【Article】

Application of Asian Environment Simulator (AES) to Environmental Assessment in Haji River Watershed

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Abstract

In response to the growing concern on environmental assessment in dam management in Japan, using numerical simulation technologies, it is often required to comprehend the dynamic features of the water (sea, lakes, rives, ice, evaporated water, etc) which is the basis of material transport system as well as eco-system. In this research, we provide an overview for the development of the simulation programs applied to Haji Dam watershed as a case of study which is required a deeper assessment due to the increasing decay in water quality originated by human activities inside the watershed. In order to demonstrate how this techniques could be use in the future to assure a better information management we will introduce a series of programs in Asian Environment Simulator (AES) which will be used to achieve the highest response to human efforts.

Keywords: environmental simulator, dam management, environmental assessment.

1. Introduction

Japan's water system (collection, transportation and treatment) has grown exponentially due to the increasing demand of this precious liquid, according to consumer's needs and the reduced amount of it. Furthermore, topographically in disadvantage, Japan's small land area and high elevation of it mountains, becomes the perfect "machinery" for losing water. In other words, when water falls because of rainfall, this water goes to the ocean in a short period of time because the length of rivers in Japan is comparatively short and their gradient is very steep. Rivers in Japan characteristically flow directly from mountain to the sea (Takeuchi and Harada, 2000). These characteristics yield high volatility in discharge. So, Japan's water management needs to elaborate systems to retain and divert the water, to be used for human purposes other than just return to oceans. It gives a necessity for dams, which are effective to cut the peak discharge.

As in many other countries, Japan has to face water-related problems, such as floods, drought, water shortage in some areas and quality of the water before and after been used. So, it is not only the main object to assure a stable water supply to cover the daily needs of the population, it is also important to guarantee the quality of the water used for human consume.

Assessments can be retrospective or prospective. The retrospective kind is the business of normal science and serves to enlarge our knowledge base. It measures and records what has happened, like water pollution measurements and the study of where the pollutant came from. The prospective kind is part of the development planning and project assessment procedure. It projects the likely consequences of the future, based on available evidence. It mean models which can be used to predict future event that could affect the management decision, specifically in this case, the dam related problems.

Nowadays, a constant quality control of service water is needed to avoid epidemic crisis or health problems that will result in an increase of the government health expenses. In order to do that, it is vital to establish a well-designed weather monitoring system which can be used to predict environmental conditions. Increasingly more, environmental models are becoming essential for informing management and decision making. This aspect necessitates that models must integrate a range of disciplinary knowledge at different scales and simulates a corresponding range of output types - e.g. ecological, hydrological, social and economic - so that results will aim to provide support for decision making and managers.

Combination of the meso-scale meteorological model, MM5, and hydrological model, HSPF, that are the modules of Asian Environment Simulator (AES) can be used as a simulation system to predict water behavior as well as material transport in the dam watershed. It can reproduce a long chain of water circulation, rainfall runoff into the rivers and reservoirs, which is as well related to the quality of the water due to all the material and sediments washed away by the rain. This study considers the application method of AES to the environmental assessment in Haji River watershed to take the scientific measures to response to whatever is needed to be done in order to reassure the safety of the people regarding also the equilibrium with the environment.

2. Background and Methodology

Environmental protection, cost saving, sophisticated management of dams/reservoirs are the top public issues in Japan like they are all over the world. Since Japan has already developed most of economic dam sites, the issue of management of exiting dam/reservoirs is particularly the major concern of the country.

Dam building technology has growth in countries where the water supply is reduced or the population density is irregular (so it is needed to transport the water to remote areas where it will be finally consumed). A dam is built in a river which by definition, belongs to a watershed. A watershed is an area of land that drains into a lake or river. As rainwater and melting snow run downhill, they carry sediment and other materials into the streams, lakes, wetland and groundwater (Zyma et. al., 1998; Hoban 1994).

Wetlands are a key link in watershed management (Mitchell 2000). The role that they play in our watersheds is critical such as protecting water quality and moderating water quantity. Wetland habitat serves as home for many plants and animals. Vegetated riparian wetlands in agricultural areas have proven to remove high percentages of phosphorus and nitrogen from runoff water.

The absence of wetlands or the force-environmental change caused by the construction of a dam, can and will affect the wetlands of the watershed, therefore without these wetlands, increased nutrient loading to rivers, streams and lakes could result in algae blooms and over-abundant aquatic plant growth. When these algae and plants die, oxygen in the water is used during the decomposition process, this can result in oxygen deprivation which may lead to fish kills or ultimately to pollute the water used for human consume.

In Japan several monitoring projects have been developed, however due to the limitation of monitoring data availability, the use of simulation technology for four dimensional monitoring is in great demand, in which the simulator interprets what is happening inside the watershed, how the water changes affect the runoff sediments, and how is the process when they enter to the dam-lake, the turbulences that take place when a heavy rain has occurs, etc. All this processes can be study in advance and be taken as an important key to understand the whole system of water circulation and material transport.

As shown AES's numerical modules in Figure 1, in order to understand the whole process that occurs inside the watershed, it is needed to be study from the big scale, such as soil, topography and weather conditions will help us to calculate the amount of water that is actually going into the watershed and therefore to the stream system. Before studying the weather condition, it is relevant to mention that as Japan is an island, the sea temperature also plays an important role in weather prediction.

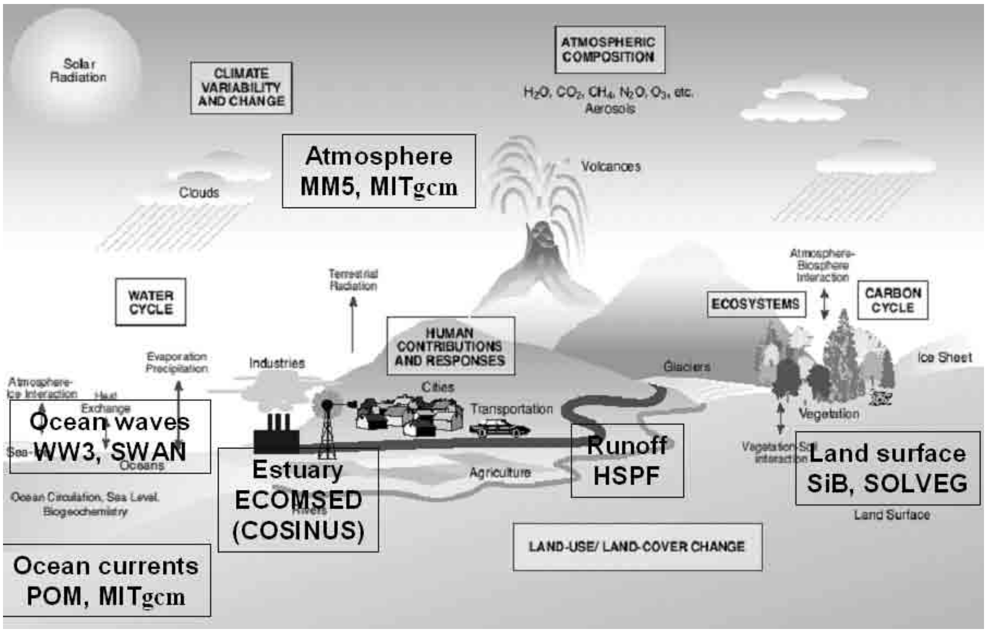

Figure 1: Numerical models in Asian Environment Simulator (AES)

3. Models for Haji Dam Watershed

As a simulation model for water circulation and material transport, we employ MM5 for meteorological simulation and HSPF for hydrological simulation, in this study (see Figure 2). This may be the simplest combination of precipitation and runoff simulation. We call it Haji Model hereafter. Model outlines are mentioned below.

MM5 is the Fifth-generation NCAR / Pennsylvania State Mesoscale Model is the latest in a series that developed from a mesoscale model used in the early '70's that was later documented by Anthes and Warner (1978). Since that time it has undergone many changes designed to broaden its applications. These include (i) a multiple-nest capability, (ii) nonhydrostatic dynamics, and (iii) a four-dimensional data assimilation (Newtonian nudging) capability, (iv) increased number of physics options, and (v) portability to a wider range of computer platforms. The purpose of MM5 modeling system in this study is to improve the accuracy of simulated wind field,

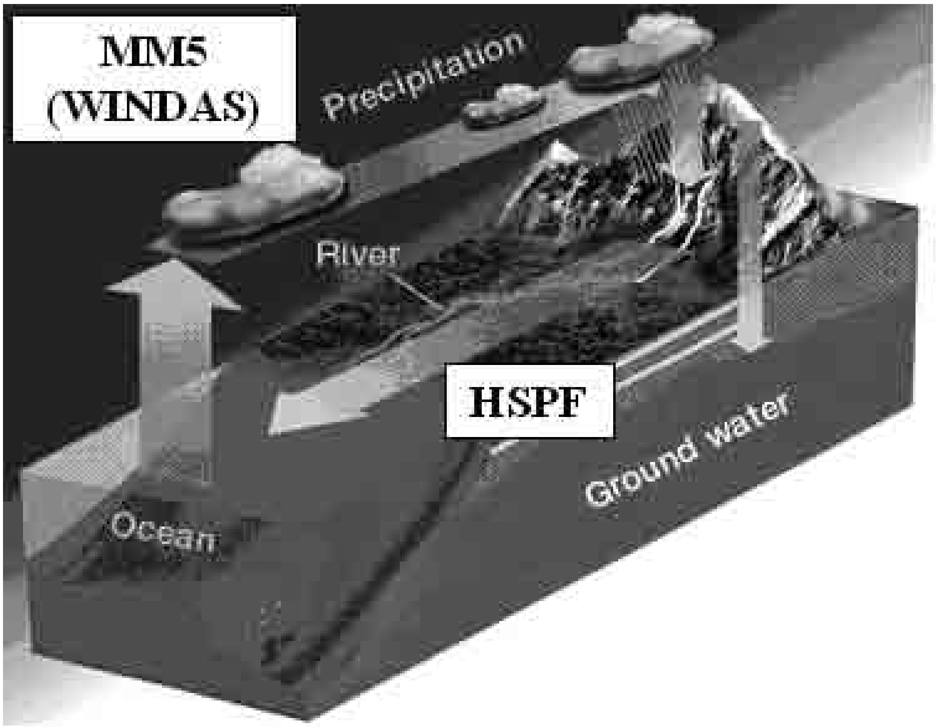

Figure 2: MM5-HSPF Combination Model for simulation in Haji dam watershed: Haji Model

data assimilation with the vertical wind profile data from Wind Profiler Network and Data Acquisition System (WINDAS). It will be called MM5(WINDAS) in this study. Precipitation simulation has the advantage of predict (within a specific period of time) or create new scenarios (heavy rain, long period of droughts) in order to asses the consequences in the water quality and quantity.

HSPF (Bicknell et. al., 1997) is a comprehensive, conceptual, continuous watershed simulation model designed to simulate all the water quantity and water quality processes that occur in a watershed, including sediment transport and movement of contaminants. Although it is usually classified as a lumped model, it can reproduce spatial variability by dividing the basin in hydrological homogeneous land segments and simulating runoff for each land segment, independently, using different meteorological input data and watershed parameters. The model includes fitted parameters as well as parameters that can be measured in the watershed.

The model can be applied to most watersheds using existing meteorological and hydrologic data. Although data requirements are extensive and learning to correctly use the model requires some time, Environmental Protection Agency (EPA) recommends its use as the most accurate and appropriate management tool available for the continuous simulation of hydrology and water quality in watersheds.

In HSPF, the various hydrologic processes are represented mathematically as flows and storages. In general, each flow is an outflow from storage, usually expressed as a function of the current storage amount and the physical characteristics of the subsystem. Thus the overall model is physically based, although many of the flows and storages are represented in a simplified or conceptual manner. Although this requires the use of calibrated parameters, it has the advantage of avoiding the need for giving the physical dimensions and characteristics of the

Figure 3: Haji dam watershed with its sub-watersheds and stream network; also is presented information about area for each sub-watershed (A) and stream length (MSL).

flow system. This reduces input requirements and gives the model its generality.

In Haji Model, for simulation with HSPF, the basin has to be represented in terms of land segments and reaches/reservoirs. A land segment is a subdivision of the simulated watershed as shown Figure 3. The boundaries are established according to the user's needs, but generally, a segment is defined as an area with similar hydrologic characteristics. For modeling purposes, water, sediment and water quality constituents leaving the watershed move laterally to a downslope segment or to a reach/reservoir. A segment of land that has the capacity to allow enough infiltration to influence the water budget is considered pervious. Otherwise it is considered impervious. The two groups of land segments are simulated independently.

In pervious land segments HSPF models the movement of water along three paths: overland flow, interflow and groundwater flow. Each of these three paths experiences differences in time delay and differences in interaction between water and its various dissolved constituents. A variety of storage zones are used to represent the storage processes that occur on the land surface and in the soil horizons. Snow accumulation and melt are also included, so that the complete range of physical processes affecting the generation of water and associated water quality constituents can be approximated.

Processes that occur in an impervious land segment are also simulated. Even though there is no infiltration, precipitation, overland flow and evaporation occur and water quality constituents accumulate and are removed.

The hydraulic and water quality processes that occur in the river channel network are simulated by reaches. The outflow from a reach or completely mixed lake may be distributed across several targets to represent normal outflow, diversions and multiple gates on a lake or reservoir. Evaporation, precipitation and other fluxes that take place in the surface are also represented. Routing is done using a modified version of the kinematics wave equation.

4. Application of Haji Model

4.1 Haji Dam Watershed

Haji Dam is located in Hiroshima prefecture (34° 39' N, 132 ° 38' E), and is part of the Gono River system (Yachiyo-cho, Akitakata City)(Figure 4), completed in 1974, is a multipurpose dam, which provides flood control, maintenance of river flow, urban water supply, and electric power generation. It discharges water through an approximately 19 Km tunnel into Nenotani River after using it to generate electric power.

Since its construction, Haji Dam has been an important source of water supply and electricity, entertainment, wildlife management, protection against floods and more over, has helped the economical growth of the town. But as every human construction it has an impact over the surrounding environment, and although carefully considered and analyzed those impacts before its construction, it is always difficult to predict what will happened because of many parameters involve, such as fast population growth, irregular density of it, not controlled agricultural activities, etc.

After more than three decades of the dam completion, Yachiyo Lake (Dam Lake) is facing several water quality related problems; which make it a center of intensive investigation, in a huge effort to understand, control, and later on, eradicate the source of the problem.

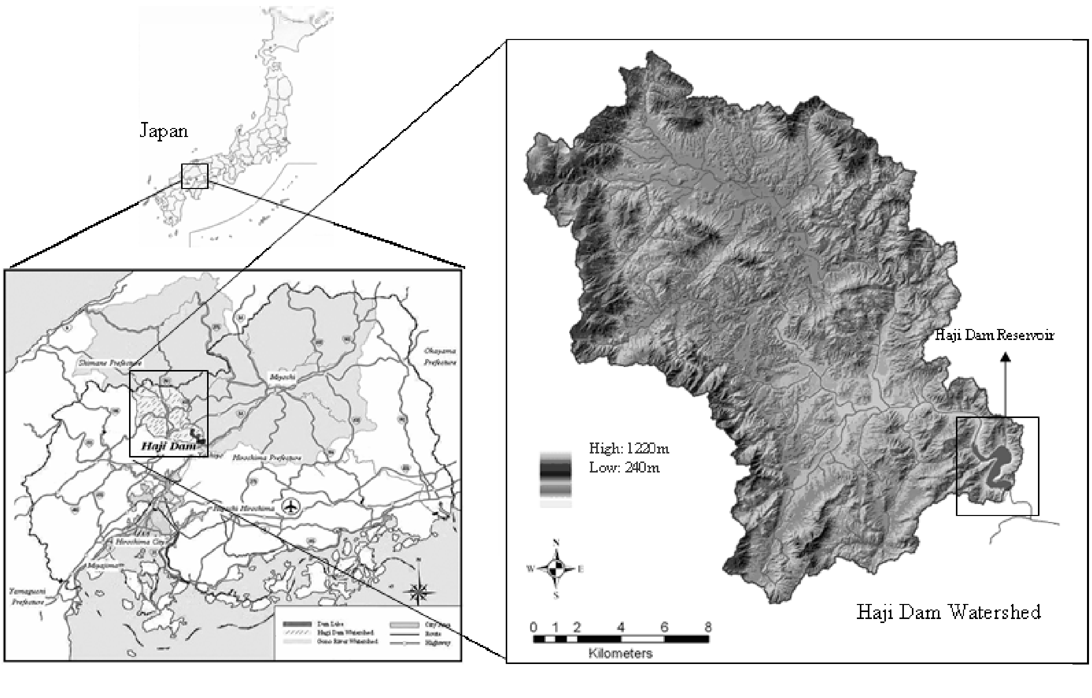

Figure 4: Location of Haji Dam watershed

Table 1 shows the statistics related to Haji Dam, and even though it is a relatively a small dam, for Hiroshima Prefecture represents an important source of water. From Table 2 is appropriate to mention that Yachiyo Lake (Haji Dam) supplies more than 15% of the total amount of water use by the City of Hiroshima, so it became very relevant the studies in water quality since few years back.

At the reservoir itself, many researchers have been working to handle several challenges, including the decline of water quality as a result of eutrophication (Nakagoshi 2005), cold effluent, prolonged periods of turbidity, studies in the dried-up zone (Suemoto et al. 2005), sediment deposition (Masis, 2001, 2003), etc.

Table 1: Haji Dam Statistics

Dam statistics	
Dam height	50.0 m
Dam top length	300.0 m
Dam mass	210,000 m^3
Entire reservoir capacity	47,300,000 m^3
Effective storage	41,100,000 m^3
Watershed area	307.5 km^2
Yachiyo Lake area	2.80 km^2
Purpose of the Dam	Flood control, water utilization and generation of electricity.
Electric enterprise	The Chugoku Electric Power Co. Ltd.
Power plant name (Approval output)	Kabe Electric Power Plant (38,000kW)
Starting/completion construction year	1966 /1974 year

Source: Haji Dam. http://ja.wikipedia.org/

Table 2: Water supply to Hiroshima City

Name of Water Purification & Receiving Plant	Supply Capacity (m^3/day)	Name of Intake Station	Water Source
Ushita	110,000	Hesaka	Ota River
Midorii	200,000	Yagi	Ota River (100,000 m^3/day) Haji Dam (100,000 m^3/day)
Koyo	200,000	Koyo	Ota River (100,000 m^3/day Takase Weir (100,000 m^3/day)
Fuchu	27,000	Hesaka (Hiroshima Prefect.)	Ota River Settled water from prefecture
Kitabara (FY 2003)	6,800		River water from Yahata River
Senogawa,Yano & Ato	41,700		Purified water from prefecture
Kochi,Kitabara&Tsuboi	42,600		Purified water from prefecture
Total	628,100		

Source: The City of Hiroshima, Hiroshima City's Water Supply System

In the eutrophication case there are methods like aeration, deep aeration facilities, selectable intake, selective intake works and other techniques. The use of such facilities to improve water quality has demonstrated clear benefits at many dam reservoirs, for example the suppression of plankton growth.

4.2 Haji Model

The most serious water quality problems found in the dam reservoir is the prolonged eutrophication due to large phosphorus loadings (Takeuchi and Harada 2000). Recently, the influent load, such as nutrient salts, on dam reservoir has increased as a consequence of changes in life styles and productive activities in the watershed. In Haji dam reservoir, eutrophication caused by the massive proliferation of algae has effected the utilization of the water and the recreational use in the dam reservoir.

Eutrophication of dam reservoirs occurs when the quantity of nutrient salts flowing into reservoirs increases, and if the temperature, sunlight, and other conditions are suitable in water areas such as dam reservoirs where water is retained longer than in natural rivers, massive proliferation of algae etc. occurs, causing the growth of water bloom. Consequently, measures to deal with this problem are categorized as follows: measures at the sources of load in the watershed, measures in the influent river of the dam reservoir, and measures in the dam reservoir. The most effective way to reduce the nutrient salt load that causes massive proliferation of algae is to introduce measures to reduce the load from the watershed itself, and here comes the role of the Haji Model.

As explained before, Haji Model assembly two models, meteorological and hydrological model. This combination will allow us to estimate the actual nutrient load to the stream system. Moreover, it will enable the creation of future scenarios that will help in the decision making of the management process of water quality impact in Haji Dam watershed.

Haji Model will be applied for simulating the water quantity and quality in Haji dam watershed. The main objective is to find the sources of the high loads of nutrients and phosphorus within the watershed. Haji Model is capable of simulating the surface runoff. Also, Haji model is able to simulate the water quality parameters within the watershed and within the stream network. In addition it can reproduce water and material circulation in the reservoir considering the interaction among water, land surface, and the atmosphere. The simulation results from Haji Model will be verified by runoff and water quality data collected at different stations in Haji dam watershed. The simulation results are expected to identify the eutrophication sources and to assess the applicability of the different scenarios proposed as countermeasures of the eutrophication in Haji dam reservoir.

5. Conclusions

As Haji Dam is a very important source of water in Hiroshima prefecture, and its water quality is threaten by organic pollutants such as phosphorus and nitrogen, its been required a deeper study on the possible cause and sources of the contaminants. As it only represent a case of study, an example of what can be done; the modeling of the water behavior, by starting from the amount of precipitation which represent one of the input data, through the runoff of the water in the watershed, until it behavior when comes into the dam lake, it is all part of a new kind of investigation that will allow us, by using computer modeling, to predict where the pollutants comes from, when is the risk highest and finally it will open doors to a new branch of investigation, to a new and better way to assure the best impact assessment that can be done.

Although this is a limited study, it shows that informatics tools can be applied using available software. This “userfriendly” software will appeal to a larger audience of ecologists. Though not presented here, these approaches also hold potential for use in exploratory analysis of data and variable importance in predictions. However, more research is needed to develop a protocol for employing such techniques.

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