Real-time surface water-ground water modelling of the Big Cypress Basin, Florida

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ABSTRACT: The South Florida Water Management District (SFWMD) is the lead agency in restoring America's Everglades – the largest environmental restoration project in US history. Many of the projects to restore and protect the Everglades ecosystem are part of the Comprehensive Everglades Restoration Plan (CERP). The region has a unique hydrological regime, with close connection between surface water and groundwater, and a complex managed drainage network with many structures. Added to the physical complexity are the conflicting needs of the ecosystem for protection and restoration, versus the substantial urban development with the accompanying water supply, water quality and flood control issues.

This paper describes a real-time surface water and groundwater modelling system developed for the Big Cypress Basin. The Big Cypress Basin includes 272 km of primary canals and 46 water control structures throughout the area that provide limited levels of flood protection, as well as water supply and environmental quality management. This real-time system is linked to the South Florida Water Management District's extensive real-time data monitoring and collection system for both surface water and groundwater. Novel aspects of this system include the use of a fully distributed and integrated modelling approach and a new filter-based updating approach for accurately forecasting river levels. Because of the close interaction between surface- and groundwater a fully integrated real-time modelling approach is required and forecasts of both surface and groundwater levels are made. Results are presented for the Tropical Storm Fay in 2008 and show in some cases extremely rapid changes in groundwater level in response to heavy rainfall. Analysis of this storm also shows that updating levels in the river system can have a direct impact on simulated groundwater levels

INTRODUCTION

The Big Cypress Basin (BCB) is located within Collier County on the west coast of the Florida peninsula, Figure 1. The climate is subtropical and the region exposed to frequent storms in the summer months (e.g. tropical storms Faye 2008 and Ernesto, 2006) that lead to heavy rainfall and flooding. Indeed some 60% of the rainfall falls in the period June – September as a result of tropical storms and thunderstorms (Obeysekera et al., 1999). While rainfall is abundant during the wet season, southern Florida is also subject to extended periods of low rainfall, resulting in droughts that require careful management to protect both the water resources and the ecological system.

The hydrological characteristics of South Florida are unique being an interconnected system of surface water and ground water. The hydrogeology of the freshwater aquifers of Collier County has most recently been discussed by Missimer et al. (2003), and Marliva et al (2008). The aquifer system consists of the following aquifers; Water Table, Tamiami, Sandstone, Mid Hawthorn and the underlying Floridian aquifer. Geological surveys in the area suggest that negligible exchange occurs between the Mid Hawthorn and Floridian aquifers. The Water Table and the lower Tamiami are separated by the leaky Tamiami confining beds. Extraction in the area is limited to the Water Table aquifer, the lower Tamiami and the Sandstone aquifers. However, the brackish waters of the Mid Hawthorne aquifer have also been recently tapped to sustain the freshwater supplies of the surficial and intermediate aquifers. For the operational model, the aquifer system is represented as three layers; 1) the Water Table aquifer, 2) the Lower Tamiami aquifer, 3) the Sandstone aquifer. Two confining units are included as lenses, the Bonita Springs confining unit between the Water Table and lower Tamiami aquifers, and the Upper Peace River confining unit between the lower Tamiami and Sandstone aquifers.

The topography in the area is low relief with very low slopes, typically 3×10^{-5}. The surface flows are dominated by low-lying wetlands, many parts of which have been drained. The surface drainage network consists of many man-made channels, with numerous and often complex structures that are required to regulate water levels in the canals that crisscross the area (Figure 1). There is relatively little storage capacity in the surface storage system making both flood mitigation and water resource management a tough balancing act with competing needs and conflicting responsibilities.

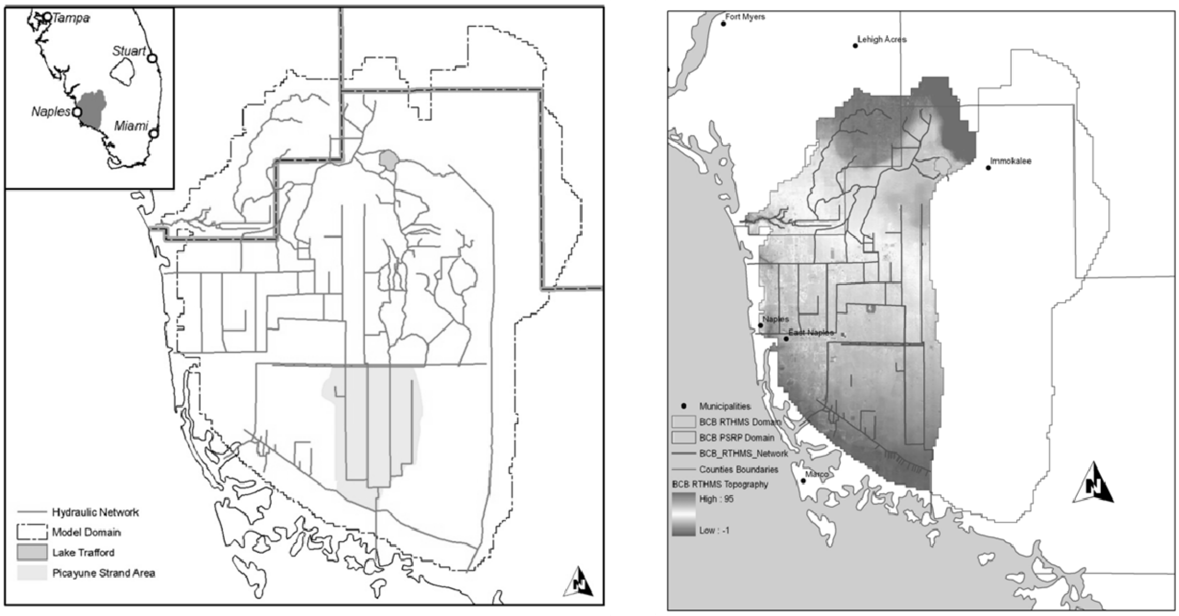

Figure 1: Location of the Big Cypress Basin (inset), the Big Cypress Basin drainage network (left) and the operational model area with topography (right)

On August 30, 2006, Tropical Storm Ernesto passed through southwest Florida. The heavy rainfall associated with this storm led to flooding within the central Big Cypress Basin. A post-event analysis carried out by the BCB staff recommended an array of mitigation measures to reduce the recurrence of such flooding to safeguard public health, safety and welfare. The development of a flood warning and assertive operating system based on real-time flood forecasting models is one of the primary recommendations of this analysis.

As a result, the project “Big Cypress Basin Real Time Hydrologic Modeling System Phase 1 - System Development and Testing” was initiated to develop a new state-of-the-art real-time hydrological modelling system. This main purpose of this development was to provide real-time monitoring and modelling information for the western urban area of the Big Cypress Basin, Florida, to the District’s water managers to support critical operational decision-making. This real-time modelling system was developed as a collaborative effort between the Big Cypress Basin, Hydrologic and Environmental Systems Modeling and SCADA and Hydro Data Management departments of the South Florida Water Management District (SFWMD) and DHI.

The major goals were:

- To exploit existing hydrological and hydraulic models, and the real-time telemetric monitoring (SCADA) network to develop a sub-regional real-time modelling and flood forecasting system for the Big Cypress Basin
- To develop a system that integrates data management, monitoring facilities, forecast models and dissemination methodologies into a single system to facilitate flood control operational decisions.

These goals were achieved by implementing and adapting the MIKE FLOODWATCH real time decision support tool and incorporating into this tool an operational MIKE SHE model developed for the Big Cypress Basin.

FORECASTING AND MONITORING SYSTEM

MIKE FLOODWATCH is a decision support system for real-time forecasting (Butts et al., 2007; Jørgensen & Høst-Madsen, 1997). Designed for use in real-time environments, MIKE FLOODWATCH integrates spatial data, real-time data, forecast models and dissemination tools in a GIS or web based environment (Figure 2). More detailed information can be found in http://www.dhigroup.com/Solutions/SolutionSoftware/FLOODWATCH.aspx).

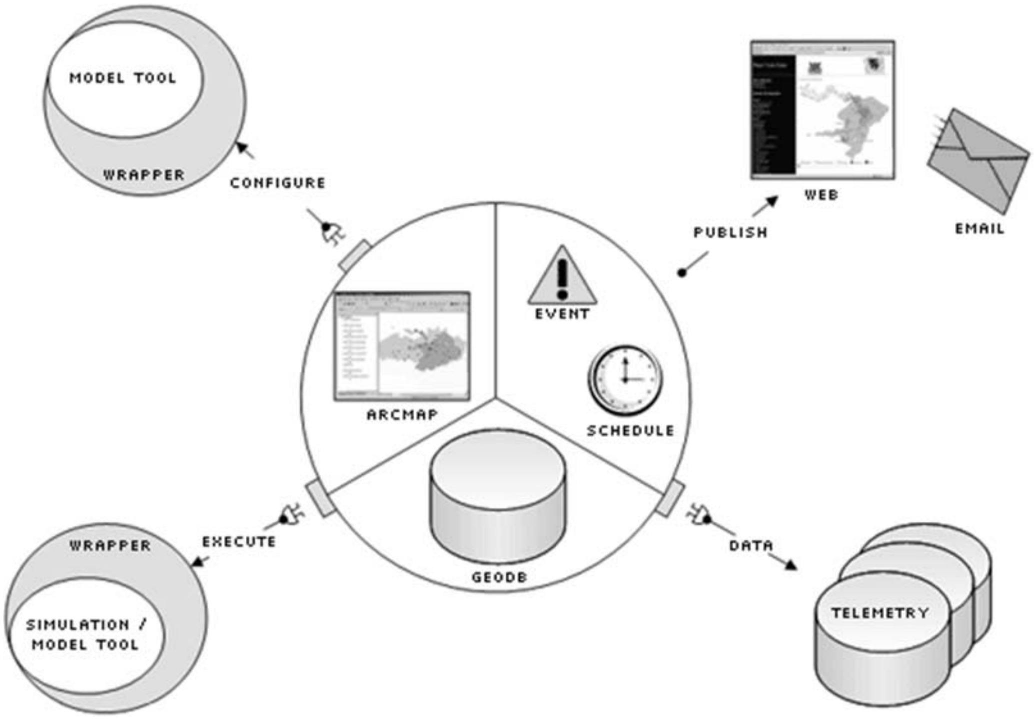

Figure 2: The overall structure of the MIKE FLOODWATCH system used in the Big Cypress basin real time modelling system

FLOODWATCH is linked to SFWMD's electronic Water Management System (WMS), which includes: (1) field systems for remote monitoring and control; (2) communications systems that route data through satellite, radio, microwave, and local networking equipment; (3) distributed real-time supervisory control and data acquisition (SCADA) systems, which present graphical information to managers and technicians for remote control of major gates and pumps; and (4) information-management systems for data-quality assurance, historical storage and retrieval, and other value-added processing.

Overall, the District’s WMS comprises more than 1,200 remote sites (distributed over almost 52,000 km^2) for electronic monitoring and control, with about 10,000 measurements continuously processed in real or near-real time. For the BCB project a subset of these measurements, about 180 in the modelling area, is combined with other measurements from the United States Geological Survey (USGS), which are down-linked by the SFWMD’s satellite ground station in West Palm Beach, and automatically transferred directly to the FLOODWATCH database in Ft. Meyers as soon as new data are received.

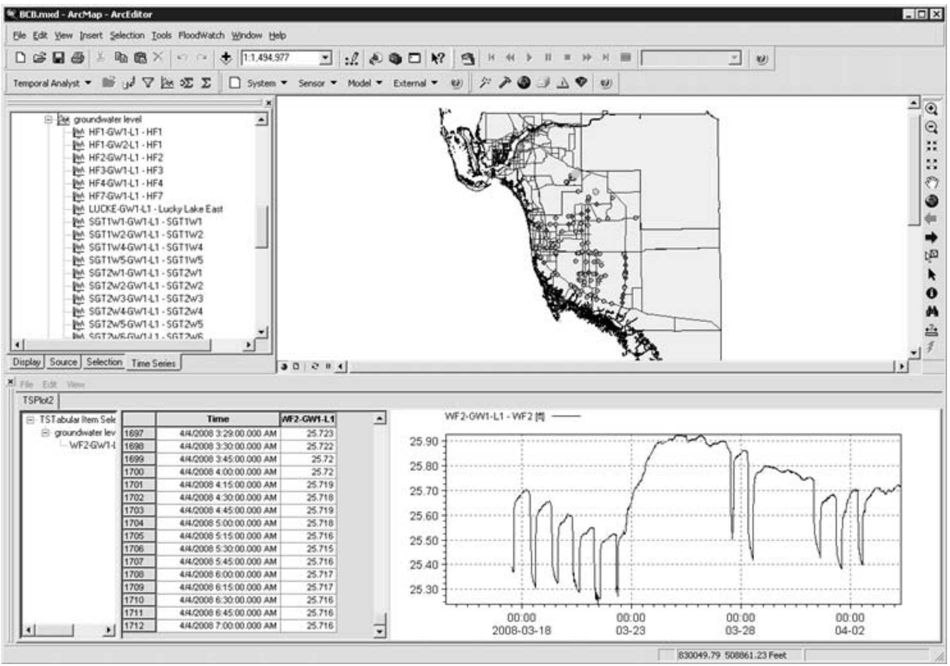

Figure 3: Examples of the GIS interface showing spatial data, plots and tabulation s for a groundwater monitoring point

The decision support system encompasses meteorological and hydrological monitoring of the surface water and ground water, hydrological forecasting of both surface water and groundwater, flood warning and real-time decision-making including operation of the various gates controlling flow and water level within the channels. Real-time hydrological forecasting systems like the BCB system, which link weather forecasts, the state of the river catchment, river discharges and water levels, can be used to respond to floods and droughts as they occur and to reduce their costs in terms of lives, property, the breakdown of infrastructure and the impacts on the ecological system. In comparison to construction of major flood protection works such as dams, dikes and polders, hydrological forecasting is cost effective and the environmental impacts are minimal.

To be effective hydrological forecasting systems should provide appropriate decision information in a timely manner to those who need it, where they need it, in a manner that is easy to understand. To achieve this, the Big Cypress Basin hydrological modelling system provides comprehensive GIS and Web interfaces for the configuration and operation of the system, (Figure 3). Furthermore, together with the operational staff within the Big Cypress Basin, a series of tailored web sites has been developed that provides both monitoring data and forecasts available to SFWMD staff over a wide geographical area. The forecasts of flooded areas and depths across the basin are made available after each forecast, (Figure 4). In addition, web displays that can use Google Earth provide both comprehensive monitoring information and a powerful geographical tool for data presentation and interpretation, (Figure 5).

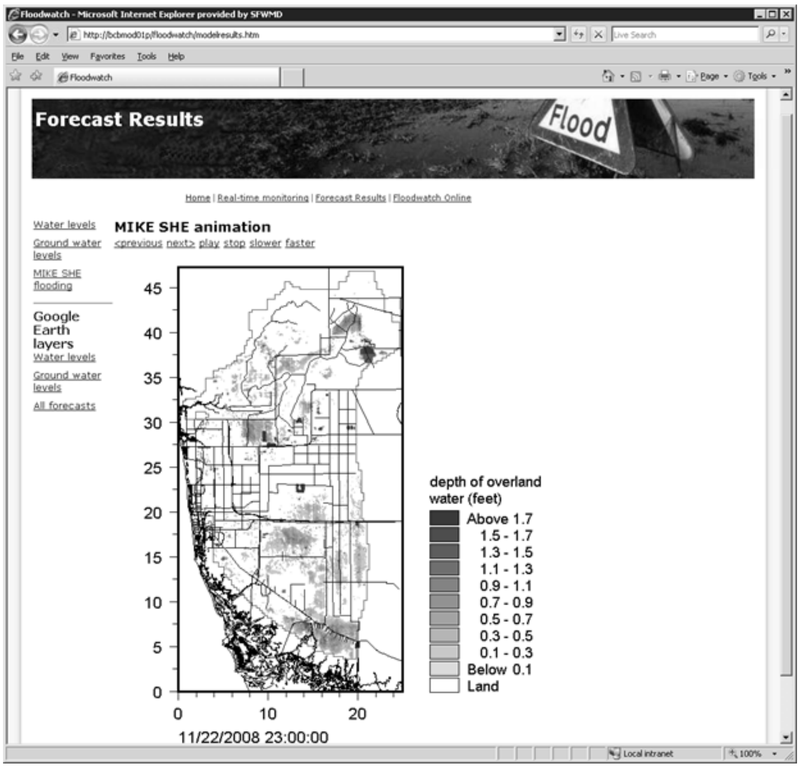

Figure 4: Flooded areas and depths across the basin are available via tailored web pages to the BCB operational staff

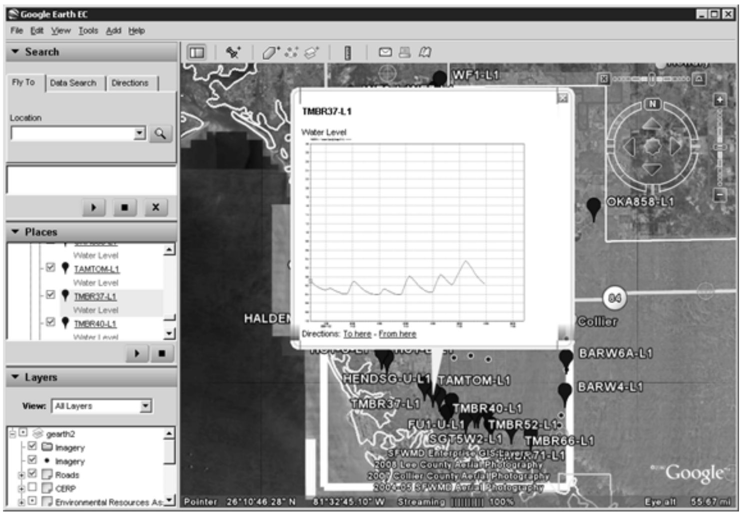

Figure 5: Displays for forecast and monitoring information using Google Earth

REAL TIME MODEL OF THE BIG CYPRESS BASIN

The forecast modelling is carried out using an integrated surface water-groundwater model, MIKE SHE. MIKE SHE is an advanced, flexible framework for hydrologic modelling (Butts et al., 2004, Graham & Butts 2006). MIKE SHE covers the major processes in the hydrological cycle and includes process models for evapotranspiration, overland flow, unsaturated flow, groundwater flow, and channel flow and their interactions. MIKE SHE can be characterised as a deterministic, physically-based, distributed model code. It simulates water flow, water quality and sediment transport, Storm and Refsgaard, 1996. The general river modelling package MIKE 11 is an integral part of the MIKE SHE framework. MIKE 11 provides comprehensive facilities for modelling, complex natural and artificial channel networks, lakes and reservoirs and river structures such as gates, sluices, weirs, locks, etc.

MIKE SHE/MIKE 11 is well-suited for hydrological modelling within the Big Cypress Basin because it can describe both the surface water and ground water processes and the two-way aquifer-river exchange essential for describing the water balance and for water supply assessment. The surface flows arising from both surface water and groundwater flooding are represented and therefore also the flow behaviour of wetlands. MIKE SHE is also is able to represent impacts on the wetlands and water quality in this interconnected system. In such a highly managed river system accurate representations of especially the operation of structures are critical for producing accurate simulations and forecasts. The suitability of MIKE SHE for modelling within South Florida has been confirmed by independent reviews (US Army Corp et al., 2002) and MIKE SHE has been widely used across South Florida (Butts & Graham, 2008).

The BCB forecasting model was developed by adapting an existing MIKE SHE/MIKE11 model of the area, most recently applied in the Picayune Strand Restoration Project (PSRP). The adaptation of the PSRP MIKE SHE/MIKE11 model involved modifying the model to address local and specific flooding concerns and to reduce computation time. In particular, the PSRP Strand model was developed and calibrated as a water resources model rather than a real-time forecasting model. As the requirements for an operational forecasting (real-time) model are different from those for a traditional simulation model, a number of modifications to this model were made. The most important modifications made to the PSRP model during this project are summarised below:

- The model area was reduced and the grid resolution was modified from 1500 feet to 500 feet
- Additional structures have been incorporated in the model
- The geometry and operation have been updated in some structures
- The land use description has been updated to reflect the latest available (2004) data
- The model input has been modified to use real-time rain gauge network
- Adjustments in the calibration were made to improve the transient behaviour of the hydrological model
- Real-time updating (data assimilation) was implemented to improve forecast accuracy

The data assimilation module is based on a new and efficient technique (Madsen & Skotner, 2005) for updating discharges and water level in the river and channel system.

TROPICAL STORM FAY (2008)

To evaluate the performance of the forecast model during a significant flood event a detailed analysis of the Tropical Storm Fay has been carried out. Tropical storm Fay, the sixth tropical storm of the 2008 Atlantic hurricane season, made landfall on the Florida Keys late in the afternoon of August 18. The storm failed to reach hurricane levels, remaining a tropical storm but traversed Florida over a period of seven days from August 18-24 and resulted in substantial rainfall across Florida. To evaluate the forecast model during Fay a sequence of 4 forecasts is shown in each case. In its' current configuration the BCB system makes water level forecast 48 hours ahead. Each forecast simulation is split into two periods, the hindcast period and the forecast period, see Figure 6.

During the hindcast period, observations of the actual water levels are used to correct any discrepancies between the water levels simulated by the model in the river and channel system and those that are measured at the same point. This correction is carried out using data assimilation or updating methods. In essence, data assimilation adjusts the level (and volume) of water in the model river system to match the observations. During the forecast period, the estimated future behaviour of the water levels is simulated. Figure 6 shows the observed water levels for the Golden Gate Canal Wier #5 Tailwater station (GG5) during this event, together with 4 forecasts. This plot indicates reasonable forecasts can be expected around 12-18 hours ahead of the peak. This length of this period however depends on the location of the forecast point in the channel system and the location and distribution of rainfall which will vary from storm to storm.

Groundwater forecasting is only rarely carried out in operational systems. This is in part because groundwater levels are seldom measured in real-time and in part because changes in groundwater levels can be expected to occur over much longer time scales than changes in the river levels during a storm or flood event. This may not be the case in South Florida because of the close connection between the surface and ground waters in the upper layers. Figure 7 shows an example of a long term simulation of groundwater levels using different groundwater modelling including the operational model, which shows the best fit to the observations. The figure shows there is indeed quite rapid response in the groundwater at this location indicating a close connection between the surface water and groundwater systems.

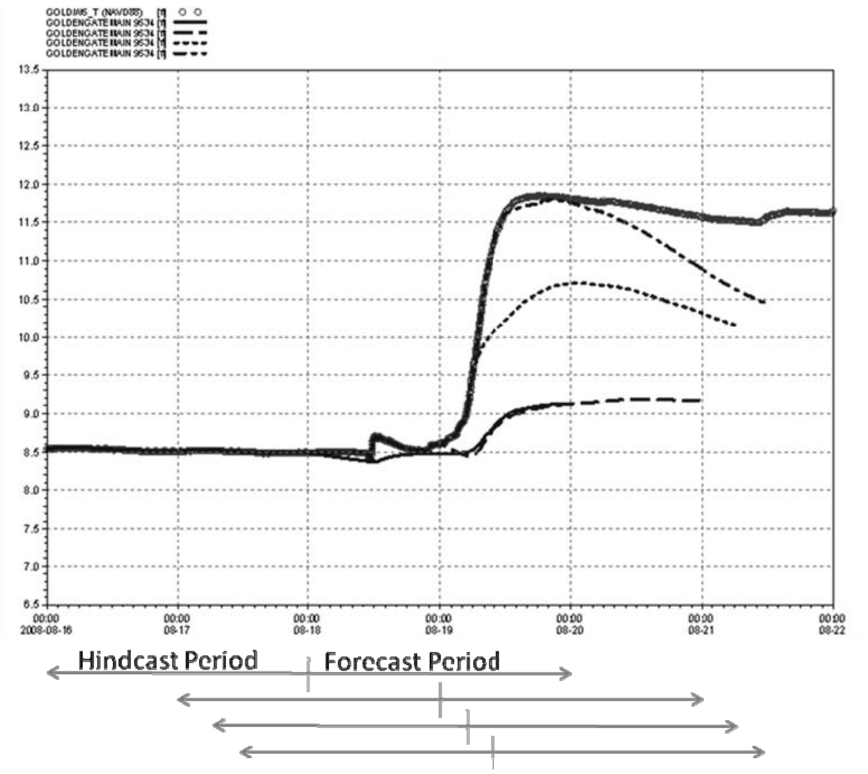

Figure 6: The observed water levels (symbols) and forecasted water levels (lines) for the sequence of 4 forecasts used to evaluate the model during tropical storm Fay

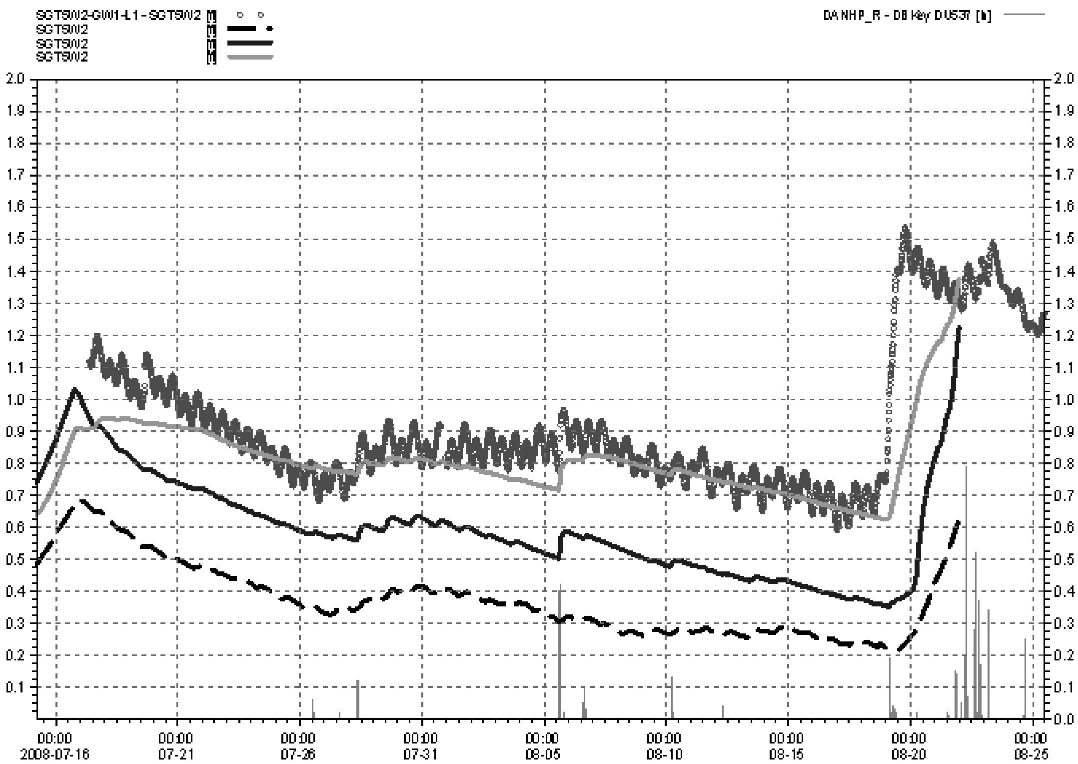

Figure 7: The observed groundwater (symbols), local rainfall (bars) and simulated groundwater levels using different groundwater models prior to and during the tropical storm Fay

CONCLUSIONS

A real-time surface water and groundwater modelling system developed for the Big Cypress Basin is presented. The main objective of this system was to integrate data management, monitoring facilities, forecast models and dissemination methodologies in a single system to facilitate flood control operational decisions. However this system is a major step towards the operational management, in real-time, of all aspects of water resources and water quality within a hydrological basin. The Big Cypress Basin includes 272 km of primary canals and 46 water control structures throughout the area that provide limited levels of flood protection, as well as water supply and environmental quality management. The real-time system was developed using the MIKE FLOODWATCH real-time decision support system. MIKE FLOODWATCH is linked to the South Florida Water Management District's extensive Water Management System (WMS) for data acquisition and processing. Novel aspects of this system include a new filter-based updating approach for accurately forecasting river levels and a fully integrated real-time modelling approach to represent the close interaction between surface- and groundwater systems in the Big Cypress Basin. This was achieved using the MIKE SHE modelling framework and forecasts of both surface and groundwater levels are made.

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