The Framework of GIS-based Decision Support Systems (DSS) for Water Resources Management at the Flint River Basin

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Abstract. In this paper, a surface water flow model with groundwater interaction for the Flint River Basin (FRB) is presented. The model consists of two layers of modeling systems which are HSPF hydrological model in first layer for streamflow simulation within subbasin and a Stella model in second layer for flow simulation in Flint River (main stream). To fully consider the dynamic interaction between surface and groundwater and more accurately simulate this complex water resources systems, a framework of dynamic surface and groundwater modeling systems is proposed for future improvement of current modeling systems. Furthermore, a framework of GIS-based decision support system (DSS) is constructed, which includes SW-GW modeling system, database, GIS-based user-friendly graphic interface, analysis tool, and alternative analysis and evaluation module. This DSS, when finished, may provide strong technical support for best managing water resources in Flint River Basin.

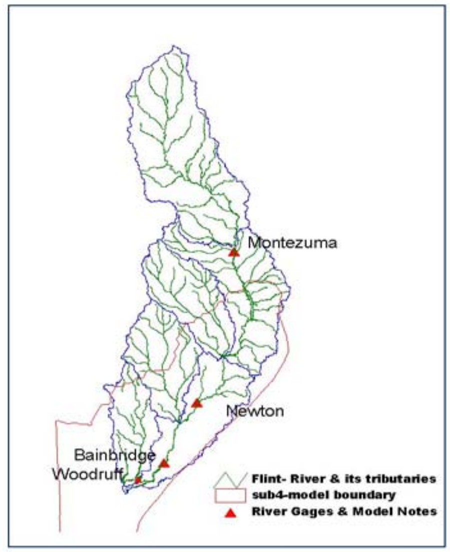

Figure 1. Flint River Basin

INTRODUCTION

The Flint River is located in the southwest of Georgia. It starts at Atlanta International Airport and flows southward approximately 349 miles, then joining the Chattahoochee River to form the Apalachicola River in Florida. The Flint River Basin drains an area of 8460 square miles, entirely within the boundaries of Georgia. The Flint River has no large reservoirs but only two major impoundments on it: Lake Blacksher, near Warwick, and Lake Worth, near Albany (GA EPD, 1998).

The Flint River above Montezuma is called the upper Flint River Basin (UFRB) in this study. The Flint River from Montezuma to Newton is called Middle Flint River Basin (MFRB), and the river from Newton to Lake Seminole is called Lower Flint River Basin (LFRB) as shown as Fig. 1.

From upstream of Lake Blackshear in MFRB, the Flint River enters the area known as the Dougherty Plain, where the Flint River has incised into the Ocala Limestone, which comprises the Floridan aquifer, from which the Flint River receives hundreds of millions of gallons of groundwater flow. This stream-aquifer relationship is unique in Georgia, and is the reason that the Flint River is of such concern to resource planners and southwest Gerogia stakeholders (GA EDP, 1998).

The LBRB is one of the state's most important agriculture areas. Irrigation pumping from both surface and especially groundwater has been an important measure to ensure productive crop harvest. The unique stream-aquifer relationship in the LFRB creates a sensitive hydrological system in which groundwater withdrawals have the potential to impact the stream and the aquifer.

Because of rapid growth in water use, especially by agriculture, and its possible impacts on water resources in the FRB, the Flint River Regional Conservation and Development Plan was initiated in June 1998 to address this increasingly important issue, and to provide a comprehensive analysis of water resources in the FRB (GA EPD, 1998). To achieve this goal, simulation models and computer analysis tools need to be developed to simulate this complex water resources system and evaluate the impacts of human activities on water resources in FRB, thereby, helping the decision makers to make wise decisions on future water uses in the area.

Schematic of the Surface Water Model

The current surface water model for FRB consists of two main components: HSPF and Stella models, which are the two layers of the modeling system (Fig. 2). The HSPF model is a rainfall-based hydrological model that is used to simulate stream flow within subbasins and to calculate unimpaired flow for the Stella model. The Stella model for the Flint River Basin is based on the Stella model for the ACF Basin originally developed by the University of Washington using Stella software (The Univ. of Washington, 1995). The model was modified and refined by adding more details to separate surface and groundwater withdrawal effect and to incorporate the interaction of surface and groundwater within subbasin; the Stella model is used to compute the flows in the Flint River at Montezuma, Albany, Newton and Bainbridge.

A complete schematic diagram of the current surface water model for the Flint River is shown as Fig. 3. The model consists of following components: (1) the HSPF hydrological model computes stream flow based on rainfall and other data; the Unimpaired flow (UIF) computation module calculates unimpaired flow (the estimated "natural" flow unaffected by man) at any ungaged location based on the stream flow generated by HSPF model, and also calculates UIF at gage locations based on observed flow and historical withdrawals and returns; (3) the ground water (GW) and surface water (SW) interaction module computes surface water reduction due to groundwater pumpage; finally, (4) outputs from these modules plus future withdrawal and return prediction are input into the Stella model for flow routing and water balance(budget) computation.

HSPF Hydrological Model

Natural stream flow conditions are important inputs to the Surface water model. Since USGS stream flow gage stations are limited, stream flows in ungaged locations of interest must be calculated for developing the detailed water resources management model. The HSPF model was selected for this purpose in this study. HSPF is a public-domain watershed model developed by the US EPA, and is a comprehensive, continuous watershed model, which is designed to simulate hydrology and associated water quality processes on pervious and impervious land surfaces and in river reach streams and well-mixed lakes, reservoirs and impoundments (Aqua Terra et al, 2004). HSPF model is a watershed model based on input data including precipitation, potential evaporation, soil and land use, and river structure and parameters. HSPF hydrological models have been developed in this study for Spring Creek subbasin and Ichawaynochaway subbasin (Zhang, Yi et al, 2005). Similar models or a regional hydrological model for other subbasins are also under development.

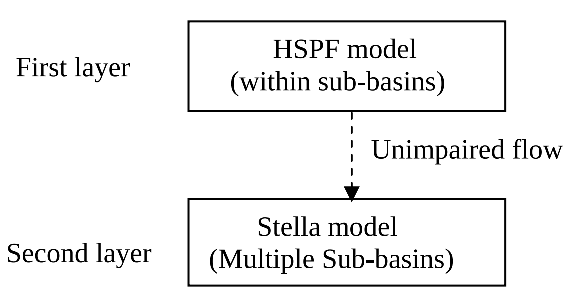

Figure 2. Two layers of SW modeling system.

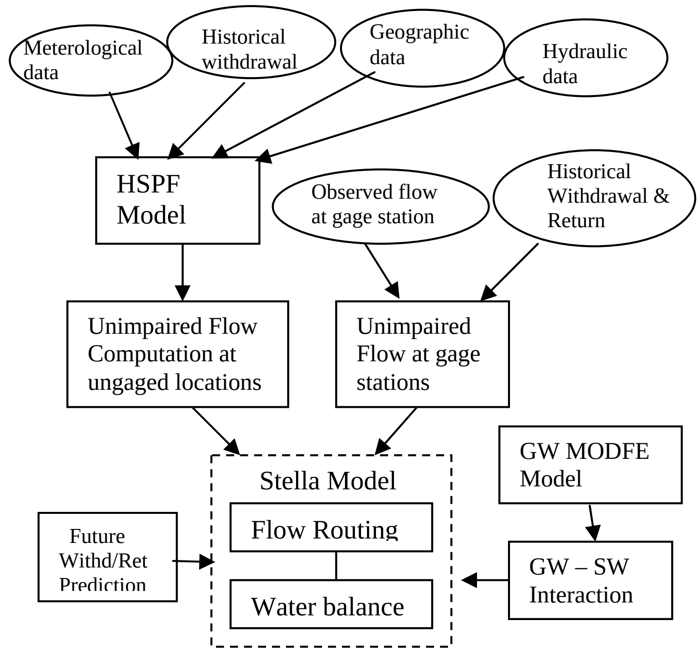

Figure 3. Schematic of SW Model for FRB.

Unimpaired Flow (UIF) Computation

Measured or observed flow records include the impacts of man-made changes within the river basins. Estimation of the impacts to the surface water system in the future requires removal of identifiable and quantifiable man-made changes to the observed flow, i.e., recovering the flow to the natural situation, called unimpaired flow. These flow adjustments include municipal and industrial water withdrawals and returns, agriculture water usage for irrigation, and increased evaporation and runoff due to the construction of surface water reservoirs. Historical UIF at Montezuma, Newton and Bainbridge gage stations has been calculated (US COE, 1997). For elsewere, the HSPF model needs to be used to compute UIF by considering various man-made withdrawal and return.

Groundwater and Surface Water Interaction

The groundwater effect on surface water in FRB is very important and has been modeled by USGS' MODFE model (Torak, J. L et al, 1996). Based on the GW model results, surface water flow reduction was calculated based on a approach suggested by Task Committee of Groundwater (TCG) in current model (TCG, 1996). USGS is currently developing a transient groundwater model based on newly available transient data for irrigation pumpage and well testing, this model will attempts to provide more accurate groundwater effects on surface water flow in the basin.

Stella Model for Surface Water Flow Computation

Stella software is a multi-level, hierarchical environment for constructing and interacting with models. A Stella software can easily be modified the model by adding new code or changing existing code. The current Stella model for FRB was developed based on the Stella model for ACF River Basin, in which FRB is a part of it and was treated quite simply in basinwide scale without separating surface water and groundwater in the subbasins. After modification and refinement, the current Stella model can evaluate the impacts of agriculture irrigation acreage change on stream flows, based on specific surface water withdrawals or/and groundwater withdrawals in the subbasins basis, and can also potentially evaluate individual permit impacts on stream flows if a groundwater sensitivity analysis is available. The model contains two main functional parts: flow routing and water balance (budget) computation based on unimpaired flow and various water uses including municipal and industrial, agriculture withdrawal and return, etc.

FRAMWORK OF DYNAMIC SW-GW SYSTEMS

Current surface water and groundwater models were developed separately by GA EPD and USGS, and are also run in separate processes. In this way, the result from GW model is input to surface water model for groundwater pumping effects on surface flow reductions, but the SW model result does not have any influence on the groundwater model result. The shortcoming of this process is that the interaction between SW and GW are not fully considered and accurately represented. As a result, the system as a whole is approximated and simplified in the models, and therefore, the model results might be compromised. Actually, interaction between surface water and groundwater is a dynamic process. Stream flow and elevation and rainfall recharge are inputs

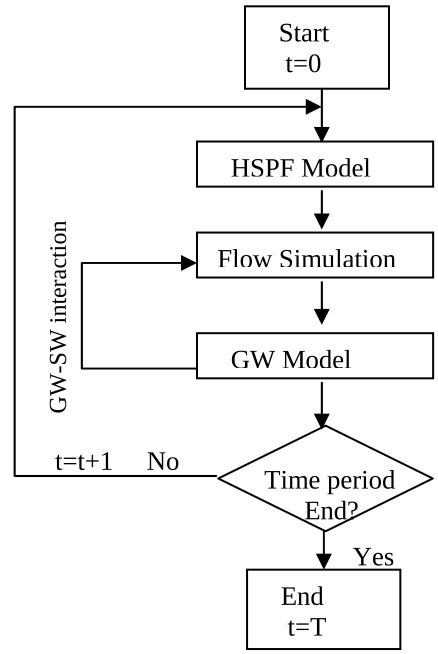

Figure 4. Dynamic SW – GW modeling systems.

for the groundwater system. On the other hand, groundwater effects due to pumpage on surface water will also affect stream flow and elevation. A more accurate modeling system should fully consider this dynamic relationship between SW and GW and capture this dynamic interaction process.

A framework for a dynamic (coupled) SW-GW modeling systems is proposed (Fig. 4) for the future improvement of the current modeling system in order to achieve this goal. In this coupled system, for each time step, surface water flow and elevation (from HSPF model and flow simulation) are input as boundary conditions to the groundwater model. Rainfall is a time-variant input as recharge to the groundwater model. Then, the groundwater model is run and groundwater pumping effects on surface water reduction are calculated. This effect is the input to the surface water model, and the surface water model is run again based on groundwater results. The surface water and groundwater model are coupled together in each time step to the end of computation period.

FRAMWORK OF GIS-BASED DSS FOR THE FRB

Furthermore, to provide the best technical support and information to management, a framework of GIS-based Decision Support Systems (DSS) is proposed and as constructed in Fig.5, which includes SW-GW modeling system, database systems, GIS-based user-friendly graphic interface and platform, results analysis tool for pre- and post-analysis, alternative analysis module for various water use rates, drought plan and permit plan, and impact analysis for groundwater level, surface water flow, Risk/Success analysis for farmers, etc.

In this DSS, SW-GW modeling system and database are a core of the system. Database can be constructed using HydroGIS or MS Access database and stores all data needed for simulation and analysis as well as simulated results. SW-GW modeling system uses data from database as an input for simulations and results are stored in Database. Graphic User Interface (GUI) is also very important and is used as a platform for a user to communicate with all modules. The Interface will use the ArcGIS or the HydroGIS as a platform with a customer-defined functionality. It is used to organize data and communicate with database, call the SW-GW modeling system for scenario simulations, and the Result Analysis tool for pre- and post-analysis, and talk to the Alternative Analysis module and Impact Analysis module for various analysis process and result display.

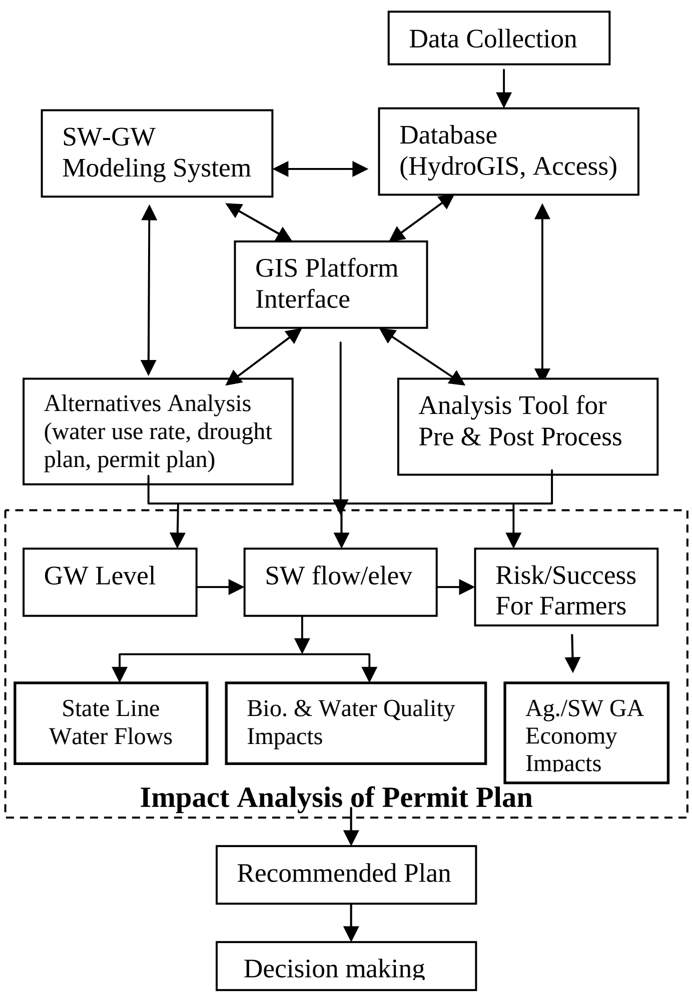

Figure 5. Framework of GIS-based DSS for the FRB.

The process for analysis and decision making includes the following steps: Step I: Inputs to Alternative Analysis; Step II: Alternative Analysis; Step III: Analysis of permit plan impact; Step IV: The Flint River Regional Development and Conservation Plan. This DSS, when finished, may provide strong technical support and guidance for this process.

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