated. The assumption of concentration addition (CA) is used (Fenner,*et..al*, 2002). The multi-media model is composed of five compartments: air, soil, water, sediments, and groundwater. First-order degradation processes are donated by k_i in each phase I (see Fig. 8), and diffusive and advective transfer processes between the phases are donated by U_{ik}, and are expressed by the following general equation:

$$\frac{dC_i^{x_1}(t)}{dt} = -K_i^{x_1} C_i^{x_1}(t) - \sum_k U_{ik}^{x_1} C_i^{x_1}(t) + \sum_k U_{ki}^{x_1} \frac{v_k}{v_i} C_k^{x_1}(t) + \sum_k \theta_i^{x_1 x_2} K_i^{x_1} C_i^{x_1}(t)$$

It includes all degradations and inretphase transfer processes between the compartments volumes V_i, V_k for a chemical species, the last term is the transformation part (Fenner,*et..al*, 2002).

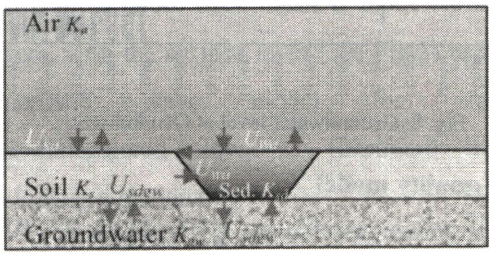


Fig. 8: Compartment model

Simulation output.

The following figures show the rainfall data from 8 satiations and the simulated output using Hydro-BEAM (see Fig 10, 11). Fig. 12 shows the distributions of COD, BOD, TP, and TN.

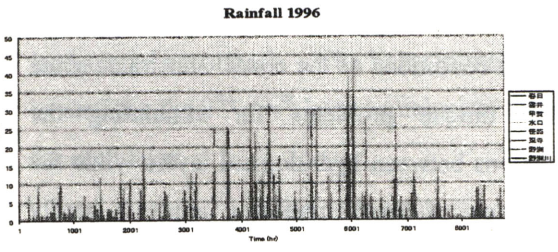


Fig. 9: Rainfall distributions

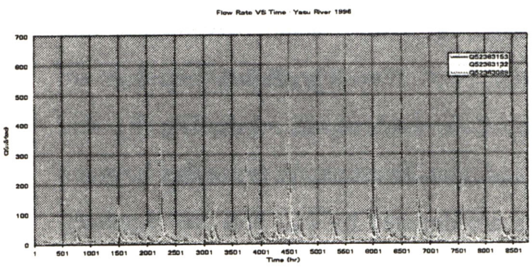


Fig. 10: Simulated River Flows

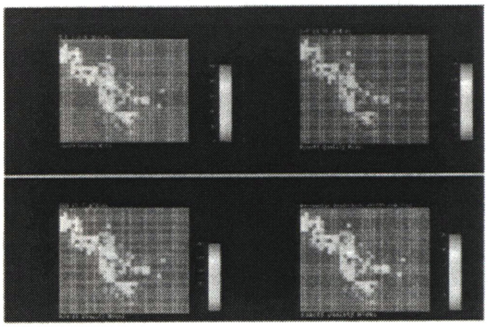


Fig. 12: Distributions of COD, BOD, TN, and TP

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