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Simulation of integrated surface-water/groundwater flow for a freshwater wetland in Selangor State, Malaysia

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Abstract— This study aimed at modelling the hydrologic processes of Paya Indah wetlands (PIW). The model includes surface water inflows and outflows, daily rainfall, potential evapotranspiration (ET), and groundwater seepage. An integrated surface water/groundwater systems approach was developed using MIKE SHE software. At this stage of PIW modelling process we calibrated surface water level and groundwater head levels to the extent that permitted by the available data. The model was simulated for both dry and wet seasons. The multi-criteria results reveal that the model performance is satisfactory.

Keywords: MIKE SHE modeling system, Paya Indah, rainfall, evapotranspiration, overland flow

INTRODUCTION

Understanding hydrologic processes of wetlands is a fundamental key in their effective ecosystem restoration and creation (Zhang & Mitsch, 2005). It is well recognized that shallow lakes and wetland systems are almost invariably connected hydraulically to the surrounding unconfined aquifer systems. The interaction between such surface waters and the surrounding groundwater regime has important implications for the effective protection and management of the high environmental values usually attached to lake and wetland habitats (Marimuthu *et al.*, 2005). Application of integrated surface water-groundwater models in support of water supply planning, basin water management, sustainability of natural resources and ecosystem management, and preservation is a common practice in the fields of water resources and environmental engineering (Hosseinipour, 2005).

STUDY SITE

Paya Indah Wetlands (PIW) which covers an area of about 242 km^2 is located in the Kuala Langat District in Selangor state (Figure 1). It consists of degraded ex-tin mining land including lakes and peat swamp forest. It portrays Malaysia's commitment to preserving and the wise use of wetlands (Haniba *et al.,* 2002; Paya Indah Wetland, 2005). The area is characterized by a uniform temperature, high humidity, light wind and copious rainfall. Geologically, the study area is covered by alluvial sediments of peat, clays and silts and unconsolidated deposits in the low-lying areas. These deposits overlay metasedimentary rocks of the Kuala Lumpur Limestone and the Kenny Hill Formation (Gobbett, 1973; MGD, 2002). Recently PIW has undergone dropping of water level of most of the lakes to extent of dry-up of two lakes. This paper summarizes the built-up steps and calibration results of the integrated surface water (SW) and groundwater (GW) model for the PIW.

MATERIALS AND METHODS

MIKE SHE is a distributed physically based modelling system capable of describing the entire land phase of the hydrological cycle over the model area. The model area is discretized by two analogous horizontal-grid square networks for SW and GW flow components. A finite difference solution of the partial differential equations, describing the processes of overland and channel flow, unsaturated and saturated flow, interception and evapotranspiration, is used for water movement modelling.

MIKE SHE Modelling Code

The 1-D and 2-D diffusive wave Saint Venant equations describe channel and overland flow, respectively. The Kristensen and Jensen methods (Kristensen & Jensen, 1975) are used for evapotranspiration, the 1-D Richards's equation (Richards, 1931) for unsaturated zone flow, and a 3-D Boussinesq equation (Boussinesq, 1904) for saturated zone flow. These partial differential equations are solved by finite difference methods, while other methods (interception/evapotranspiration and snowmelt) in the model are empirical equations obtained from independent experimental research.

Model Development

Discretization

The PIW model uses Selangor Cassini coordinates in metric units. The area is divided into number of computational cells (200 x 200 m) for the numerical solution of the governing equations of water movement (Figure 2). Ground surface elevation is used by the overland flow model and as a reference level for the unsaturated and saturated zone models.

Surface topographic information was obtained via two sources: digitized topographic maps (20 m contour interval) and detailed topographic surveys in Cyberjaya.

Meteorological input

Rainfall data were obtained from Malaysia Meteorological Department (MMD) and Drainage and Irrigation Department of Malaysia (DID). Accumulated daily rainfall was counted for four stations within or close to the catchment using a Thiessen polygon (Figure 3 and Table 1). Potential evapotranspiration was calculated using the Penman method (Penman, 1948) which requires daily minimum and maximum temperature, relative humidity, wind speed and percentage cloud cover. These data were obtained from the KLIA meteorological station. Leaf area index and root mass distribution were retrieved from the landuse map for 2006. Figure 4 shows meteorological inputs.

Unsaturated Zone Input

Peat represents the key-interest of this study since it is the predominant type of soil within the catchment. Other soil types include Minded Land soil association (Sandy clay), Selangor-Kangkung series (alluvial sediments), Perang series (clay loam), Serdang-Bungor-Munchong series (clay loam), and some sedimentary rock outcrops (Figure 5). A total of ten random locations were chosen for each soil type for *in-situ* measurements and disturbed soil sampling for hydraulic properties tests.

Surface water model

The overland flow process is simulated in each grid square by solving the two-dimensional diffusive wave approximation of the Saint-Venant equations. For stream network canal flow (Figure 6), the one-dimensional form of the equation is solved in a separate node system located along boundaries of the grid squares. Required input data for the MIKE11 model consists of branch network, cross-sections, Manning's M (roughness coefficient), control structure geometry and operation schedules (if any).

Geological Model

Based on the hydrogeological investigation carried out by the current study as well as previous studies (Bahaa-eldin *et al.,* 2008; MGD, 2002), the PIW model could be divided into three layers with distinct different hydraulic properties based on the available geological information (Figure 7).

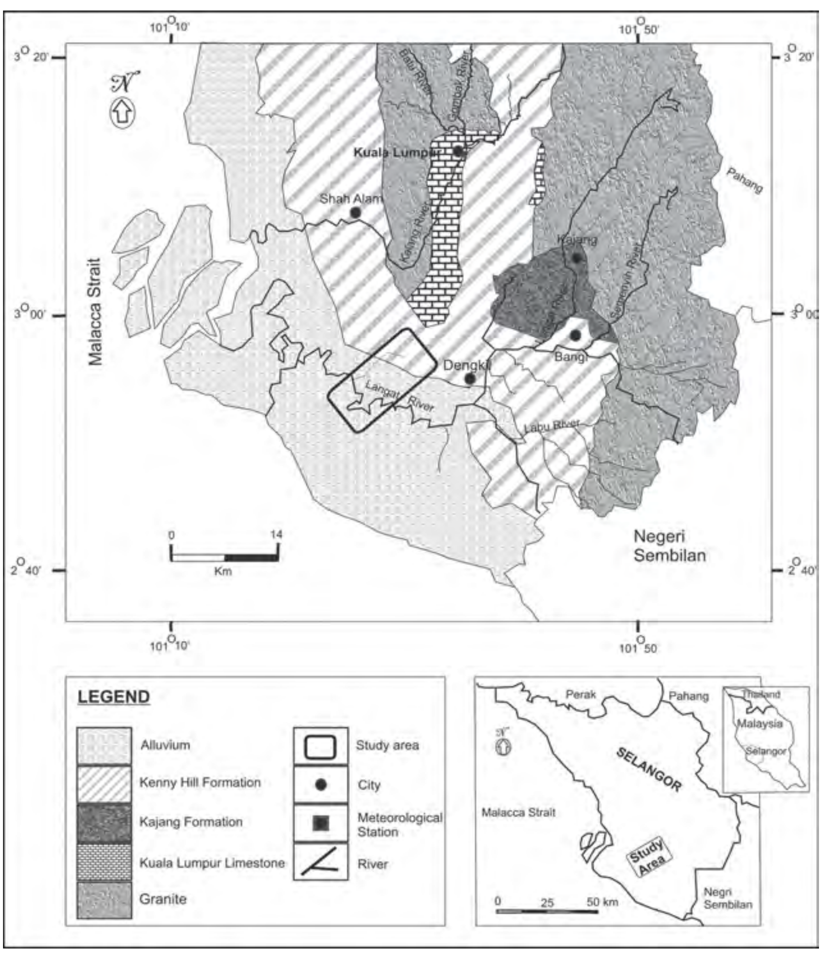

Figure 1: Location and geological map of the study area (modified after GSD, 1985).

Table 1: Rainfall area weighted factors for the PIW*.

Station	**Weighted Factor** (%100)
Sungai Manggis	40.10
Bukit Cheeding	36.17
Perang Besar	20.78
KLIA	2.95

* Area: 242.21 km^2

Table 2: Multi-criteria assessment for the simulated data.

Statistic	BH1	BH3	SWL1 (Inlet)	SWL2 (Outlet)	Main Lake	Lotus Lake
Mean Error (ME)	0.052	0.002	0.066	-0.002	0.002	0.044
Mean Average Error (MAE)	0.144	0.073	0.167	0.170	0.041	0.124
Root of Mean Square Error (RMSE)	0.180	0.091	0.166	0.205	0.052	0.149
Standardized Residuals (STDres)	0.172	0.091	0.207	0.205	0.052	0.142
Coefficient of Correlation (R)	0.824	0.866	0.848	0.458	0.755	0.645

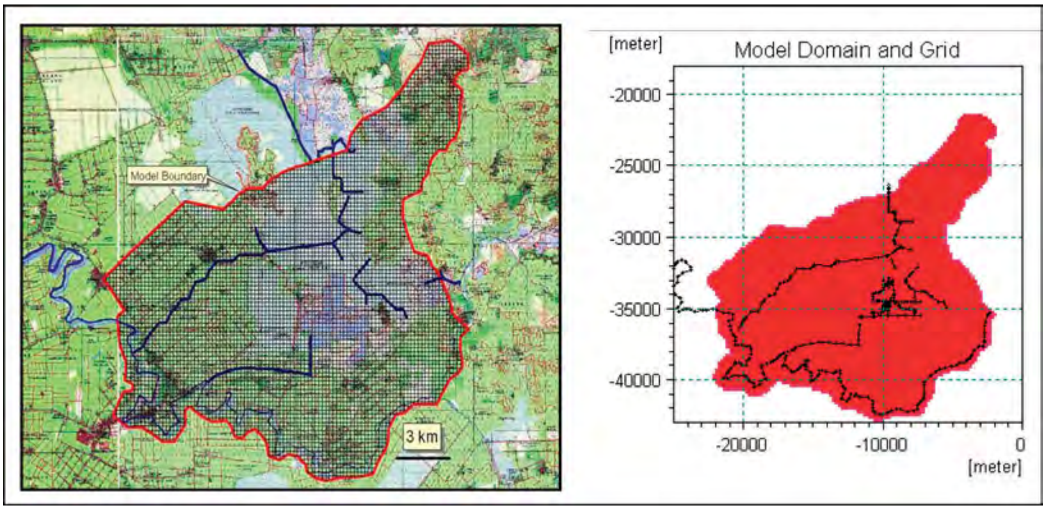

Figure 2: Model domain and computational mesh.

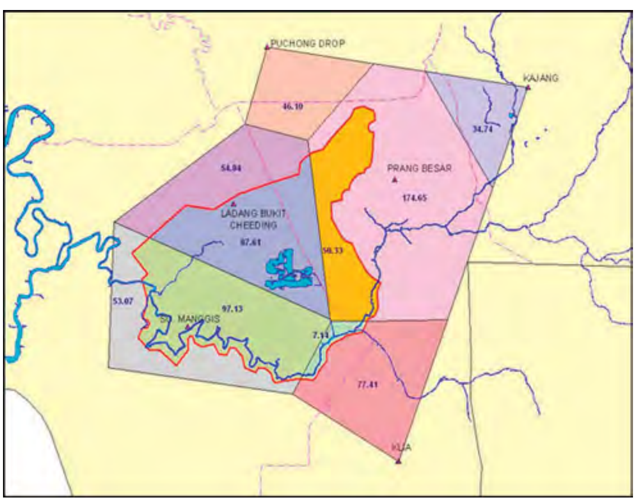

Figure 3: Estimated rainfall fields for PIW using Thiessen-polygon method.

These include:

Layer 1: peat/peaty clay (~5-8 m thick).

Layer 2: silty clay/sandy clay – aquitard (~20 m thick).

Layer 3: silty sand/ silty gravel – aquifer (~30 - 60m thick).

RESULTS AND DISCUSSION

In terms of water balance the ability of the model to simulate both wet and dry period conditions is required. However at this stage of modelling process, the model

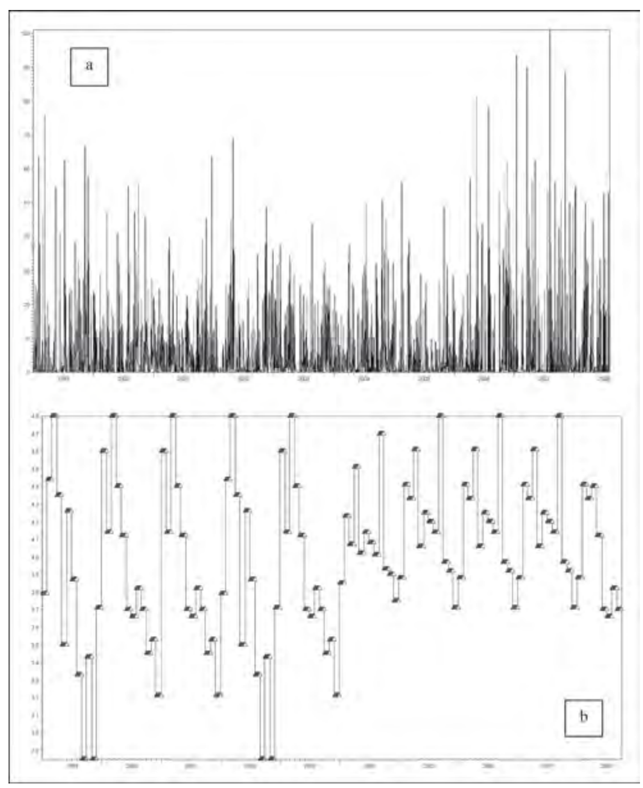

Figure 4: Meteorological inputs for PIW. (a) Daily rainfall (b) Reference ET.

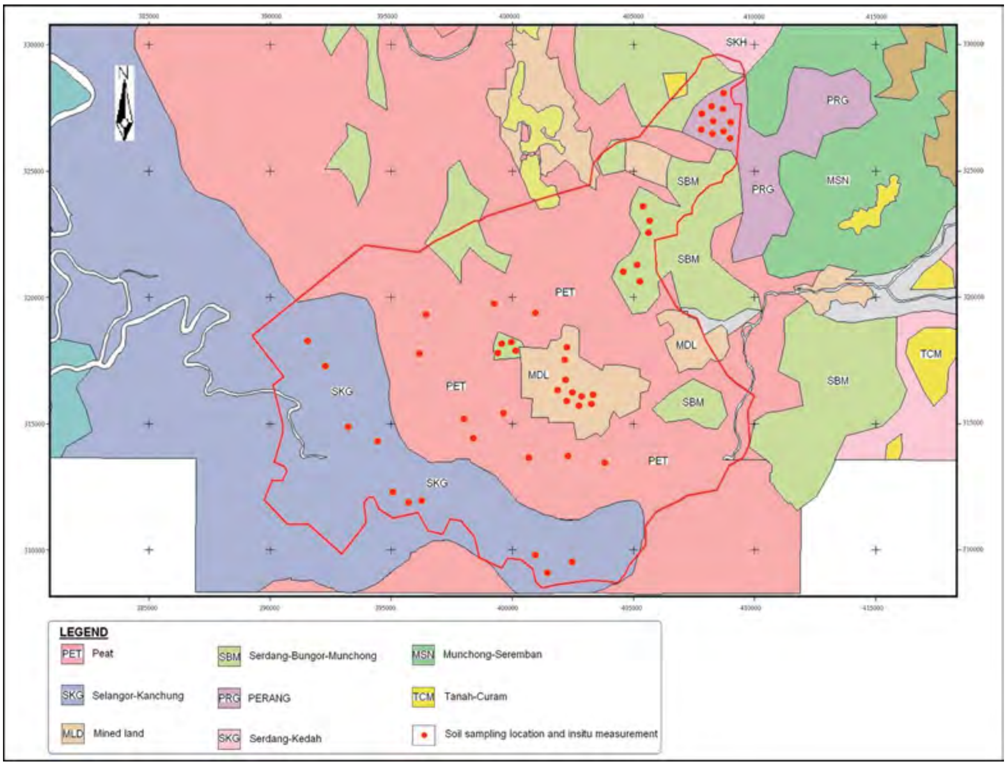

Figure 5: Soil types and locations of sampling and in-situ measurements.

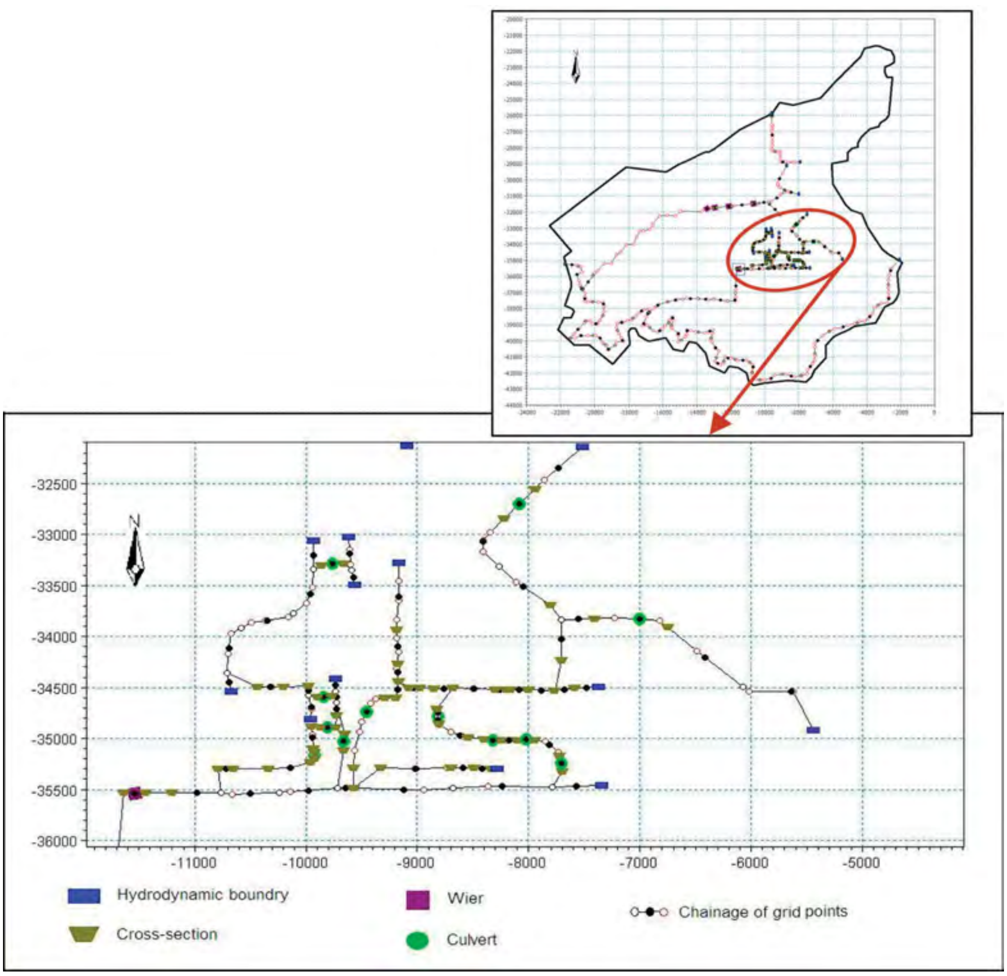

Figure 6: Modelled lakes and canals network of PIW.

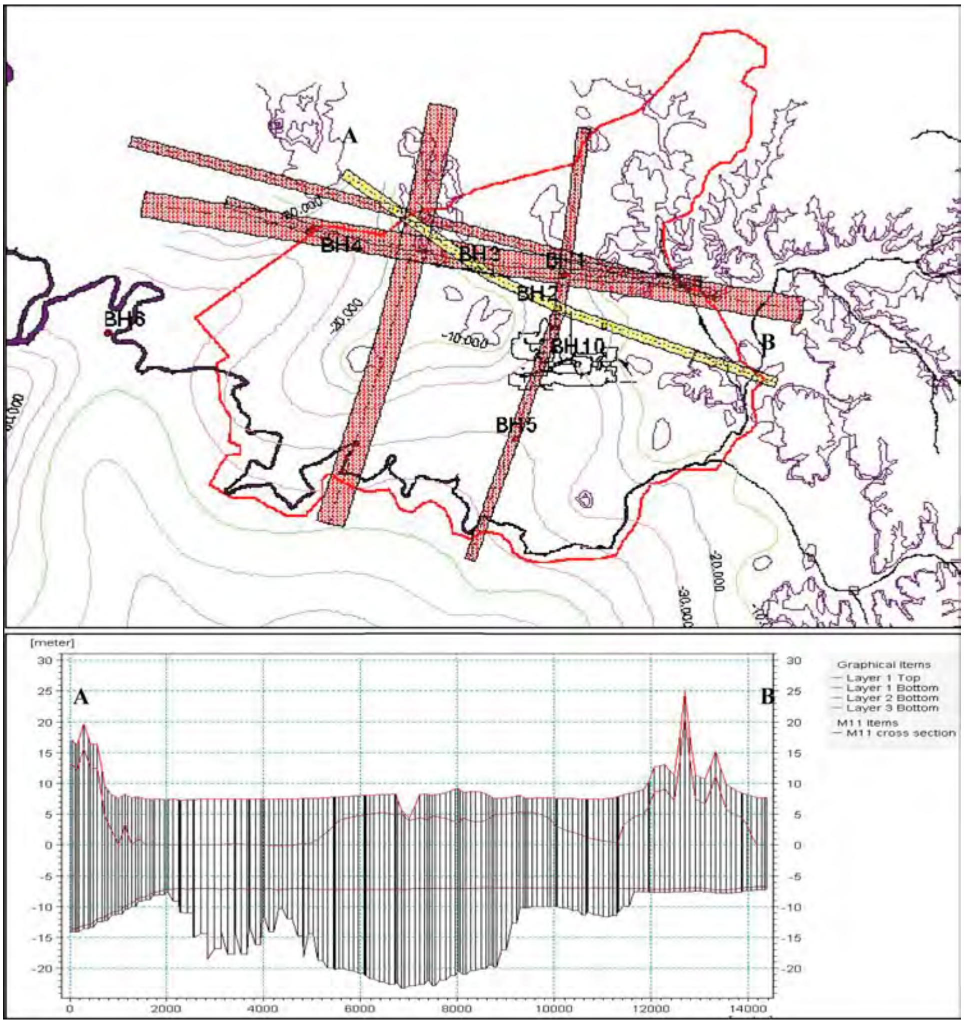

Figure 7: Presentation of a geological cross-section across the catchment.

was calibrated in two stages including SW level and GW head. The calibration period extended from July 1st, 1999 to October 31st, 2004. This period was chosen because of availability of SW and GW observation data. Discontinuity in observation data as shown in some hydrographs represents some missing data due to some reading errors associated with the measuring devices. Interpolation process was eliminated due to an occurrence of a remarkable discrepancy between observed and simulated values. Aquifer hydraulic properties, infiltration, ET, and OL were the main factors that controlled the calibration process for the PIW. The SW level and GW head were calibrated at twelve and eight locations respectively; in which observed data and model-simulated values were matched. Figure 8 shows selective calibrated hydrographs for Gw head (Figures 8a and 8b) and SW level (Figures 8c to 8f). The multi-criteria assessment indicates that the simulation accuracy characterized by good statistics where the coeficient of correlation (R) is greater than 0.75 and root of mean square error (RMSE) is close to 0 (Table 2). However anomalous statistics that measured at Louts Lake (Figure 8c) and SWL2 (Figure 8f) are associated mainly to unscheduled flow operations that took place at the control gate of SWL2.

CONCLUSION

Integrated SW and GW physically distributed models of Paya Indah Wetlands catchment were set up and successfully coupled using the advantage of MIKE SHE modelling system. The simulation of both surface water level and groundwater head provided a quite good visual description of the hydrodynamic interaction at PIW. The model was calibrated against SW level and GW head. Both visual judgment and overall statistical evaluation show that the model performs satisfactorily.

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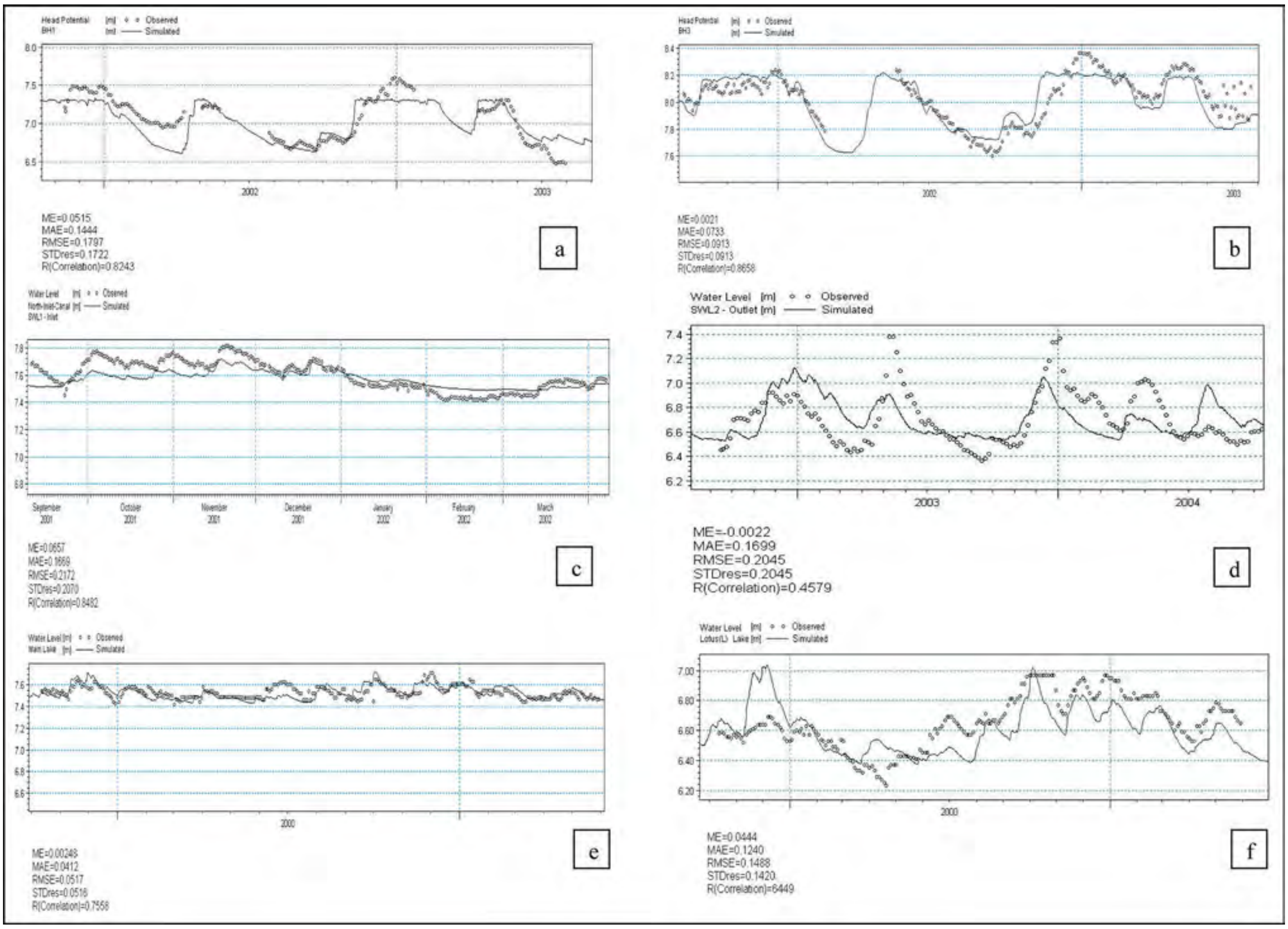

Figure 8: Calibration of GW and SW level at: (a) BH1, (b) BH3, (c) SWL1, (d) SWL2, (e) Main Lake (uppermost lake), (f) Lotus Lake (lowest lake).

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