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Simulation of the effects of the alteration of the river basin land use on river water temperature using the multi-layer mesh-typed runoff model

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ABSTRACT

A model displaying river water temperatures was established, and applied to a small river basin. Based on the results, the effects of the alteration of the river basin on the budget and river water temperature were discussed. The model was a multi-layer mesh-typed runoff model, and the behavior of water and heat transference was depicted. Also, in order to verify the model, the daily changes of streamflow and river water temperature were measured and compared with the model results. From the calculation, the flow rate and river water temperature profile agreed well with the measured ones along the streamline. Using the model, the effects of deforestation and air temperature rise on river water temperature were discussed. With deforestation, the temperature in summer was calculated to rise and fall in winter. This was explained by the change of flow pass of surface and subsurface. The air temperature was thereafter changed in the model. From the simulation under the air temperature rises, the daily air temperature was evenly changed through a year, and the ratio of the change of the river water temperature to the air was less than unity (i.e., $>1\,^{\circ}C_{river\ water}/^{\circ}C_{air}$). By close investigation of the model calculation, the most influential factor was determined to be subsurface temperature. The rise of surface temperature was also less than unity, due to the enhancement of heat loss with the augmentation of evaporation at the surface, and because the subsurface temperature is calculated on the surface temperature as boundary condition, rise of subsurface temperature was also less than unity. Overall, the mechanism of the alteration of river water temperature was described as follows: with the change of river basin land use or meteorological conditions, the pass of subsurface flow is changed, and the streamflow and river water temperature are also changed.

1. Introduction

Global temperature is predicted to rise due to human activities, and the influences of global warming are believed to be a great threat to the natural environment and human activities (Harasawa, 2001; Smith and Tirpak, 1989). Recently, a considerable number of studies have been focused on various natural and socioeconomic effects of global warming on aquatic ecosystems. These changes are considered to cause disruptions such as the deterioration of river water quality,

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eutrophication of lakes and coastal zones and so on (Avila et al., 1996; Cruise et al., 1999; Fukushima et al., 2000; Magnuson et al., 1997; Ozaki et al., 1999, 2003; Pilgrim et al., 1998; Schindler, 1997; Sumi et al., 1996). Also, due to global warming, the water temperature rises are thought to affect various living organisms directly or indirectly, and thus cause changes in ecological situations (Gitay et al., 2002). Water temperature changes arisen from increased temperatures will alter thermal cycles of lakes and the solubility of oxygen and other materials, and thus affect ecosystem structure and function. Climate change will affect freshwater ecosystems through alteration in hydrological processes. For example, river water temperature rises have been proven to influence fish thermal habitats in streams (Jensen, 1987; Eaton and Scheller, 1996).

So, for the modelling of riverine ecosystems, it is important to discuss how the stream water temperature changes, as well as the streamflow, due to the alterations of the river basin with the urbanization, or the meteorological changes. A large number of researchers investigated these effects experimentally or by field researches (Moore et al., 2005a). For streamflow, the many elaborated models have been developed and applied for river water discharge management (Tang et al., 2005; Bellot et al., 2001). For stream water temperature, however, the calculation in the models mainly begins with certain upstream points, and the integrated models on the water discharge models have not been well developed yet. Moore et al. (2005a) summarized the present research situation of this field, and discussed the effects of riparian microclimatic changes on the stream temperatures. For further investigation, they pointed out the influences of surface/subsurface water exchange on stream water temperature.

In this paper, the mesh and multi-layer runoff model was applied for a small stream, and the behavior of heat transfer was modelled on the water runoff model. In order to verify the model, the daily changes of streamflow and river water temperature were measured, and the calculation with the model was conducted using on meteorological data and compared with the measured data. The reason why this stream was selected for this study is that intensive measurements of air and stream temperature could be conducted along the streamline, and, also, different land use could be seen for this small area. The mechanism of the river temperature formation itself is common from a microscopic view. Hence, the knowledge obtained from the simulation of physical processes would be common to other rivers independent of the study river's spatial scale.

2. Field measurements

The Yamanakatanigara river has a catchment of 1.7 km^2 and is located in southwest Japan (Fig. 1), of which the topographic height is between 200 and 300 m above sea level. The total catchment area is located on the campus of Hiroshima University. The climate condition of this area is moderate, with a yearly averaged temperature of 13 °C (2003), and a mean annual precipitation of 1500 mm (2003). Precipitation is mainly rainfall, and snow falls just several times in a year. About half of the area is forest, and the rest is pavement. The stream length is around 1.0 km, and there are two ponds in the area; the one is in an upstream zone (pond A), and the other is in a midstream (pond B).

In the study area, five stream temperature measuring points were located (St. 1–5; Fig. 2), and the temperature was measured with a small, portable and autonomous data logger (StowAway TidbiT; Onset Computer corporation, USA). Also, the streamflow was predicted from the *H*–*Q* curve obtained from the consecutive measurement of the depth of water from 01 November 2000 to 31 January 2001 and the occasional stream velocity measurements at the time of rain occurrence at St. 2.

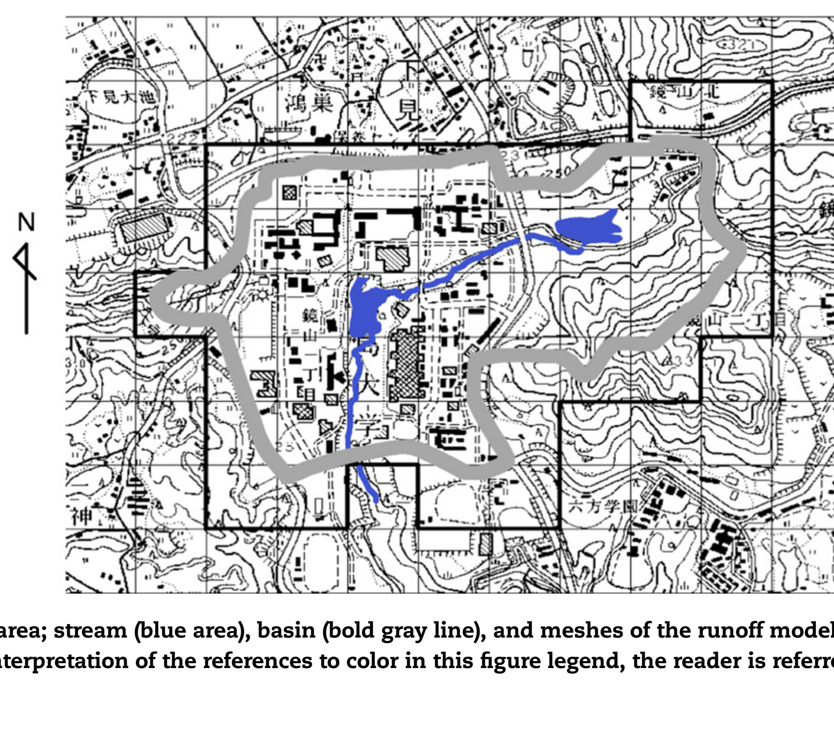

Fig. 1 – Map of study area; stream (blue area), basin (bold gray line), and meshes of the runoff model. (Mesh size: 200 m × 200 m.) (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)