CHAPTER V

MODEL CALIBRATION AND VALIDATION

The current integrated hydrological model covers the sub-basin of Paya Indah fresh water lakes and Kuala Langat Swamp Forest and their surroundings which are part of the regional Langat River Basin. It is an integrated model including a suite of model components simulating the flow on overland and in river/canals, flow in the unsaturated and saturated zone, evapotranspiration losses to the atmosphere and an extension to describe the water balance and its distribution.

The conjunctive use of surface water and groundwater requires a resource assessment including both surface and subsurface domains. The calibration has consequently been aimed at obtaining a satisfactory agreement for the simulated and observed groundwater heads, surface water level and open-channel flow within the catchment.

Discontinuity in observation data as shown in some hydrographs of this thesis represent 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. Following the calibration and validation of the model, a sensitivity analysis was carried out to test how the model responds to variation of certain parameters or input data.

5.1 CALIBRATION

The calibration process is primarily aiming at obtaining a set of model parameters, which provide a satisfactory agreement between model results and field observations considering the fact that calibration of distributed parameters is a complicated procedure.

In general there are mainly three categories of parameters that control the accuracy of calibration process. These include: (1) the saturated hydraulic conductivity and the specific yield of the aquifer of groundwater model and the model for water exchange between aquifers and channels, (2) the infiltration and evapotranspiration rates which are used in the 2-layer water balance of unsaturated zone model, and (3) the Manning roughness coefficient for overland grid cells and channel grid cells. The second group guarantees correct simulation of the water yield volume. Parameters of this group are multipliers to that are used in the infiltration and evapotranspiration models.

The Paya Indah wetland model was calibrated in three stages for the period of July 1st, 1999 to November 1st, 2004. This period was chosen because of availability of different historical observation data which were required to achieve the calibration targets.

5.1.1 Calibration targets

In terms of water balance the ability of the model to simulate both wet and dry period conditions is required. On the other hand problems of water table dropping in the shallow aquifer and subsequently surface water at the Kuala Langat swamp Forest of the Paya Indah hydrological system are only seen during dry period and associated with high water loss due to the evapotranspiration which implies that low flows periods should be subjected to special attention. The formulated calibration targets have been based on general criteria as well as been tailored to the specific purpose of the Paya Indah wetland model and the availability of field data. Subsequently, they should be seen as overall guidelines.

For the groundwater component of MIKE SHE, the objective first of all was a simulation of the groundwater head at eight boreholes distributed across the modelled catchment; in which observed data and simulation values were matched. This simulation helped in calibrating the hydrological properties of the geological layers, i.e. horizontal and vertical hydraulic conductivity. Furthermore, the range of potential head (maximum and minimum levels) should be represented; and the model, to the extent possible, should be able describe the full dynamics given limitations in input data.

The simulation water level of rivers and channels of the model were included as another calibration target. The calibration locations included the North-Inlet-Canal (SWL1), Lakes' system, and Lotus Lake Outlet (SWL2), in which all the simulated parameters matched over the observed data.

In order to evaluate the model predictive capability, simulation of open-channel flow was adopted for the inflow and outflow associated with the Paya Indah lakes system. The North-Channel-Inlet (SWL1) and Lotus-outlet (SWL2) were considered as calibration locations for inflow and outflow respectively.

5.1.2 Primary calibration parameters

The choice of calibration parameters was based on prior experience and a simple sensitivity analysis. The number of calibration parameters is a key issue in the calibration procedure and should be high enough to secure an optimal solution and full exploitation of the input data and model complexity, but low enough to avoid over-parameterization and non-uniqueness as well as excessive computation times (Refsgaard, 1997 “quoted” in Stisen et al., 2008). The hydrological regime and thus the water balance of the Paya Indah wetland are characterized by high rates of rainfall (2000 - 2300 mm/year) and evapotranspiration (pan evaporation of 1100 - 1300 mm/year). The evapotranspiration is the dominant factor of the water budget with or without considering artificial irrigation bearing in mind that the catchment of Paya Indah wetland is characterized by rain-fed farming. The infiltration capacity of the soils is high and the net rainfall seems to recharge the water table aquifer noticeable at the area between Lotus Lake and Langat River. The flow in the water table aquifer is in general directed towards the Langat River, unless there is no groundwater abstraction taking place at the Megasteel Company’s property then the groundwater would flow towards the discharging point. Due to the shallow groundwater table at peat layer (±1 m below ground surface) and furthermore occurrence of dense drainage and irrigation canals network, a partial hydraulic contact between surface water bodies and the upper aquifer sequence is more likely take place allowing lateral flow between the shallow groundwater and the canals.

5.2 CALIBRATION RESULTS

The simulation of both surface water level and groundwater table provide a quite good visual description of the hydrodynamic interaction at the modelled catchment of the Paya Indah Wetland. Based on a visual qualitative assessment, a satisfactory performance was attained at all the surface water and groundwater calibration points. However, noticeable biases between observed measurements and simulated values were encountered causing some overestimation as well as underestimation trends. Other than equipments errors, these biases were mainly attributed to the unscheduled lock operations and over-abstraction of groundwater that is carried out within the modelled catchment.

Distribution of different calibration locations were shown in Figures 1.3 and 4.21 for surface water stage and discharge, and groundwater heads respectively.

5.2.1 Simulation of surface water level

The Paya Indah Wetland model was calibrated against surface water level at twelve locations and the simulation results were shown in Figures 5.1-5.12. Results revealed that drought conditions have caused the water level to drop between 20cm – 60cm.

Good performance was obtained in nine calibration locations (Figures 5.1-5.9) in which agreement between observed and simulated water levels were matched, with a correlation (R) ≥0.75, during most of the calibration period. However, the observable overestimation or underestimation trends that occurred only during short-time intervals were attributed to the normal uncertainty associated with modelling; most possibly due to scaling problem.

On the other hand, some sharp overestimated fluctuations were simulated for the water level causing a considerable mismatching (0.45 ≥R≥ 0.65) between observed and simulated values. It seems that in order to maintain an appropriate water level for the lakes system during special events (e.g. storm and drought), the control gate at the Lotus-Outlet (SWL2) used to open and close as requirements for water release and reduced flow processes respectively depending upon the event. However, due to the absence of information on actual past control strategy (e.g. setting of gate opening, maximum rate change etc) and the exact operational schedules, the model could not represent such events accurately as shown in the calibrated water level hydrographs of the Lotus-Outlet (Figure 5.12) and the closest lakes including Chalet, Typha and Lotus Lakes (Figures 5.9, 5.10 and 5.11).

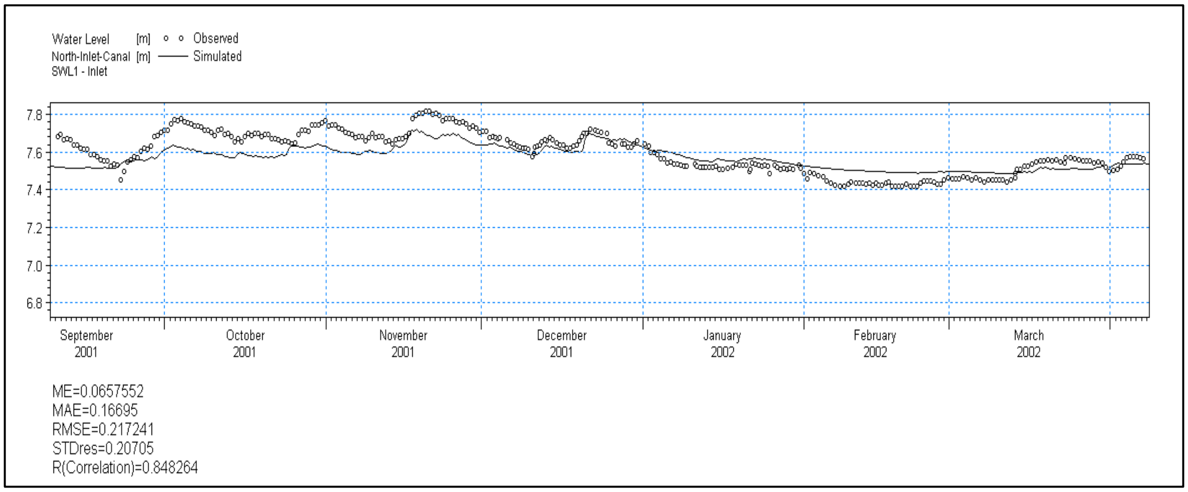


FIGURE 5.1
Calibrated Water Level Hydrograph for North-Inlet-Canal (SWL1)

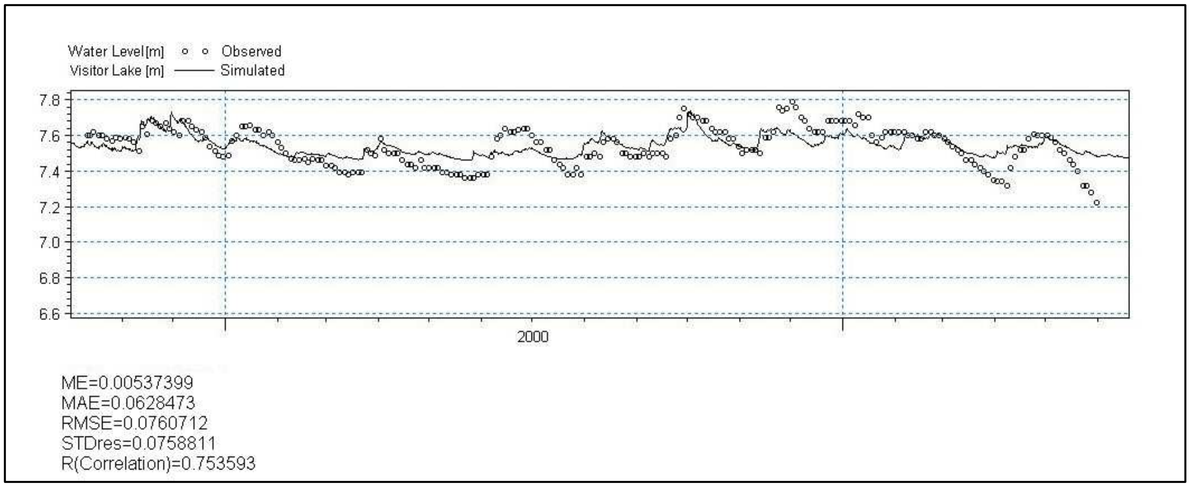


FIGURE 5.2
Calibrated Water Level Hydrograph for Visitor Lake

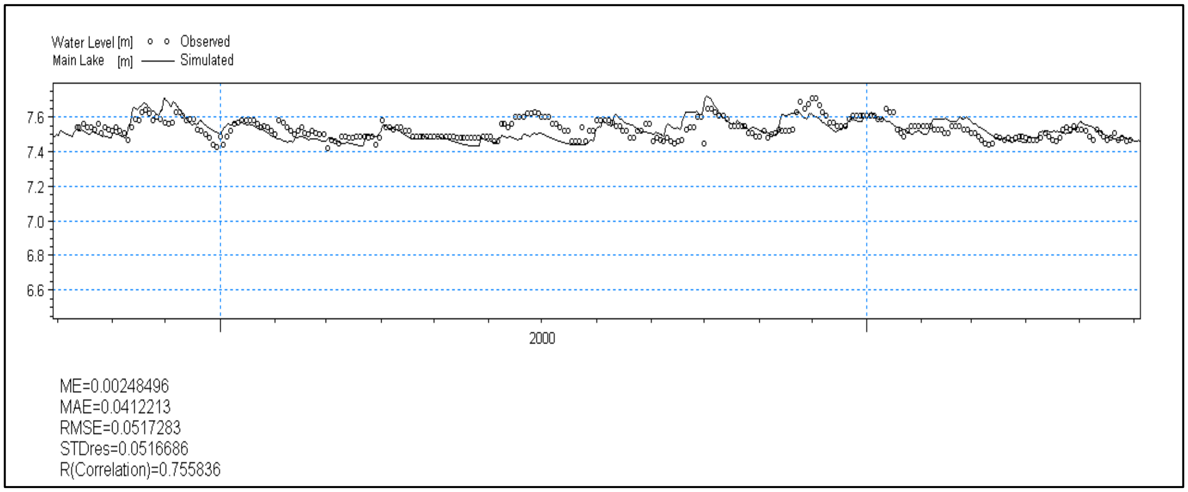


FIGURE 5.3
Calibrated Water Level Hydrograph for Main Lake

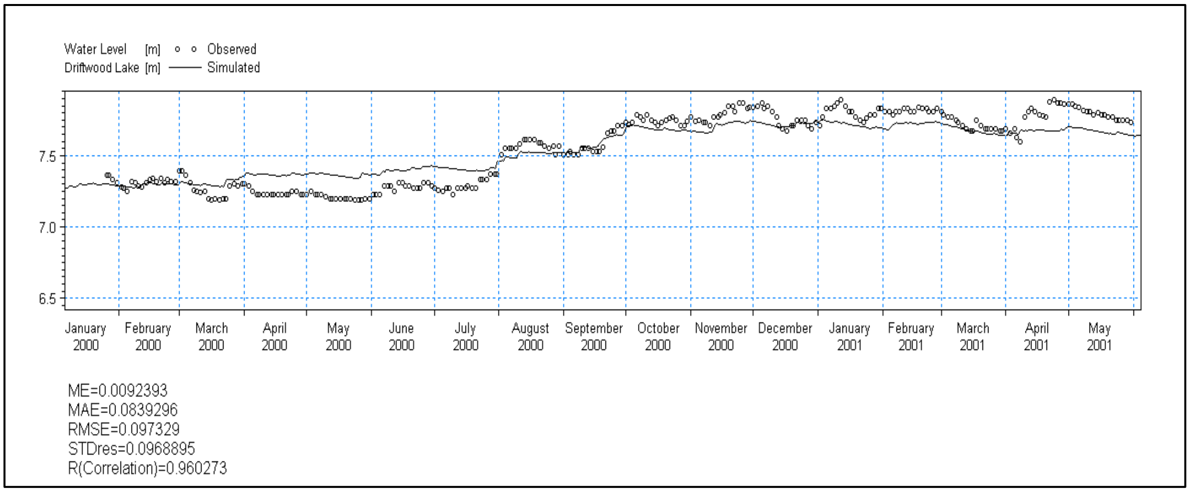


FIGURE 5.4
Calibrated Water Level Hydrograph for Driftwood Lake

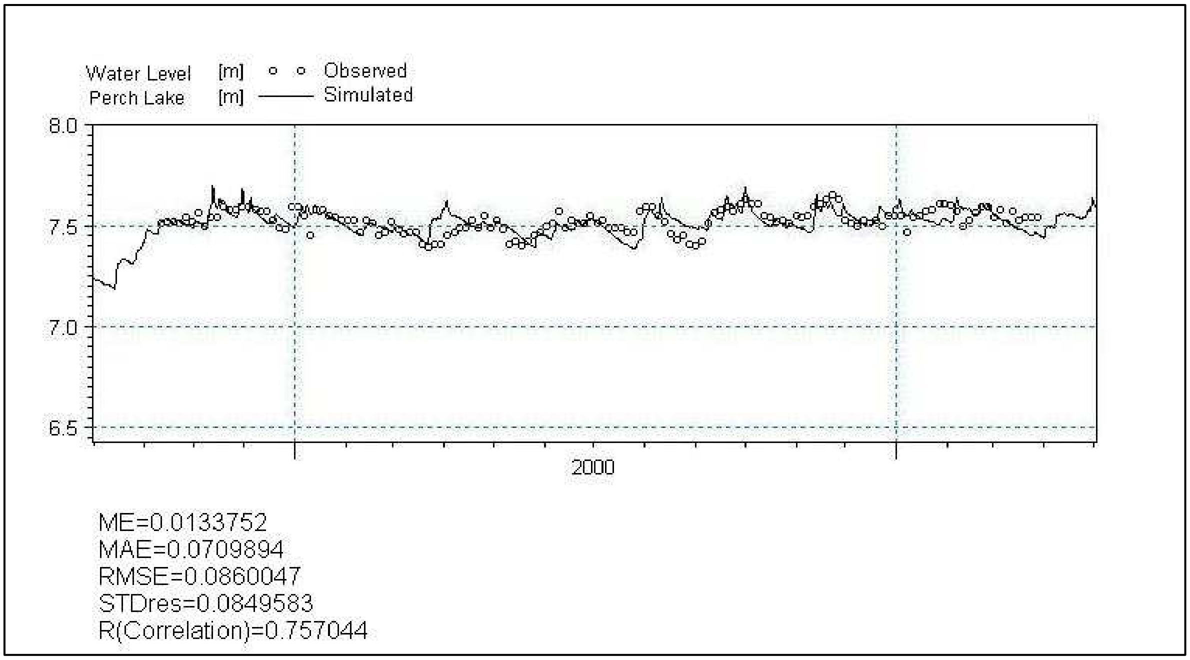


FIGURE 5.5
Calibrated Water Level Hydrograph for Perch Lake

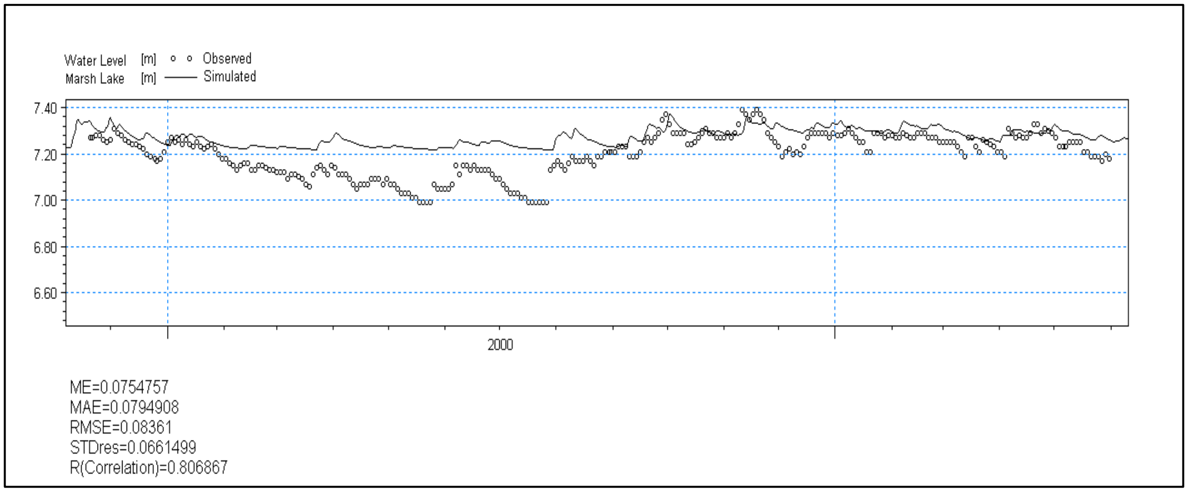


FIGURE 5.6
Calibrated Water Level Hydrograph for Marsh Lake

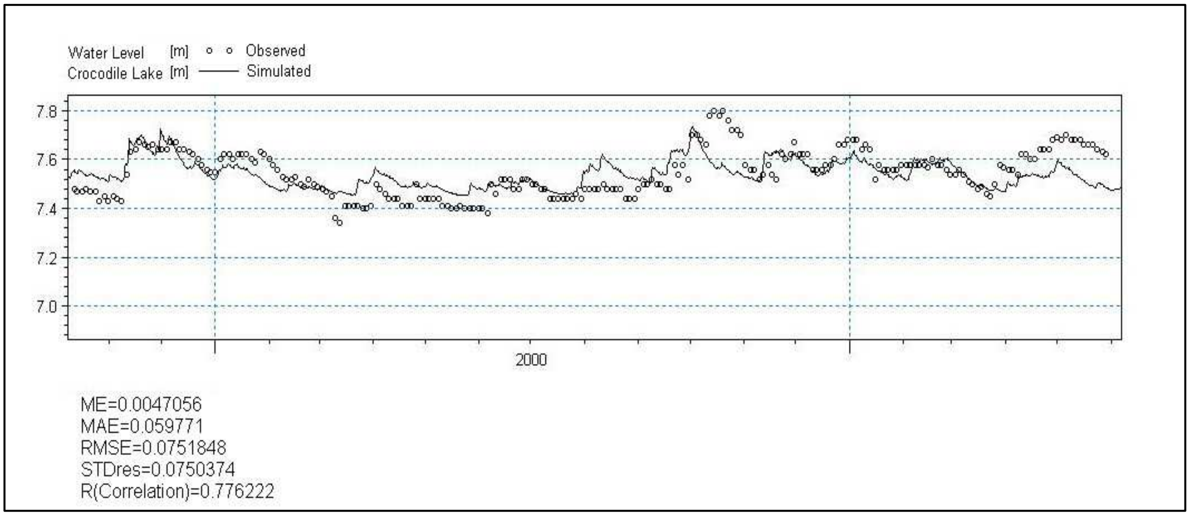


FIGURE 5.7
Calibrated Water Level Hydrograph for Crocodile Lake

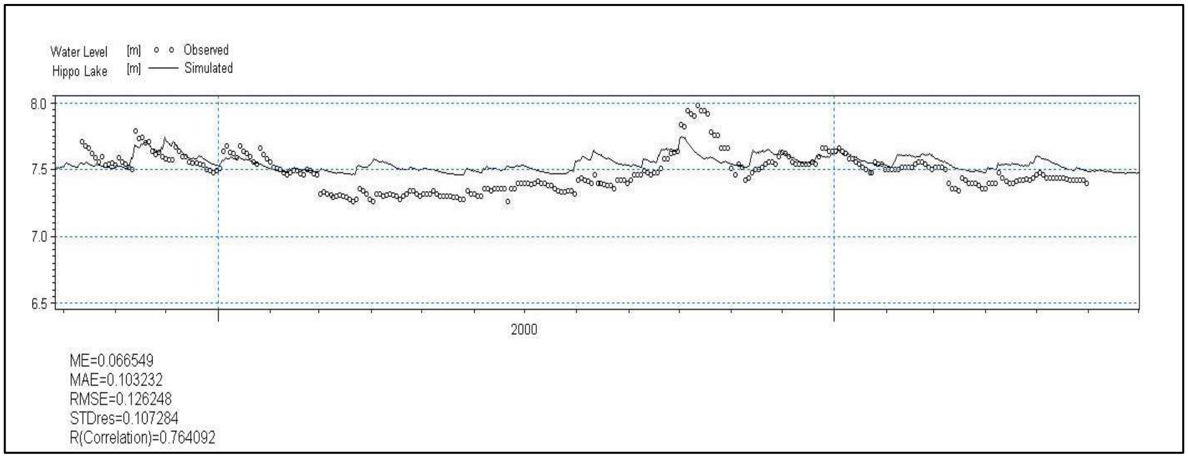


FIGURE 5.8
Calibrated Water Level Hydrograph for Hippo Lake

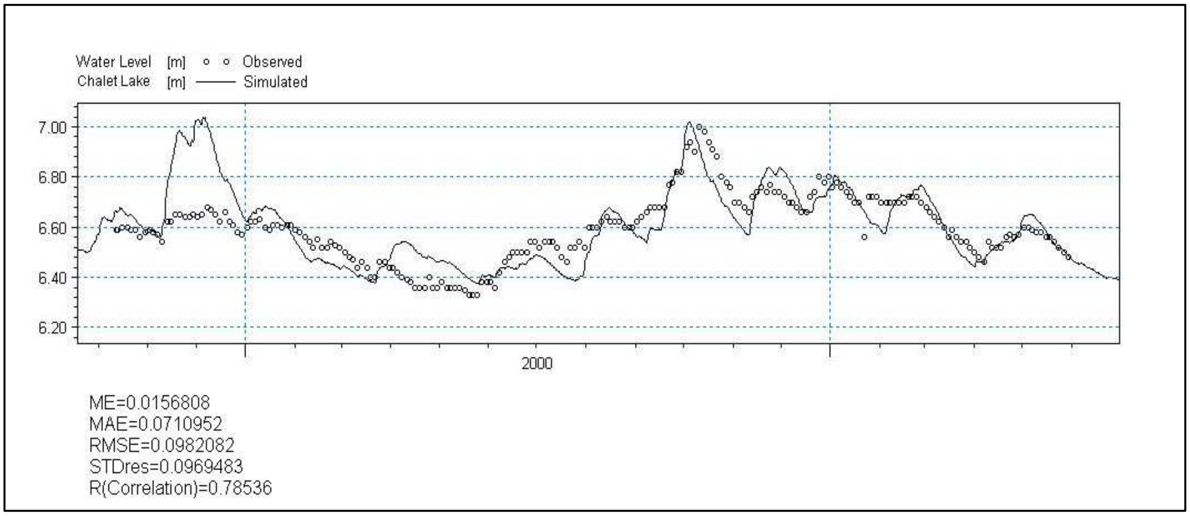


FIGURE 5.9
Calibrated Water Level Hydrograph for Chalet Lake

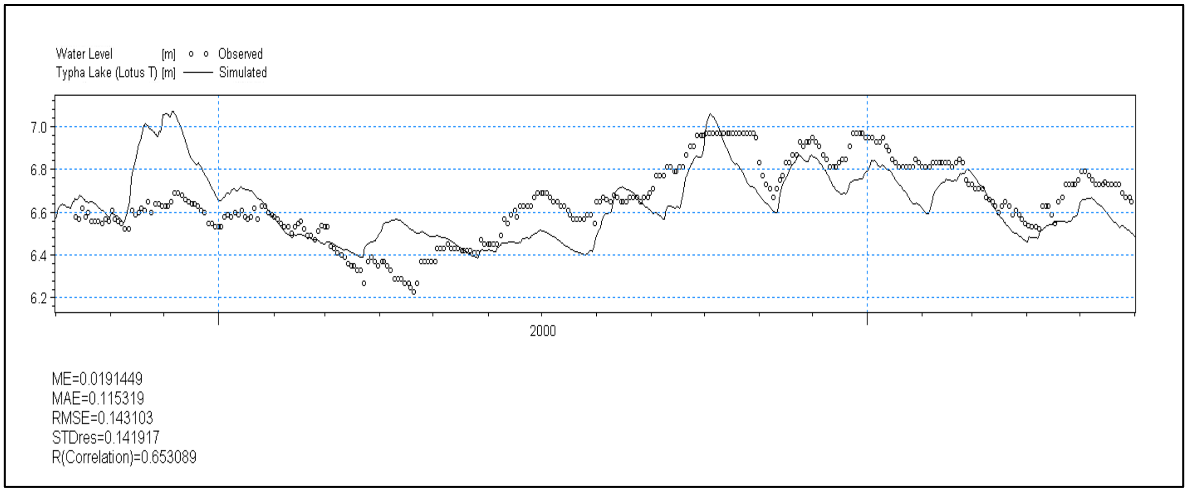


FIGURE 5.10
Calibrated Water Level Hydrograph for Typha Lake

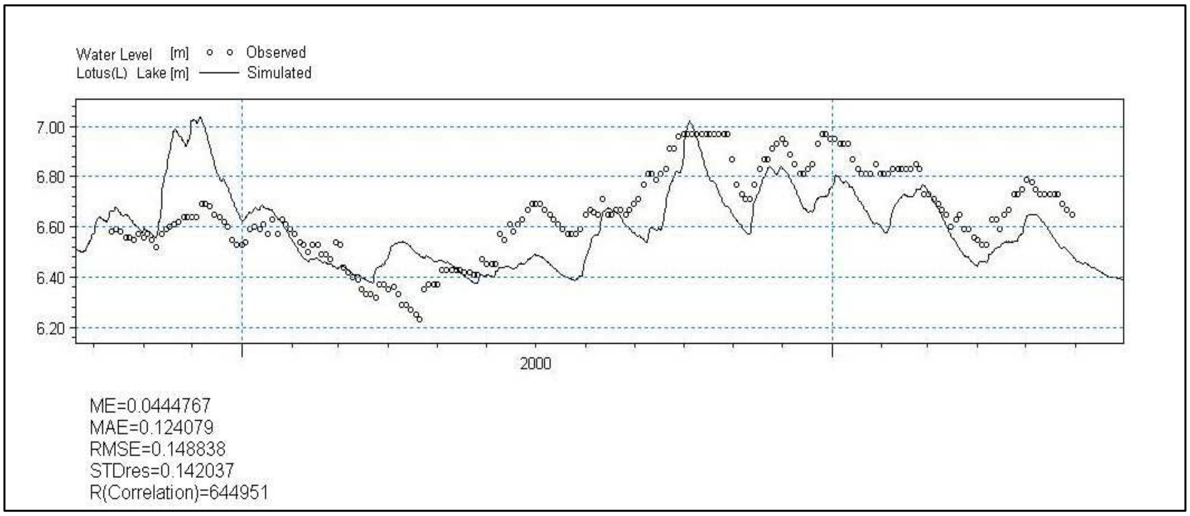


FIGURE 5.11
Calibrated Water Level Hydrograph for Lotus Lake

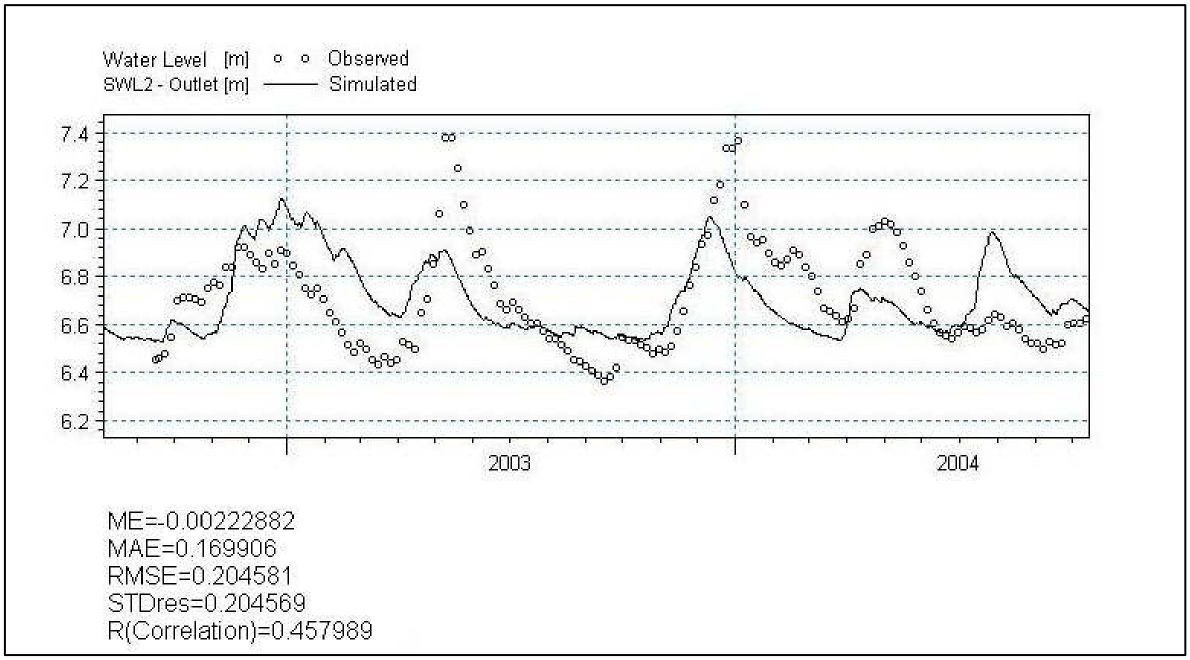


FIGURE 5.12
Calibrated Water Level Hydrograph for Lotus-Outlet (SWL2)

5.2.2 Simulated groundwater heads

Results for groundwater heads are shown in Figures 5.13-5.20. Based on a visual qualitative judgment of the overall calibrated hydrographs, five out of eight locations show a good agreement between simulated and observed groundwater heads in terms of fluctuations description. It found that the rise-and-fall patterns in the piezometers BH1, BH2 and BH3 (Figures 5.13 – 5.15) are much dynamic in the upland areas in the northern upper part of the modelled catchment compared to BH6, BH7 and BH8 (Figures 5.17 – 5.20) which show a gradual fluctuation. It seems that groundwater head in the upper part of the catchment rose and declined abruptly in response to the periodic flow exchange between saturated and unsaturated zones caused by seepage from overland flow and inflows from the surrounding Kuala Langat swamp forest. These fluctuations caused by the groundwater table across the modelled catchment to drop between 0.45 m to 0.65 m during dry season. In fact, while the measurements are point values, collected at groundwater piezometers, the model simulations are representative of average groundwater elevations within an area of 242.21 km^2.

Groundwater head in BH3 is expected to have a limited episodic influence in response to a subsurface leakage from the nearby the Main Lake, taking into consideration the substantial difference of groundwater head fluctuations in BH3 and those shown for this Lake (Figure 5.3). Thus, there was no a clear relation between the groundwater head around BH3 and water level of the Main Lake to consider as an aquifer-lake interaction.

On the other hand, the downstream part of the catchment which extends from Lotus Lake to the reach of Langat River lies within the influence zone of the Megasteel pumping wells which strongly control the groundwater heads as discussed in Chapters 6.3 and 7.3 of this thesis.

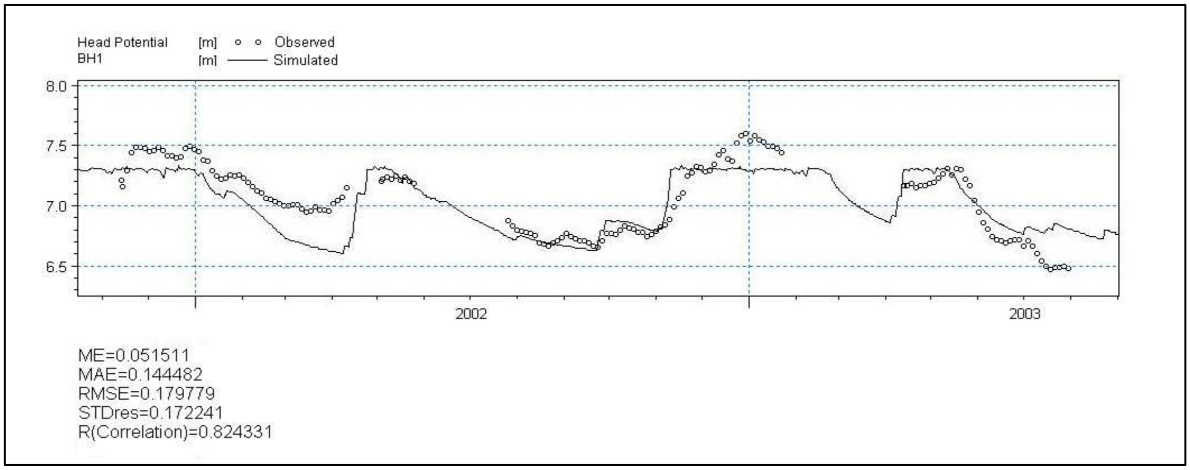


FIGURE 5.13
Calibrated Groundwater Head Hydrograph for BH1

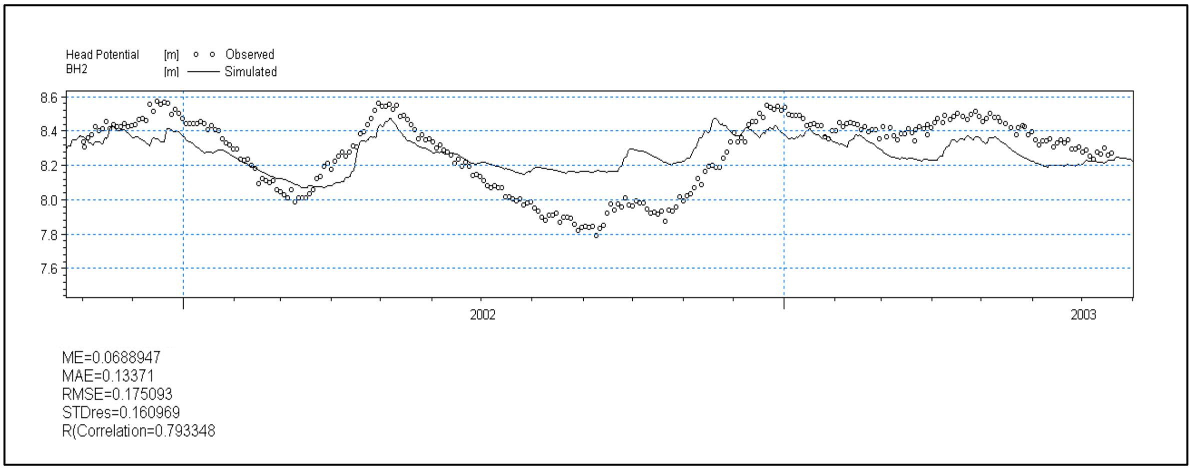


FIGURE 5.14
Calibrated Groundwater Head Hydrograph for BH2

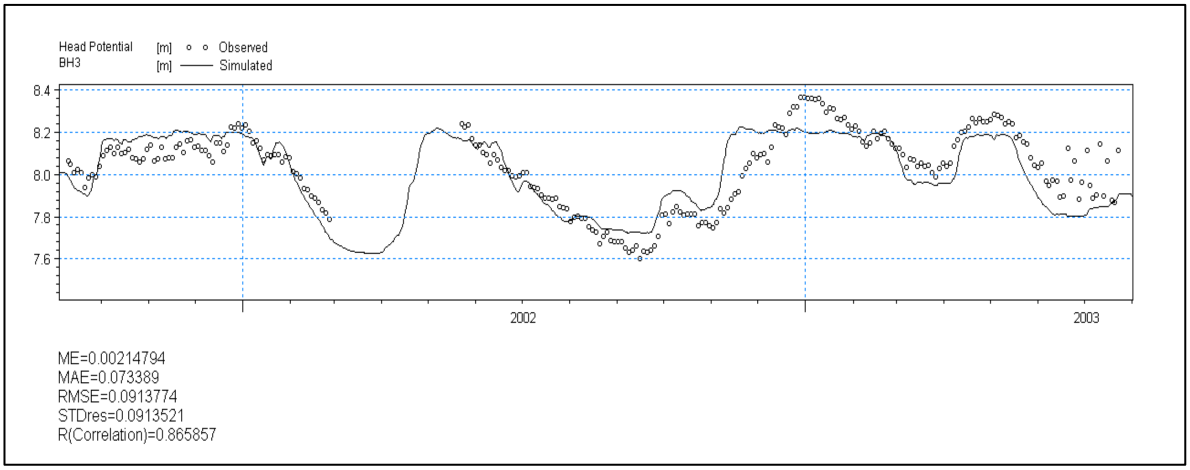


FIGURE 5.15
Calibrated Groundwater Head Hydrograph for BH3

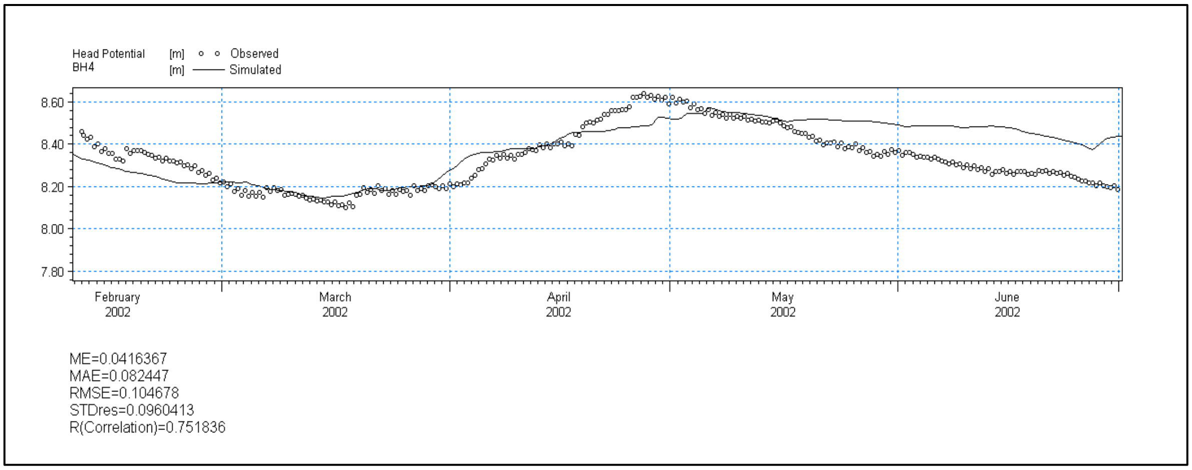


FIGURE 5.16
Calibrated Groundwater Head Hydrograph for BH4

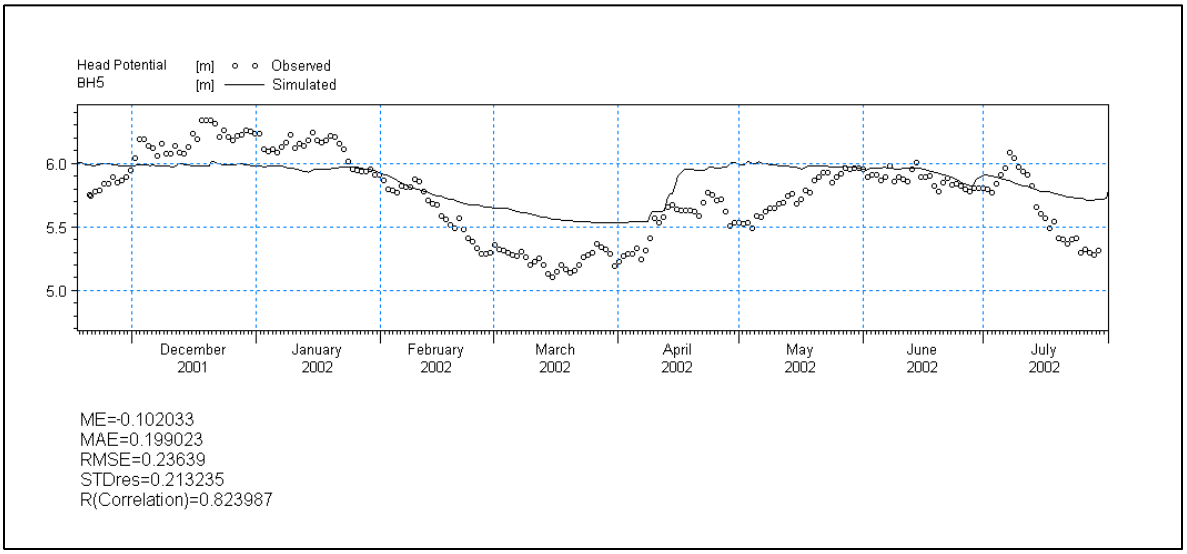


FIGURE 5.17
Calibrated Groundwater Head Hydrograph for BH5

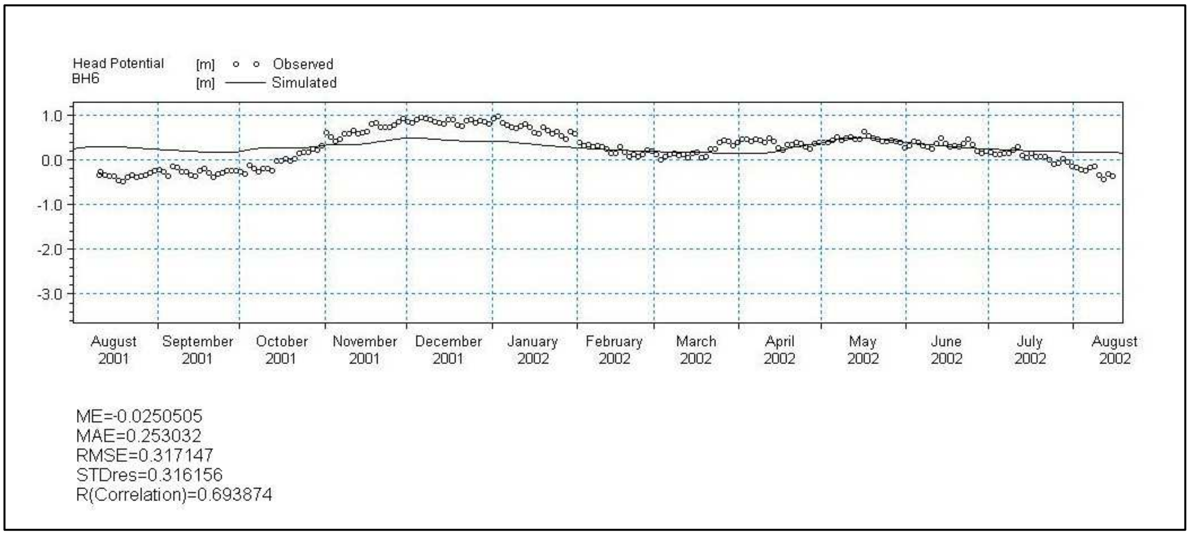


FIGURE 5.18
Calibrated Groundwater Head Hydrograph for BH6

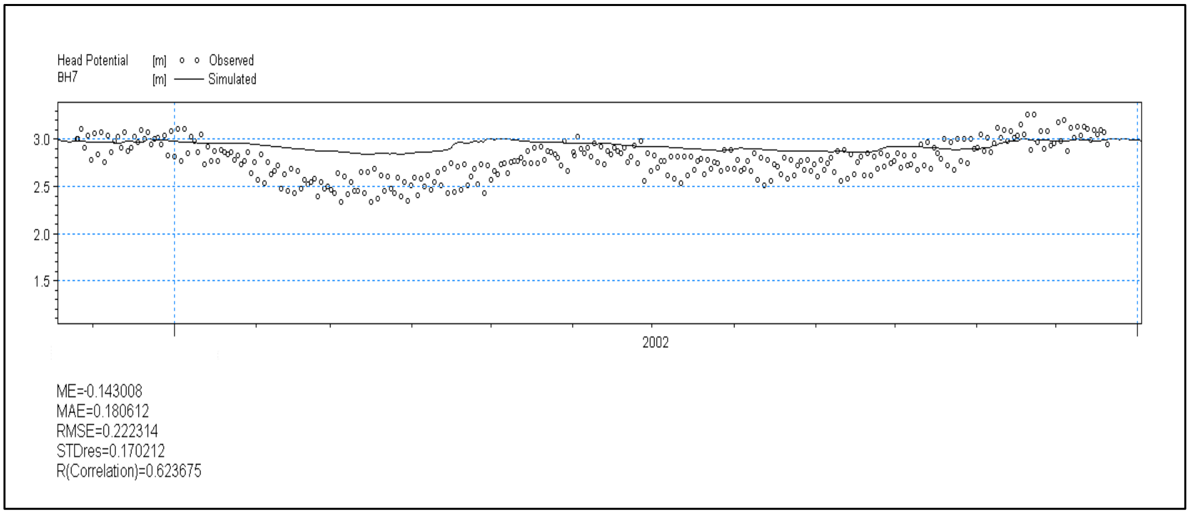


FIGURE 5.19
Calibrated Groundwater Head Hydrograph for BH7

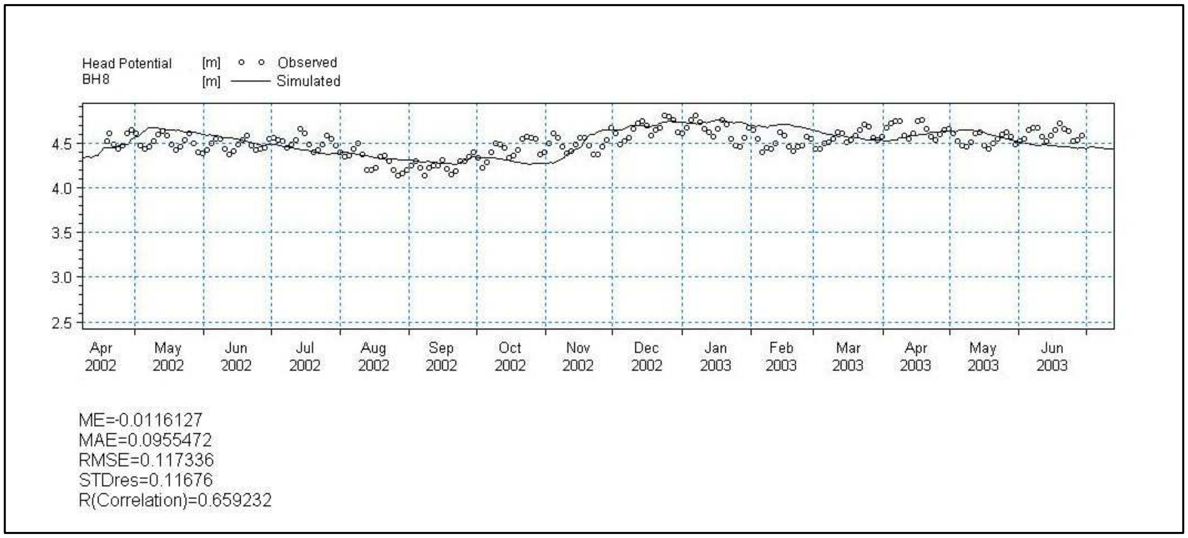


FIGURE 5.20
Calibrated Groundwater Head Hydrograph for BH8

5.2.3 Simulation of channel flow

In order to further examine the dynamics and strengthen the prediction capability of the surface water and groundwater coupled model of the Paya Indah wetland, the model was calibrated against channel flow. Calibration of the inflow and outflow was performed for the North-Inlet-Canal (SWL1) and Lotus-Outlet (SWL2) respectively. Results revealed that simulated flow follows quite satisfactory its respective observed hydrograph of SWL1 (Figure 5.21). Furthermore, precipitation hyetograph shows a satisfactory correspondence with that the simulated hydrograph of SWL1 in terms of timing and quantity (Figure 5.22).

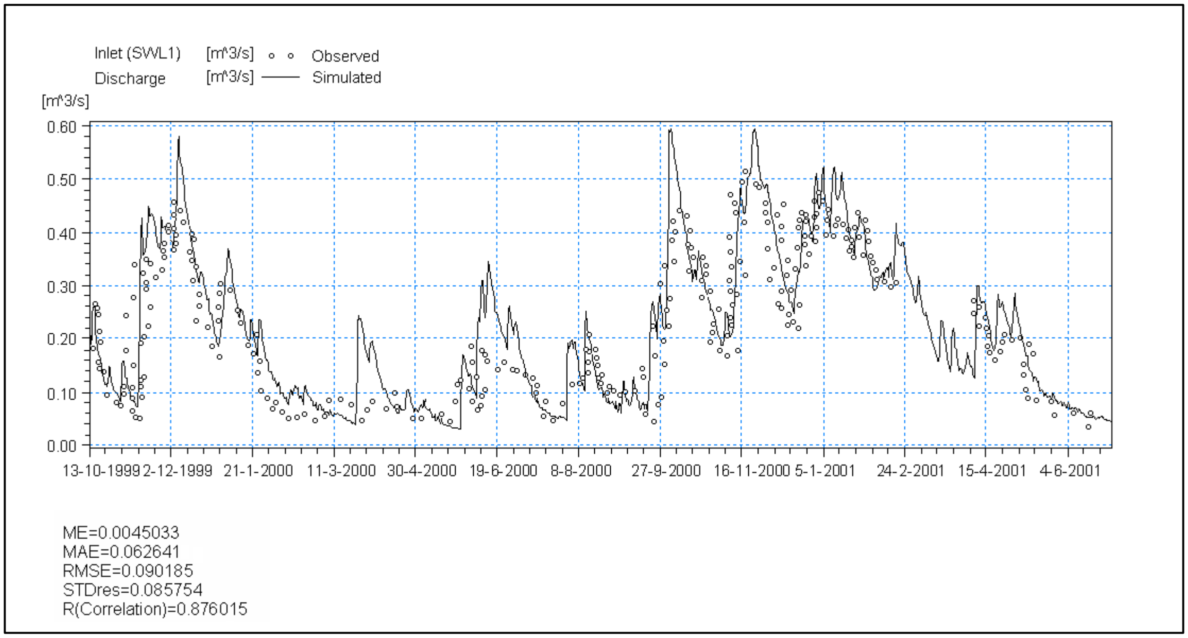


FIGURE 5.21
Calibrated Channel Flow Hydrograph for SWL1

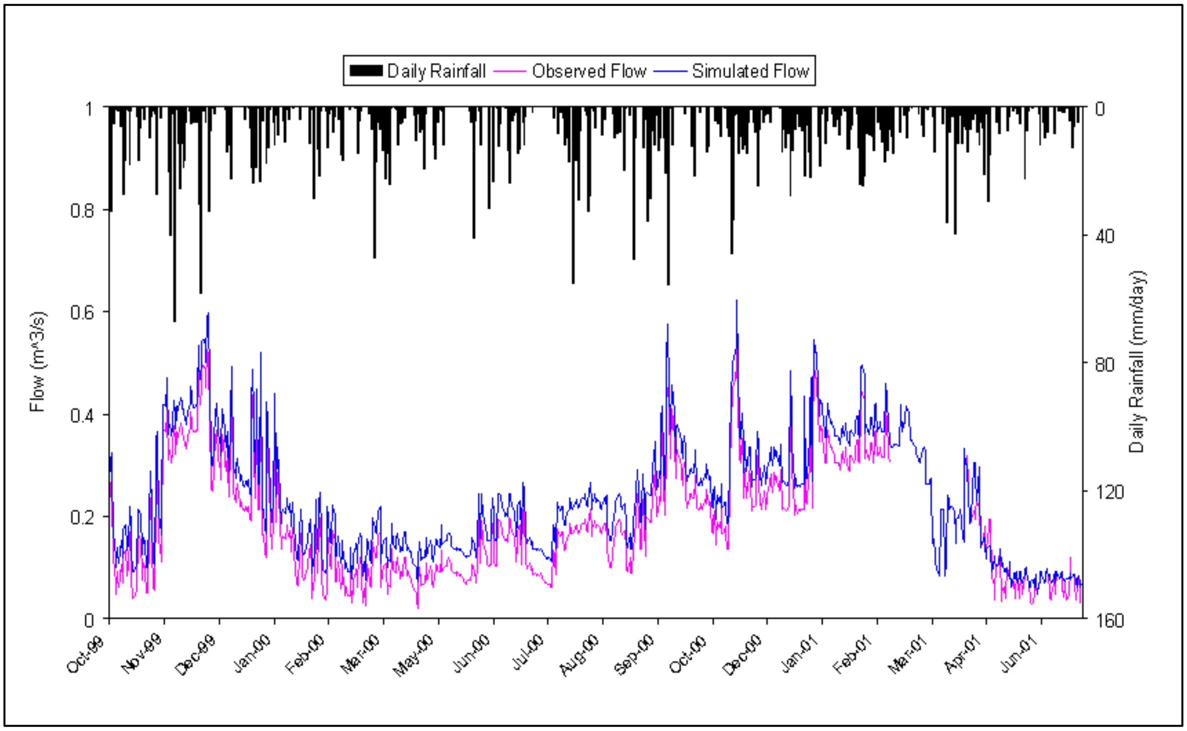


FIGURE 5.22
Hyetograph and Hydrographs for SWL1

Results revealed that the simulated discharge at SWL2 was generally not in a good fit with the observed one. This disagreement was attributed mainly to the unscheduled operations taking place at the weir that of Lotus-Outlet. Similar to the water level at this location (Figure 5.12), these operations obviously influenced the flow in both dry and wet periods which justified the occurrence of so many uncaptured limbs of the simulated hydrograph (Figure 5.23). Conversely, the simulated discharge pattern shows a reasonable agreement with the precipitation as shown in Figure 5.24.

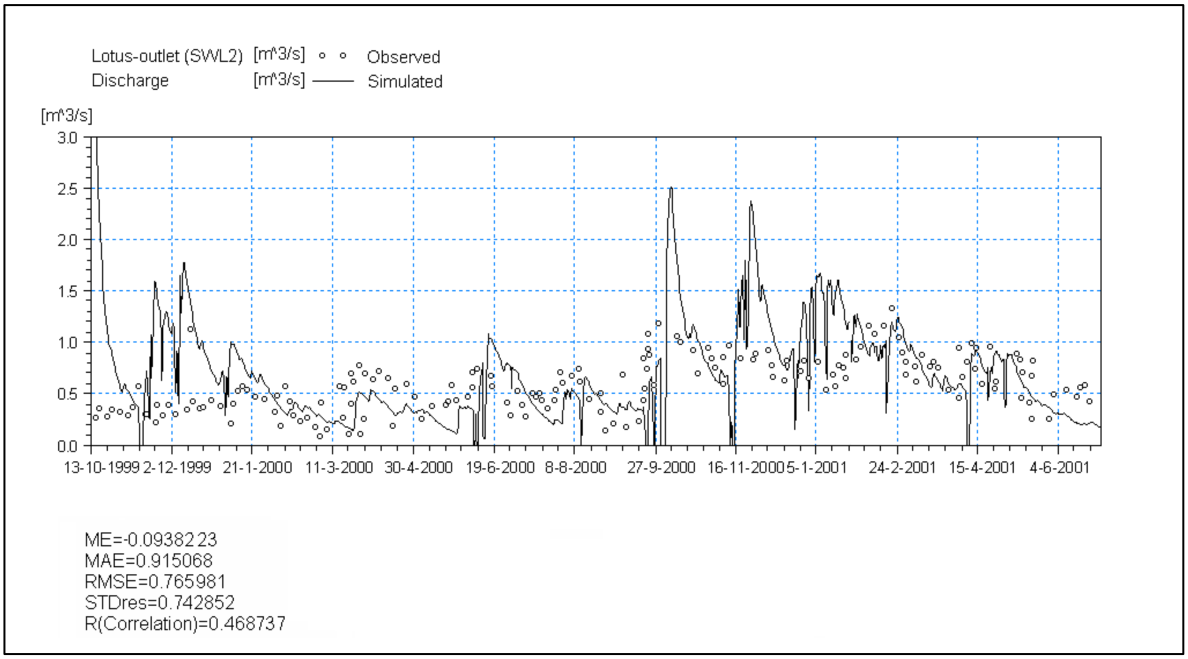


FIGURE 5.23
Calibrated Channel Flow Hydrograph for SWL2

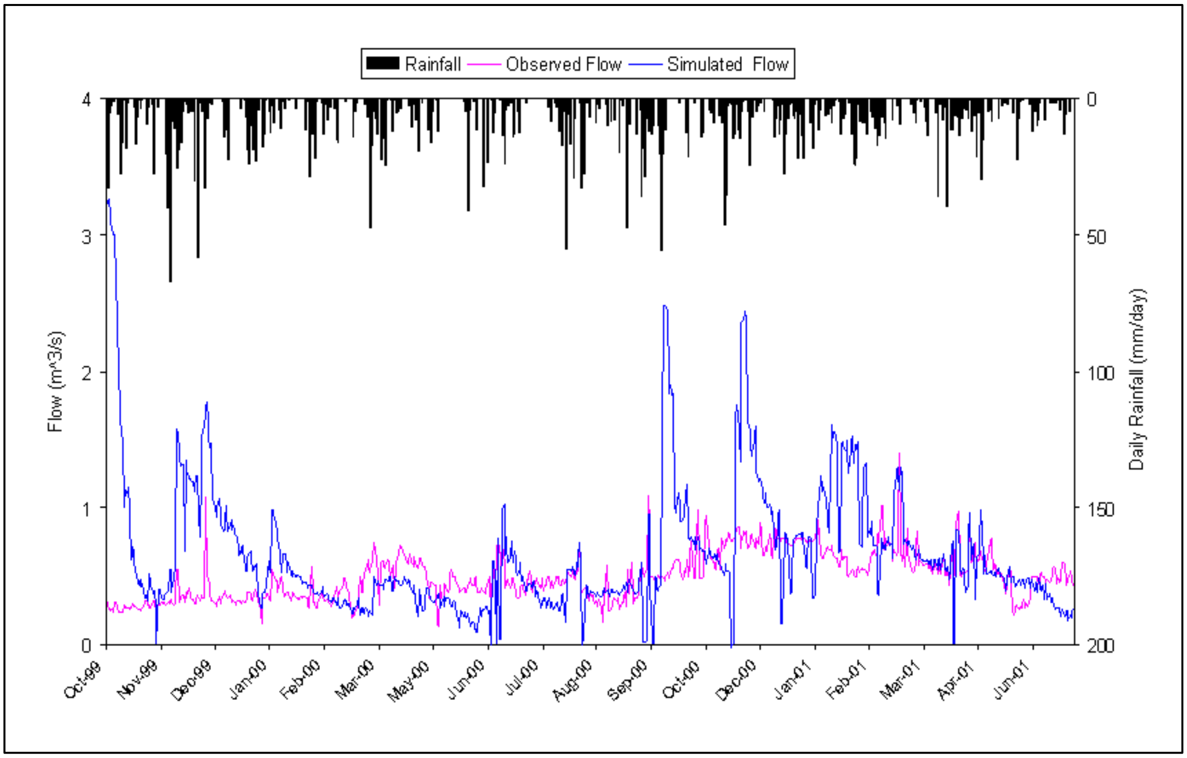


FIGURE 5.24
Hyetograph and Hydrographs for SWL2

5.3 ASSESSMENT OF THE CALIBRATED MODEL

Evaluation of the different aspects of the performance of a complex hydrological model like the Paya Indah wetland model using only one statistic is unfeasible process. Thus, an evaluation approach of a multi-criteria set of statistics that are preferably unrelated or somehow correlated is needed together with the consideration of supporting simulation unit timeseries graphs, hyetograph-hydrograph combination and scattered plots.

5.3.1 Performance of the coupled model

The statistical analysis aimed at qualifying the relationship between the Paya Indah wetland model outputs and input data. The analysis was undertaken for each individual calibration point**.** Results are presented in Table 5.1

Although the mean error (ME) is not an accuracy measure as it does not provide information of the prediction errors, however it allows a limited conclusion such as that mean error (ME) equal to zero indicates on average, while as values above and below the zero is an indicative of bias systematic error. In this context the model residual mean error (ME) ranges between -0.002 to 0.157 for surface water level; -0.094 to 0.62 for the water discharge and -0.012 to 0.069 for the groundwater head simulation. This result indicates that, there were minor systematic overestimations in the measured average systematic difference between the simulated and the observed values. While as the minus sign of the calculated ME in calibrated water level and discharge at SWL2 and groundwater heads at the piezometers BH5, BH6, BH7 and BH8 indicates that the measured value was less than the expected values. This result coincided with the fact that the recorded observation data at SWL2 were influenced by the unscheduled operations of the controlled gate; while as the groundwater heads at the piezometers BH5 to BH8 were influenced by the groundwater extraction at the Megasteel wells.

The Mean absolute error (MAE) has been used to avoid the aggregation problem of the ME since there is no compensation for positive and negative deviations. The results shows that the calculated MAE ranges between 0.041 to 0.167 and 0.073 and 0.199 for the surface water level and groundwater head respectively, which is an indicative of a small deviation between the observed and simulated data. Conversely, the highest MAE value of 0.92 which was calculated for the discharge at SWL2 indicates relatively a large deviation between simulation and prediction values.

Unlike the mean absolute error (MAE), the root mean square error (RMSE) is highly sensitive in terms of assessing large errors, thus provides a better judgment. In this concern the calculated RMSE varied between 0.052 to 0.217, and 0.091 to 0.317 for surface water and groundwater levels respectively. Despite the considerable biases between observed and simulated hydrographs of the SWL2 resulted in a relatively large RMSE value of 0.77, these results revealed that the vertical distance of the observed data from the fitted line of the model parameters is very narrow which in turn, demonstrates that the average random discrepancies between simulations and observations were small.

With the exception to SWL2 data in which observed and simulated flow values deviate a significant volume ($P \leq 0.01$) of 0.74 m^3/s from its mean value; the overall low standard deviation values which were calculated for the whole calibrated hydrographs indicate a satisfactory prediction accuracy of the model. Furthermore, this result was further strengthened by the Pearson distribution index (R^2) and coefficient of efficiency (CE) which were calculated for the channel flow.

The values of the coefficients of correlation (R) varied widely among the different calibrated categories. Values that were obtained for the surface water level and discharge range from 0.46 to 0.96 and 0.47 to 0.86 respectively. While as the groundwater head obtained values range from 0.62 to 0.87. The strong correlation values calculated for the majority of the simulated points indicate good one-to-one match between the measured and simulated values. However, the relatively low correlation coefficient values of both stage (0.46) and discharge (0.47) at SWL2 and the moderate correlation coefficient values of 0.645 and 0.653 for Lotus and Typha lakes respectively, were attributed mainly to the bias of operations of unscheduled water release and control at the Lotus Outlet controlled gate which influenced both the water stage and discharge. On the other hand the low correlation coefficient value of 0.62 for BH7 and the moderate correlation coefficient values of 0.65 and 0.69 for both BH8 and BH6 respectively indicate the influence of over-extraction and irregular withdrawal rate of groundwater that is carried out by the Megasteel Co. Ltd. on that part of the modelled catchment.

TABLE 5.1
Statistical Evaluation Criteria for the Calibrated Model

Hydrologic Point			**Coordinates** (Cassini System)		**Evaluation Criteria** [a]				
Calibration Target	**Category**	**Name**	**X**	**Y**	**ME**	**MAE**	**RMSE**	**STD$_{res}$**	**R**
Water Level (m)	Surface-water	North-Inlet-Canal (SWL1)	-7770.00	-33950.0	0.066	0.167	0.217	0.207	0.848
		Visitor Lake	-7373.50	-34496.3	0.005	0.063	0.076	0.076	0.753
		Main Lake	-9170.00	-33280.0	0.002	0.041	0.052	0.052	0.755
		Driftwood Lake	-9562.21	-33496.5	0.009	0.084	0.097	0.097	0.960
		Perch Lake	-9958.52	-34811.5	0.013	0.071	0.086	0.085	0.757
		Marsh Lake	-9733.34	-34415.2	0.075	0.079	0.084	0.066	0.806
		Crocodile Lake	-8620.00	-34720.0	0.005	0.060	0.075	0.075	0.776
		Hippo Lake	-8620.00	-34720.0	0.066	0.103	0.126	0.107	0.764
		Chalet Lake	-8280.00	-35300.0	0.157	0.071	0.098	0.097	0.785
		Typha Lake (Lotus T) [b]	-7346.48	-35460.1	0.019	0.115	0.143	0.142	0.653
		Lotus Lake (Lotus L)	-7346.48	-35460.1	0.044	0.124	0.149	0.142	0.645
		Lotus Outlet (SWL2)	-11690.0	-36140.0	-0.002	0.170	0.205	0.205	0.458
Water table (m)	Ground-water	BH1_LED2	-10094.3	-26813.7	0.052	0.144	0.180	0.172	0.824
		BH2_J1-1-2	-8764.66	-31583.4	0.069	0.134	0.175	0.161	0.793
		BH3_J2-1-1	-9253.24	-32662.5	0.002	0.073	0.091	0.091	0.866
		BH4_J10-1-2	-7592.13	-33242.2	0.042	0.082	0.105	0.096	0.752
		BH5_WF2	-11028.3	-37772.6	-0.102	0.199	0.236	0.213	0.824
		BH6_JB	-13186.1	-41540.7	-0.025	0.253	0.317	0.316	0.693
		BH7_WF1	-16698.5	-39235.0	-0.143	0.181	0.222	0.170	0.624
		BH8_KSM	-17616.6	-38289.4	-0.012	0.095	0.117	0.116	0.659

TABLE 5.1 (continued)

Channel Flow (m^3/s)	Surface-water	North-Inlet-Canal (SWL1)	-7770.00	-33950.0	0.005	0.063	0.090	0.086	0.88
		Lotus Outlet (SWL2)	-11690.0	-36140.0	-0.094	0.915	0.766	0.743**	0.57

[a] Evaluation Criteria:
ME: mean error
MAE: mean absolute error
RMSE: root mean square error
STD_{res}: standard deviation of the residuals
R: correlation

[b] Typha Lake is considered as an extension for Lotus Lake
** Values differed very significantly at *P*≤ 0.01 from the mean value.

5.3.2 Assessment of model predictive capability

Regression relations were established between simulated and observed instantaneous the channel flow which was measured at SWL1 and SWL2. Simulated discharge can be estimated from the linear regression line depending on the changes in the regression parameters. Thus, for the ideal situation where the estimated parameters can be compared to the virtual hydrological reality, Pearson distribution index (R^2) and coefficient of efficiency (CE) were used evaluate the coupled model predictive capability. Results for the calculated R^2 and CE are presented in Table 5.2, while as Figures 5.25 and 5.26 show the scattered plot for the observed and siumlutated channel flow at SWL1 and SWL2 respectively.

TABL3E 5.2
Evaluation of Predictive Accuracy of the Calibrated Model

Discharge Calibration Point	**Coefficient** [a]		**Regression Parameters**	
	CE	**R^2**	**Slope**	**Intercept**
SWL1	0. 81	0.78	0.93**	0.16**
SWL2	0.43	0.21	0.35	0.27*

Coefficient [a]:
R^2: Pearson distribution index
CE: Nash and Sutcliffe coefficient of efficiency
* Values of the slope significantly different at $P \leq 0.05$ from its ideal value of zero
** Values of the slope and intercept are very significantly different at $P \leq 0.01$ from the ideal values of 1 and 0, respectively

The regression results show a fairly strong relationship based on the distribution index (R^2) of 0.78 for SWL1 supported by very significant explanatory regression variables in which slopes near to one, and intercepts near to zero (Table 5.2; Figure 5.25). These results confirm the fairly close relationship between observed and simulated discharge. Furthermore, the noticeable agreement between the observed daily rainfall and simulated channel flow in terms of timing and quantity was evidenced in the positive high coefficient of efficiency value of 0.81. This result pointed out the best fit simulation result of the model which in turn indicates that the model predicts simulation results with a high accuracy than the mean of the measured data.

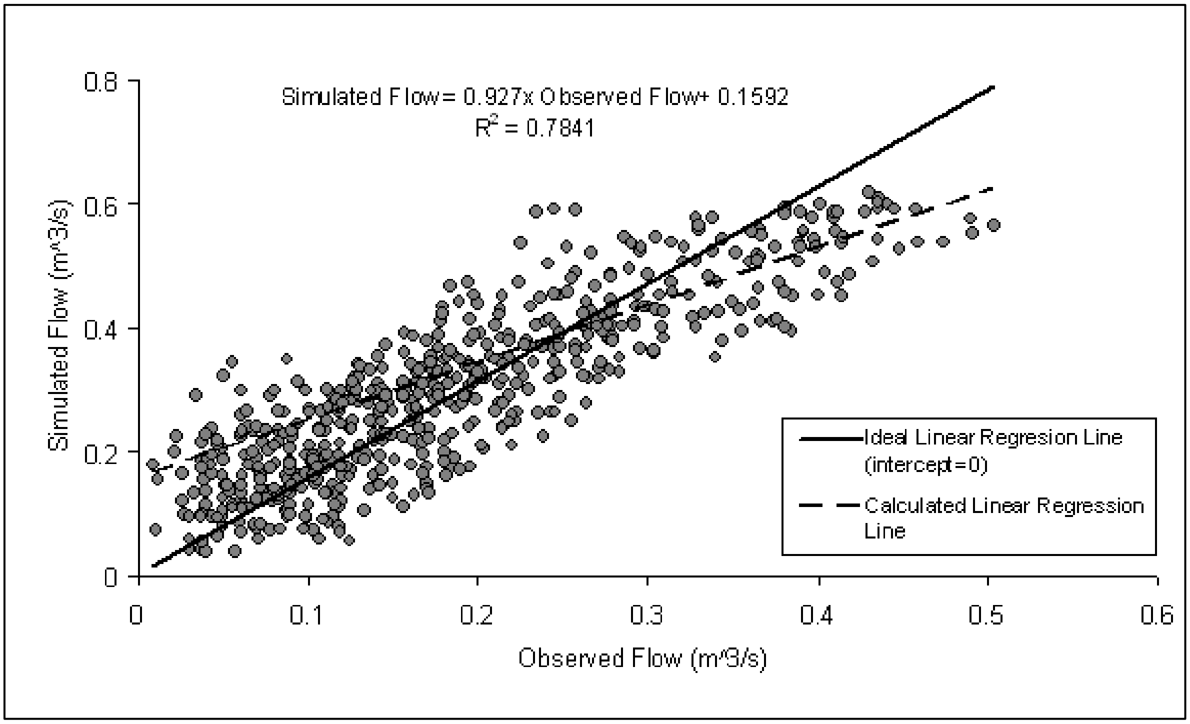


FIGURE 5.25
Scattered Plot for the Observed and Simulated Channel Flow at SWL1 during Calibration Period

Unsurprisingly both of the calculated distribution index (R^2) and coefficient of efficiency (CE) for flow simulation at SWL2 were in a low range due to large discrepancies between observed and simulated flow. This disagreement comes in consistent with the results of water level simulation for the same location (Figure 5.12; Table 5.1). Generally, these results were considered as inevitable consequences of the influence of unscheduled operation at Lotus-Outlet controlled gate.

The Overall, statistical analyses showed that the performance of the Paya Indah wetland model to simulate hydrological processes within modelled catchment was to a satisfactory level.

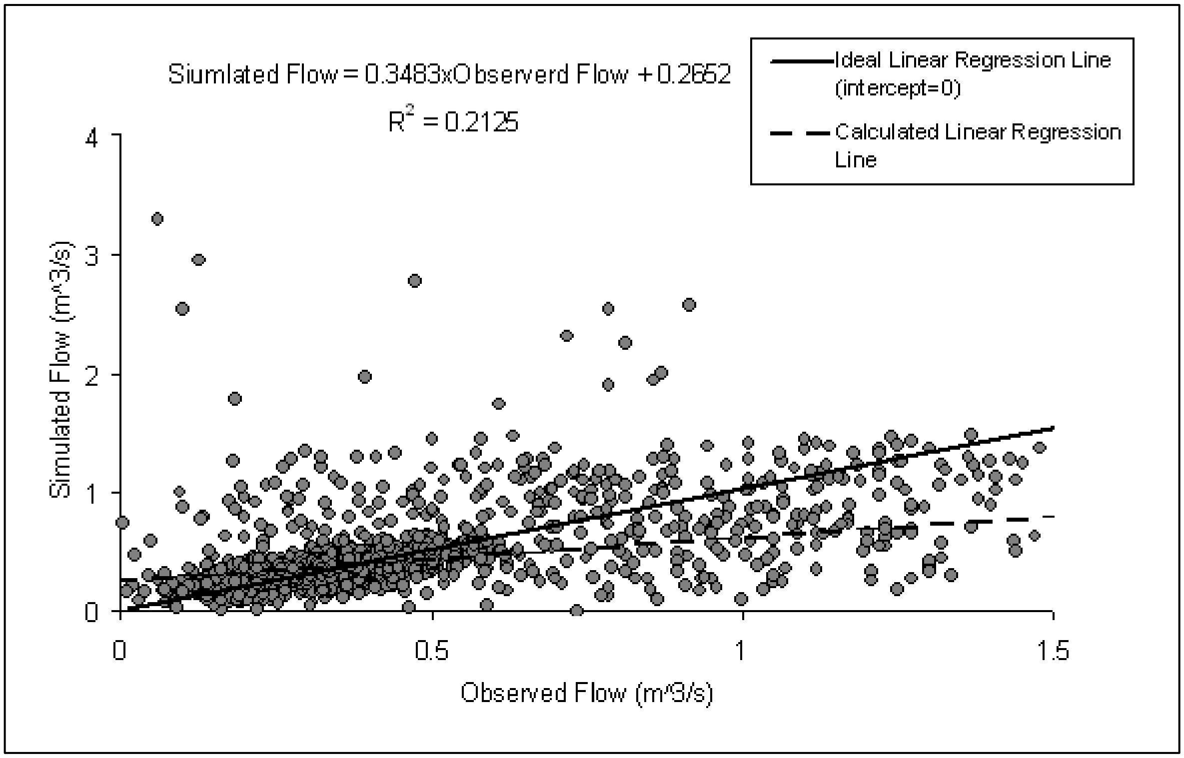


FIGURE 5.26
Scattered Plot for the Observed and Simulated Channel Flow at SWL2 during Calibration Period

5.4 VALIDATION

A distributed hydrological model can be considered validated not only if it is able to produce good simulations for future conditions, but also if it is able to perform reliable predictions at internal/multi-site locations (Refsgaard, 1997). On this context, the performance of the calibrated model was validated for one year using present data. The period from August 2007 to August 2008 was chosen for the model validation in order to cover one full hdrologic year. All parameters applied in the calibration are unchanged during validation. The validation of the model was aimed at investigating the reliability of model parameters which were applied for the calibration period (July 1999 - November 2004) in order to simulate the ongoing land use change in the Paya Indah wetland catchment. The canal network and groundwater wells locations are assumed identical for the calibration period implying that the canal system, but not necessarily the water flow and level, is unchanged.

Due to vandalism problem which was discussed in Chapter 4.7of this thesis, the validation process was confined to eight locations for the surface water level, two locations for groundwater heads, and two locations for channel flow excluding the North-Canal-Inlet (SWL1) where the automatic logger was smashed.

5.4.1 Validated surface water flow

Surface water level was validated at eight different locations including Visitor, Main, Tin, Crocodile, Hippo, Chalet, Typha and Lotus lakes. Figures 5.27 – 5.34 illustrate observed and simulated water level hydrographs. The results clearly revealed that the validated model response was much better than the calibrated model. Despite the short-term running of the validation period, it was found that the dynamics of the water level was well represented by the validated model. Furthermore most of the simulated flow peaks matched well with their observed counterparts especially for the upper and middle lakes (Figures 5.27 to 5.31). However at the lower lakes, mainly Chalet, Typha and Lotus, it seems that the model missed capturing two anomalous peaks that were occurred during the periods 04 - 11 January 2008 and 22 – 25 March 2008 i.e. occurred after certain events (Figures 5.32 to 5.35). These anomalies were justified by the occurrence of four and two successive storms during the first and second periods respectively which in turn represented 8.2% and 3.2% of the total rainfall during the whole validation period.

On the other hand, based on an information tip from the local authorities there were no operations for the SWL2 control gate during the whole validation period. This action may explain the good representation of the surface water dynamics characteristics during the validation period rather than the calibration one. Thus the slightly overall under-estimation especially lower lakes, was mainly related to the fact that the accumulation of water in the Lotus lake after storm events tends to exceed the discharge intake capacity of the broad-crested weirs type of the controlled gate.

Generally speaking the validation results showed a good potentiality for the model to predict the impacts of hydrological modifications on a complex hydrologic system such as the Paya Indah wetland.

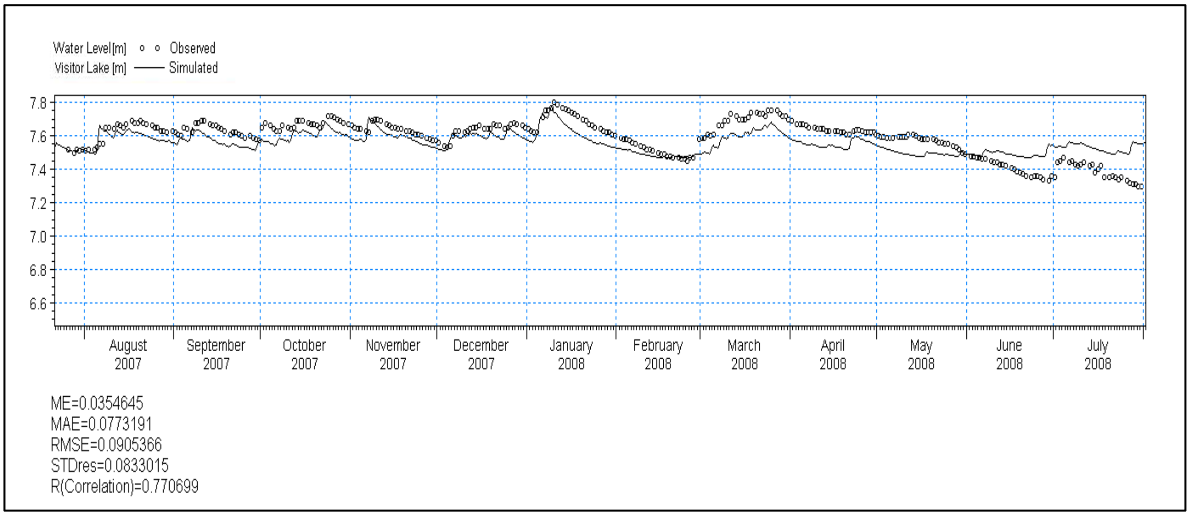


FIGURE 5.27
Validated Surface Water Level Hydrograph at Visitor Lake

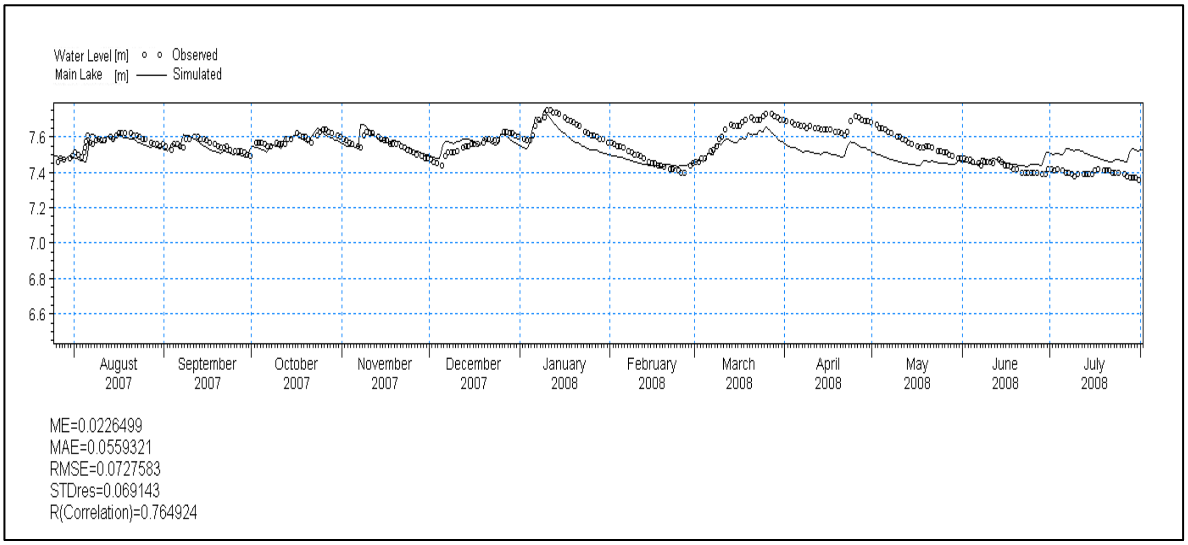


FIGURE 5.28
Validated Surface Water Level Hydrograph at Main Lake

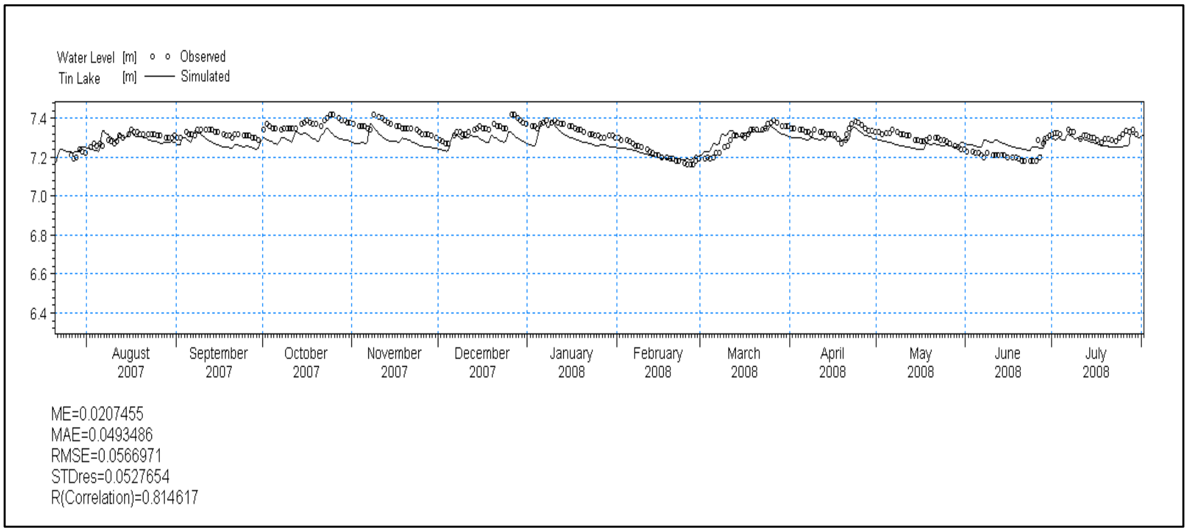


FIGURE 5.29
Validated Surface Water Level Hydrograph at Tin Lake

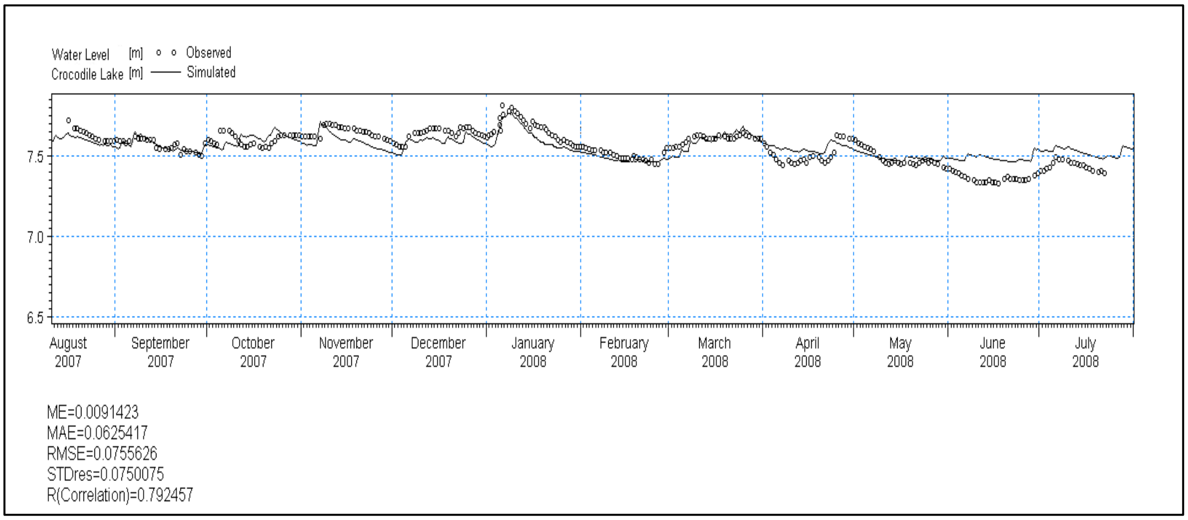


FIGURE 5.30
Validated Surface Water Level Hydrograph at Crocodile Lake

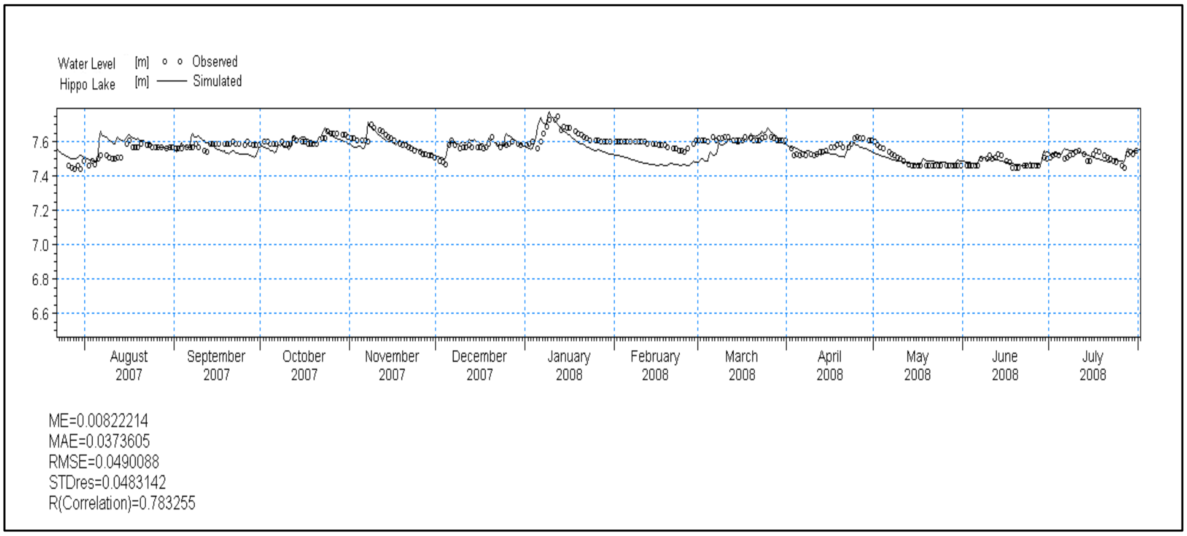


FIGURE 5.31
Validated Surface Water Level Hydrograph at Hippo Lake

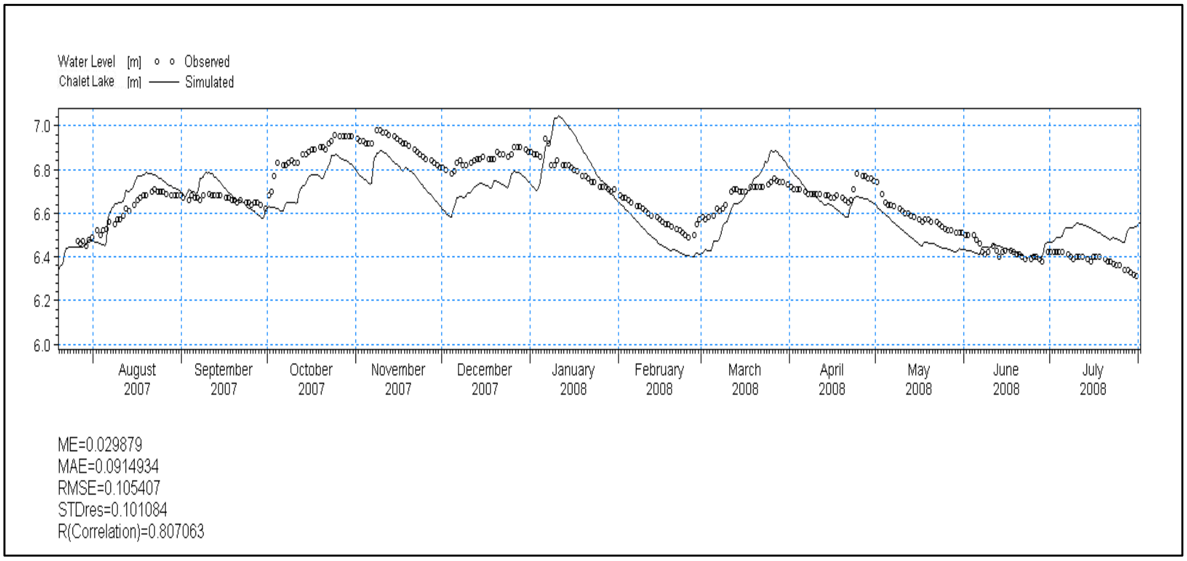


FIGURE 5.32
Validated Surface Water Level Hydrograph at Chalet Lake

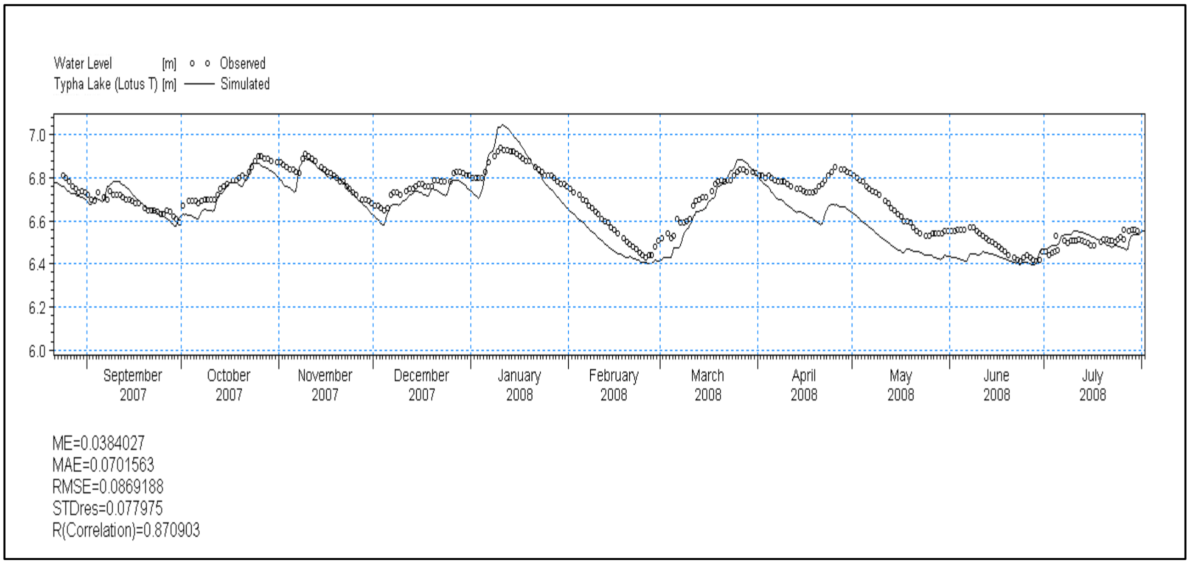


FIGURE 5.33
Validated Surface Water Level Hydrograph at Typha Lake

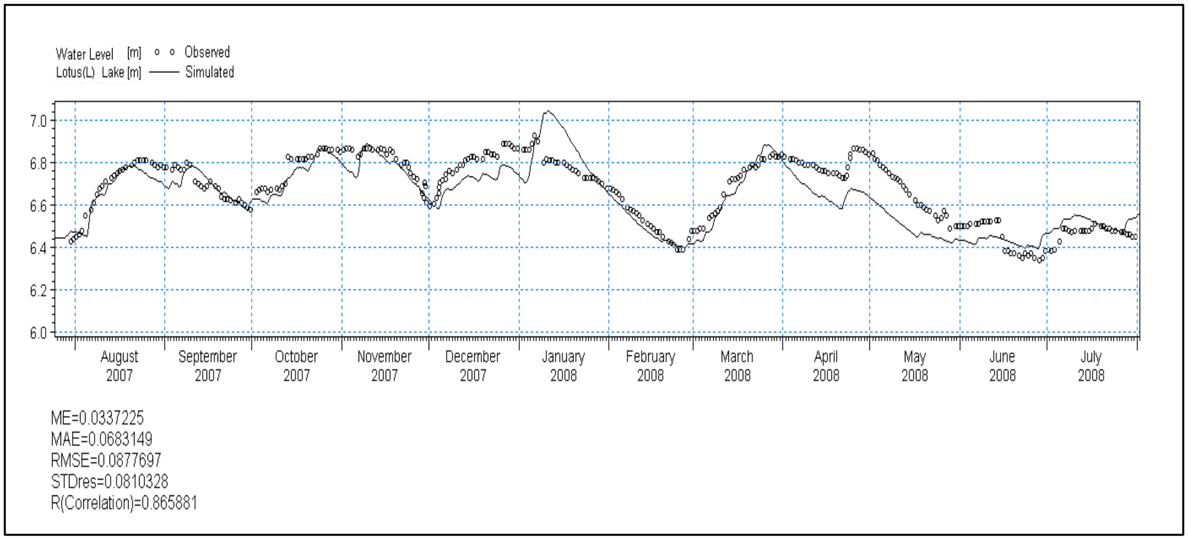


FIGURE 5.34
Validated Surface Water Level Hydrograph at Lotus Lake

5.4.2 Validated groundwater head

The validation of groundwater table was bound to two piezometers including BH3 and BH5 (Figures 5.35 and 5.36).The results revealed that similar to the calibration performance, the validated model showed satisfactory spatially-distributed predictions of the dynamics of groundwater levels with a performance somehow similar to that achieved at the calibration piezometer BH3. However, the nearly flat representation of the groundwater level in the simulation hydrograph of BH5 might reflect an occurrence of some expected uncertainties at the part of the modelled catchment, mostly associated with the groundwater pumping at Megasteel wells. This assumption was strongly supported by the fact that while the simulated groundwater table tended to rise up about 0.2 m at BH3 compared to calibration period for the same piezometer (Figures 5.15 and 5.35), it was found that at BH5 the groundwater head dropped ~ 0.75 m during both wet (November, December and January) and dry (May, June and July) periods of the year (Figures 5.17 and 5.36).

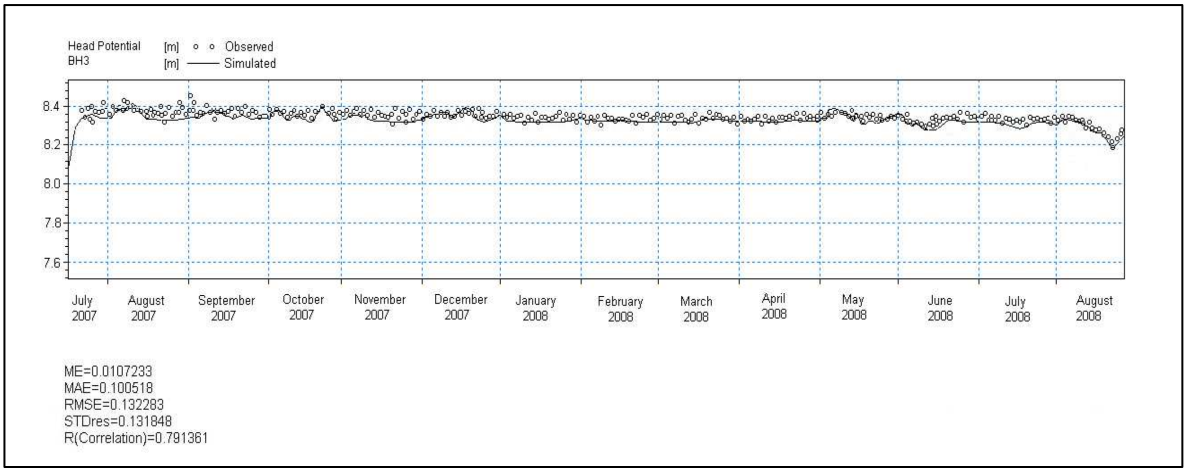


FIGURE 5.35
Validated Groundwater Level Hydrograph at BH3

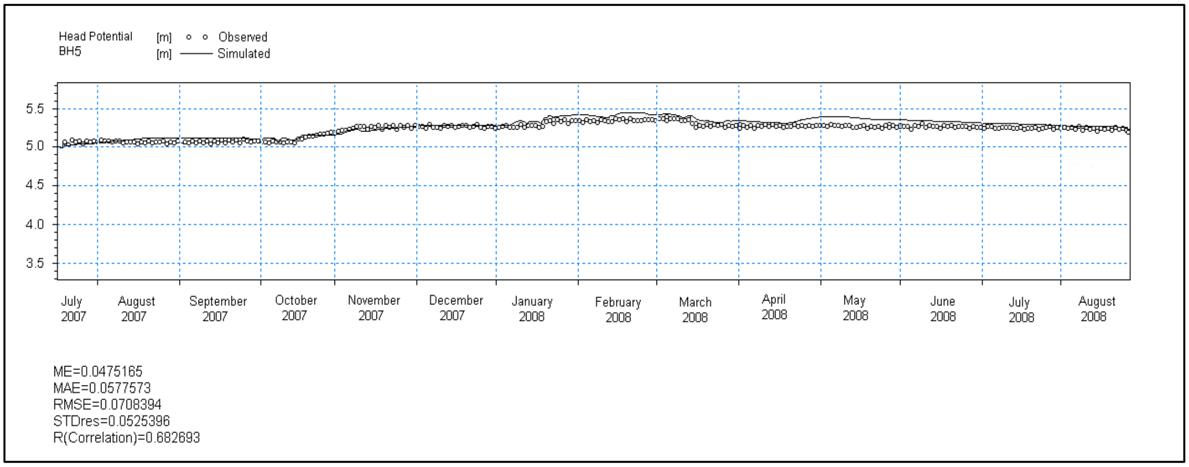


FIGURE 5.36
Validated Groundwater Level Hydrograph at BH5

5.4.3 Validation of channel flow

The flow validation was performed for two locations including the reach of Langat River and Lotus-Outlet (SWL2). Results for the validated channel flow are shown in Figures 5.37 and 5.38. Results showed that in terms of quantity and timing all the simulated well-identifiable flow peaks for the reach of Langat River matched fairly well with the observed ones though some overestimation occurred (Figure 5.37). Unlike the calibration period the simulated discharge at SWL2 follows quite satisfactorily the observed hydrograph shape, but miscaptured the flow peak during storm event. Moreover, a slight overestimation occurred. One explanation is that such overestimation mostly due to the relatively low uniform value of Manning number of 10 that was assigned for all the water courses within the catchment, in order to avoid the subsequent instabilities that were arisen due to the over-parameteriztion problem, assuming a high degree of meandering and vegetation in the streams of typical tropical area like Malaysia. While as due to a highly vegetated surface the Manning number for the remaining peat surface was set as low as 5.

In the same manner, the non-uniqueness of time interval between the parameters sets of daily rainfall and monthly flow resulted in occurrence of a tendency of over- and under-prediction in the flow at SWL2 (figure 5.38).

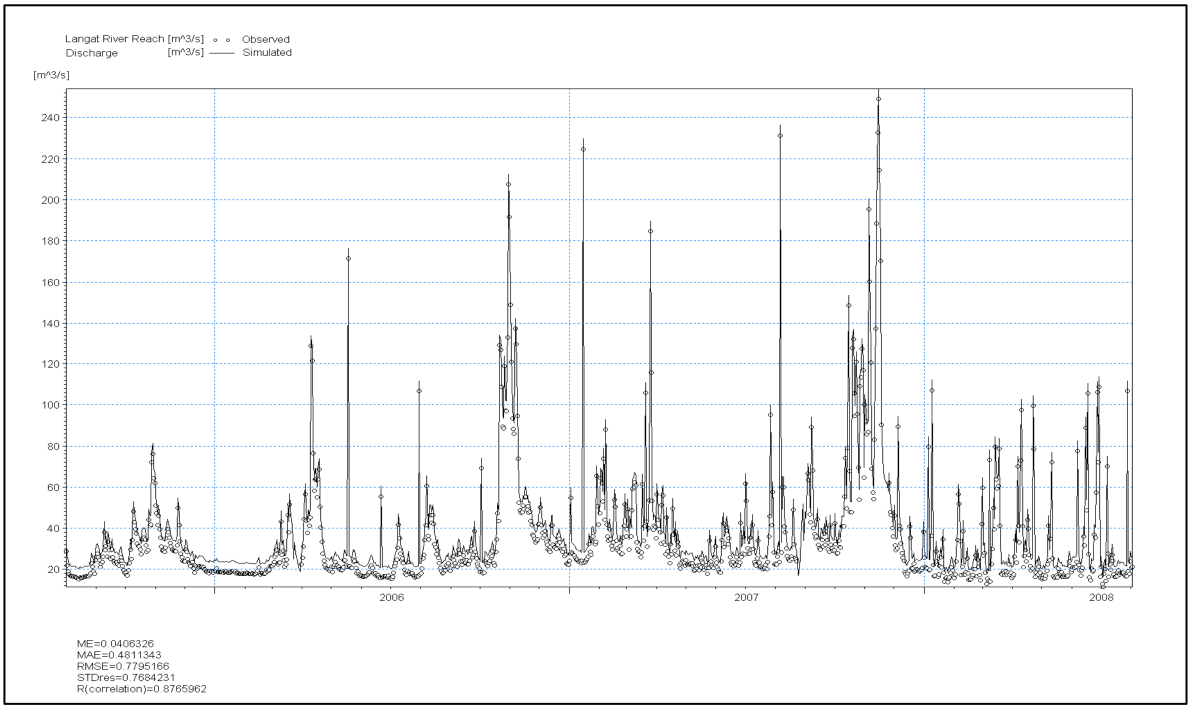


FIGURE 5.37
Validated Channel Flow Hydrograph for the Reach of Langat River

The results evidenced that, the water level in the lakes and channels system fluctuates in response to climatic variability, and furthermore, due to flat topography, it has the ability to retain a significant part of the runoff, especially during storm events. Thus, subsequently the rate of surface water flow varies greatly from year to year and event to event.

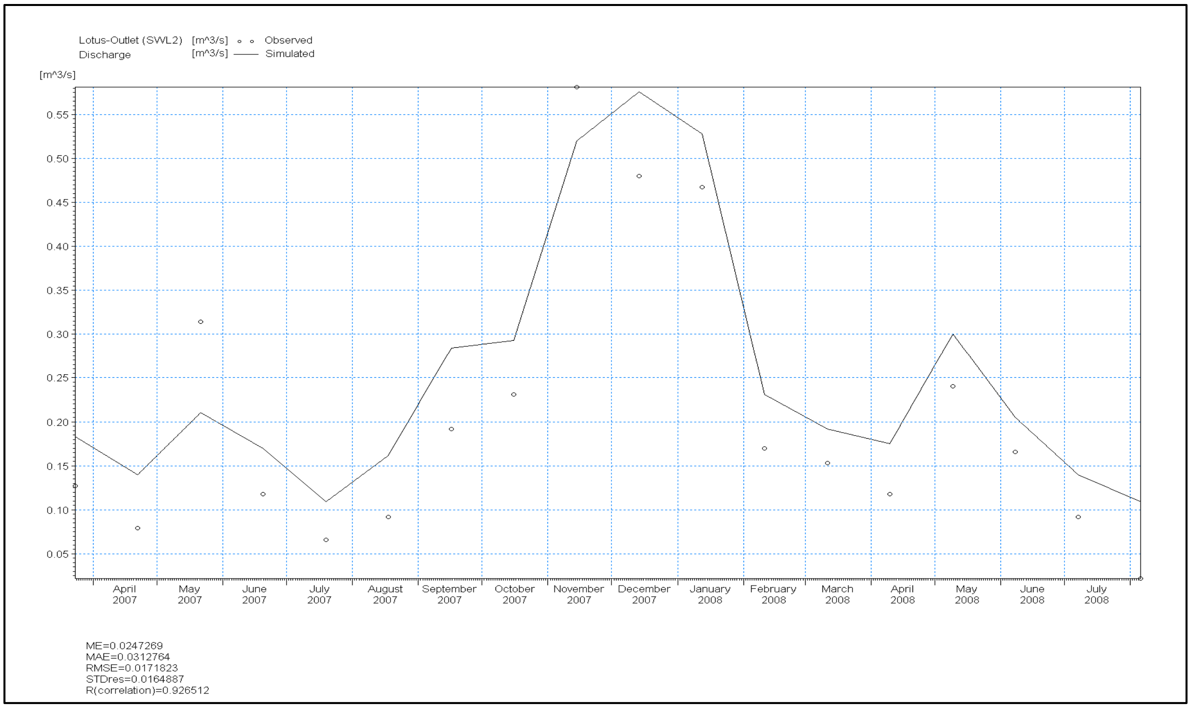


FIGURE 5.38
Validated Channel Flow Hydrograph for SWL2

The relationship between rainfall and channel flow is shown in Figures 5.39 and 5.40. The results showed that the simulated flow hydrographs and the rainfall hyetograph are of comparable shape which from one hand demonstrates a satisfactory degree of consistency between the model parameters, and on the other hand indicates a large contribution by overland flow. In considering all the storm events, two different types of relationships can be identified: for small rainfall events less than 10 mm, the channel flow response was always limited, which in turn resulted in occurrence of a limited overland flow of less than 2 mm; for rainfall events larger than 10 mm, a significant and progressive increase in channel flow was observed as an evitable result of the overland flow. The transition between the two relationships was not sharply identified.

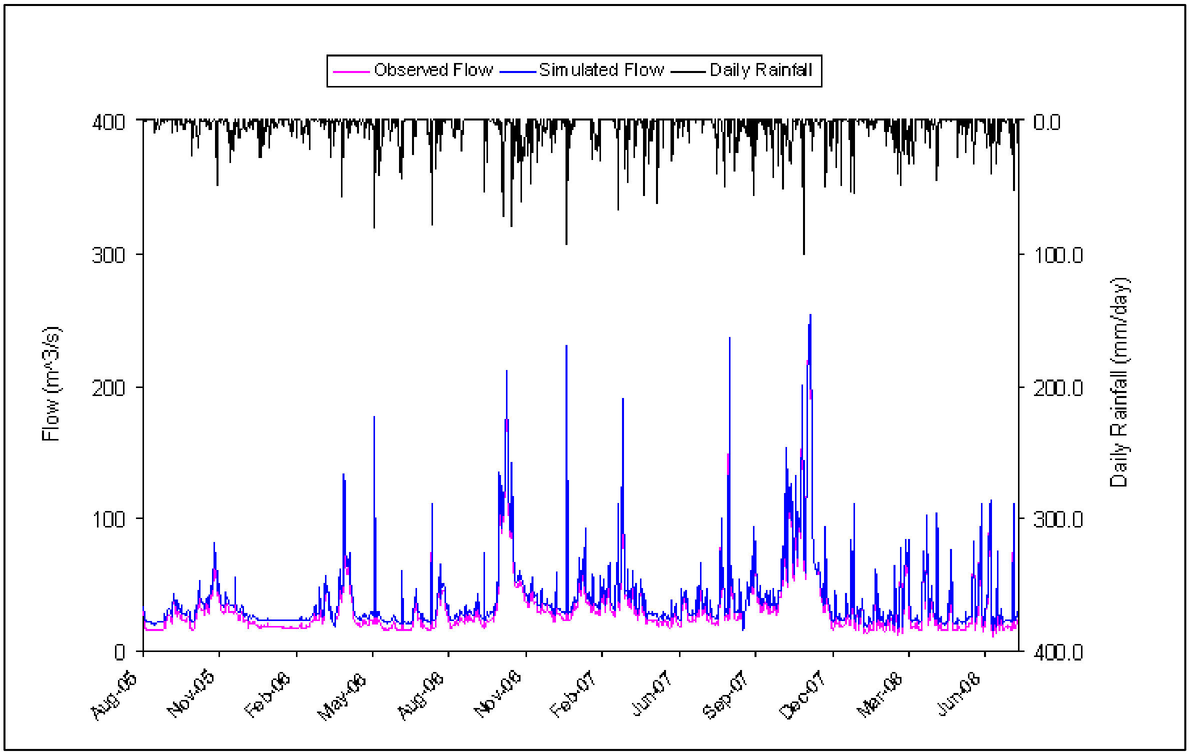


FIGURE 5.39
Hyetograph and Validation Hydrograph for the Reach of Langat River

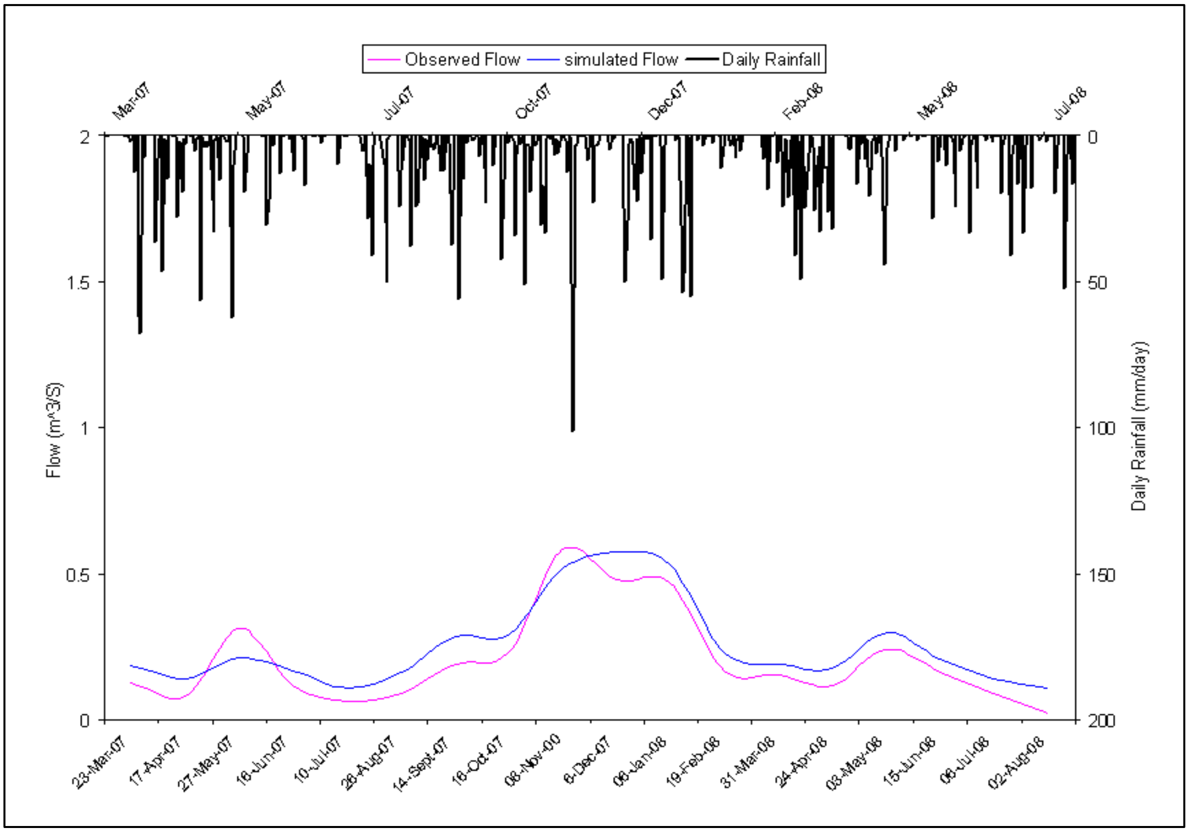


FIGURE 5.40
Hyetograph and Validation Hydrograph for SWL2

5.5 ASSESSMENT OF THE VALIDATED MODEL PERFORMANCE

Performance of the valided model was assessed using the same statistical criteria and supporting graphs which were used for the calibrated model. The coupled model sccored the highest correlations in the validation period but also the largest bias and RMSE errors compared to the calibrated model. This because of the fact that while validation period was shorter (12 months) and the observation data were continuous, the calibration period which extended for sixty four months was characterized by some missing observation data,which in turn, excluded from the statistical assessment. Generally the best performance in the validation period was achieved by the surface water level and discharge.

5.5.1 Performance of the coupled model

The analysis was undertaken for each individual validation point as presented in Table 5.3. The results showed that the values of mean error (ME) and mean absolute error (MAE) were in the ranges of 0.08 to 0.048 and 0.031 to 0.48 respectively. RMSE values ranged from 0.049 to 0.78; while as STDres ranged from 0.048 to 0.77. Despite high RMSE value of 0.78 m^3/s and STDres (0.77) which differed significantly from its mean value at $P \leq 0.01$, in fact there were no large discrepancies between simulated and observed hydrographs. Generally the values close to zero of both RMSE and MAE indicate perfect fit, while as values less than half of the STDres values of the observations indicated that the model possesses a satisfactory predictive accurrancy. Generally, there were high correlations (R) between observed and simulated values which varied from 0.63 to 0.92. The correlation coefficient values of $0.90 \geq (R) \geq 0.80$ were obtained at five locations while as other four locations obtained values of $0.80 \geq (R) \geq 0.75$.

TABLE 5.3
Statistical Evaluation Criteria for the Validated Model

Hydrologic Point			**Coordinates** (Cassini System)		**Evaluation Criteria** [a]				
Calibration Target	**Category**	**Name**	**X**	**Y**	**ME**	**MAE**	**RMSE**	**STD_{res}**	**R**
Water Level (m)	Surface water	Visitor Lake	-7373.50	-34496.3	0.036	0.077	0.091	0.083	0.771
		Main Lake	-9170.00	-33280.0	0.023	0.056	0.073	0.069	0.765
		Tin Lake	-9733.34	-34415.2	0.021	0.049	0.057	0.053	0.814
		Crocodile Lake	-8620.00	-34720.0	0.009	0.063	0.076	0.075	0.792
		Hippo Lake	-8620.00	-34720.0	0.008	0.037	0.049	0.048	0.783
		Chalet Lake	-8280.00	-35300.0	0.030	0.091	0.105	0.101	0.807
		Typha Lake (Lotus T) [b]	-7346.48	-35460.1	0.038	0.070	0.087	0.078	0.871
		Lotus Lake (Lotus L)	-7346.48	-35460.1	0.034	0.068	0.088	0.081	0.866
Water Table (m)	Ground-water	BH3	-9253.24	-32662.5	0.011	0.101	0.132	0.132	0.791
		BH5	-11028.3	-37772.6	0.048	0.058	0.071	0.053	0.683
Channel Flow (m^3/s)	Surface-water	Langat River	-2207.72	-35100.4	0.041	0.480	0.780	0.770**	0.877
		Lotus Outlet (SWL2)	-11690.0	-36140.0	0.024	0.031	0.017	0.016	0.927

[a] Evaluation Criteria:
ME: mean error
MAE: mean absolute error
RMSE: root mean square error
STD_{res}: standard deviation of the residuals
R: correlation
[b] Typha Lake is considered as an extension for Lotus Lake
** Values differed very significantly at $P \leq 0.01$ from the mean value.

5.5.2 Assessment of model predictive capability

Regression relations were established between simulated and observed instantaneous discharge rate which measured at Langat River and SWL2. The different performance measures including Pearson distribution index (R^2) and Nash-Sutcliffe efficiency (CE) are presented in Table 5.4 and Figures 5.41 and 5.42. The result show that the model performed satisfactorily during the channel flow simulation. The overall channel flow simulation over the validation period was labelled with ranges of 0.77 to 0.83 and 0.79 to 0.86 of CE and R^2 respectively. Furthermore the obtained values for slope and intercept varied widely at $P \leq 0.01$ which asserted the strong relationship between the observation data and the simulation values calculated by the model.

Generally both of visual comparison and overall statistical evaluation showed that the model was validated satisfactorily to adequately estimate and predict the total water balance and impacts of future development scenarios respectively within the Paya Indah wetland catchment.

TABLE 5.4
Evaluation of Predictive Accuracy of the Validated Model

Discharge Calibration Point	**Coefficient** [a]		**Regression Parameters****	
	CE	**R^2**	**Slope**	**Intercept**
Langat River	0. 77	0.79	0.95	0.16
SWL2	0.83	0.86	0.90	0.07

Coefficient [a]:
R^2: Pearson distribution index
EC: Nash and Sutcliffe coefficient of efficiency
** Values of the slope and intercept are very significantly different at $P \leq 0.01$ from the ideal values of 1 and 0, respectively

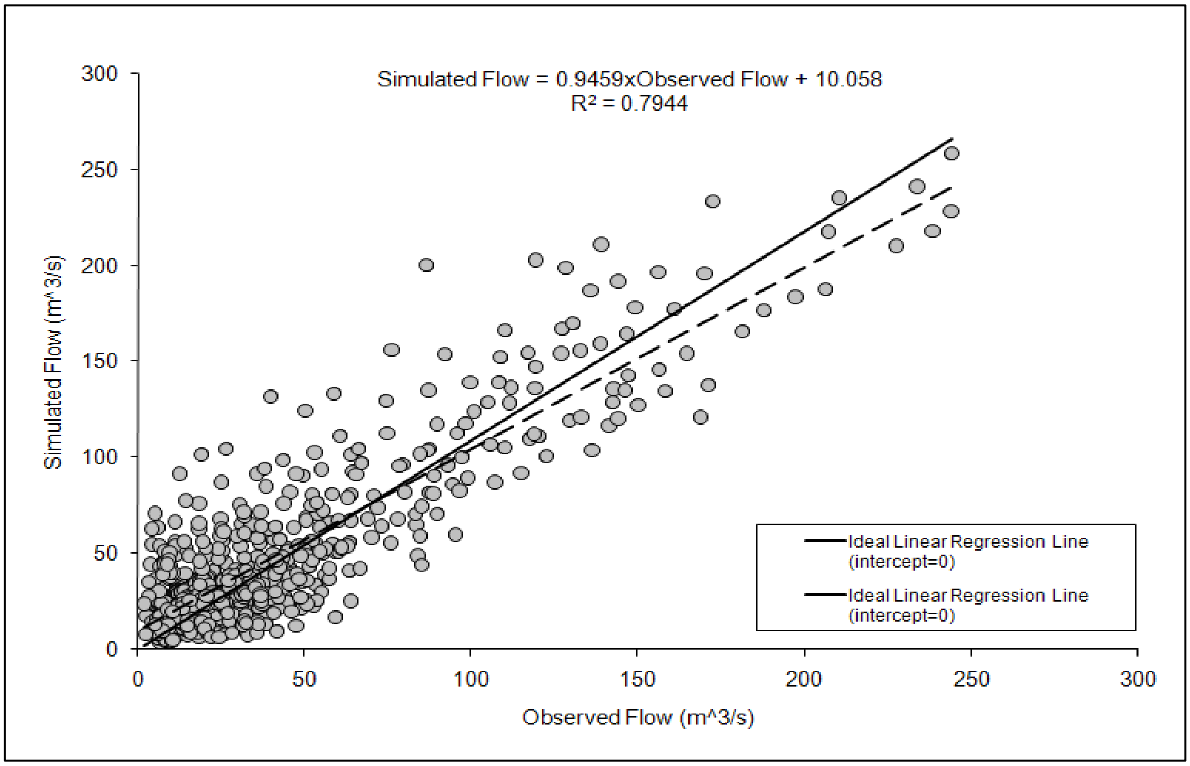


FIGURE 5.41
Scattered Plot for the Observed and Simulated Channel Flow at the Reach of Langat River during Validation Period

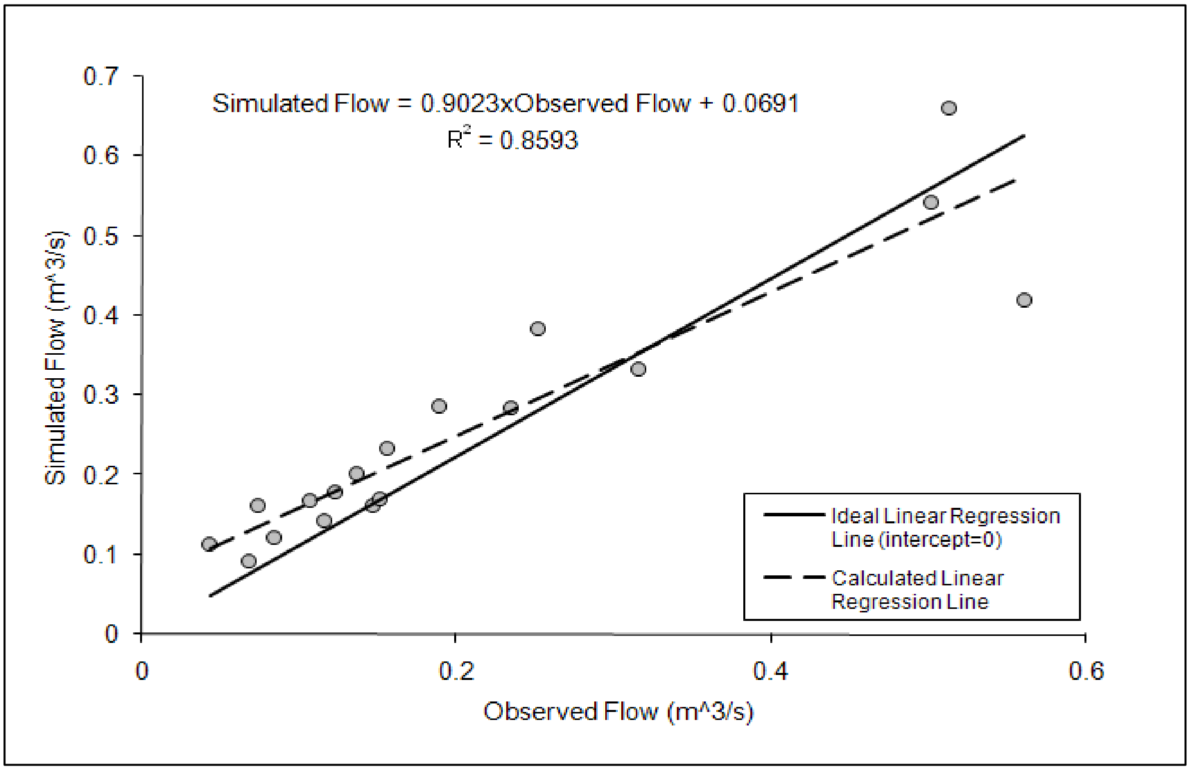


FIGURE 5.42
Scattered Plot for the Observed and Simulated Channel Flow at SWL2 during Validation Period

5.6 SENSITIVITY ANALYSIS

The sensitivity analysis was aimed at assessing the validated model behavior by weighing the set of parameters that have primarily the most influence on model output. A trial-and-error procedure was involved in this analysis until a satisfactory simulation was obtained. RMSE was chosen because in order to distinguish between sensitive and insensitive parameters, furthermore it can indicate the extent to which the predictions are over- or under-estimating observed values. A minimum possible value for RMSE respresented a satisfactory simulation. The results were expressed as a percentage of the average value of the observations.The analysis was conducted by modifying a single input parameters within their feasible limits, from the basic values while the rest were kept untouched during the analysis. By carrying out a series of model runs varying the parameter or input data within given ranges a general overview of the models sensitivity is established.

During the calibration process, Manning's Number coefficient for overland flow and the vertical saturated hydraulic conductivity of the top soil in the unsaturated zone were adjusted to model the peak flows. The horizontal and vertical hydraulic conductivity in the saturated zone and the leakage coefficient were considered during the calibration of groundwater head. The calibrated parameters are summed up in Table 5.5.

TABLE 5.5
Model Parameters and Statistical Evaluation of each Calibration and Validation Simulation Run

Trial	**MIKE SHE parameters**								**Measured**	**Simulation performance efficiency**			
	C1	**C2**	**C3**	**Cint**	**Aroot**	**K_v** (m/s)	**K_h** (m/s)	**M**	**Qo,ave** (m/s)	**Qs,ave** (m/s)	**R**	**ME**	**RMSE**
Calibration													
PIWc1	0.3	0.2	20	0	0.50	4.8E-05	1.0E-04	10	0.127	0.183	0.724	0.0060	0.3210
PIWc2	0.3	0.2	20	0	0.25	4.8E-05	1.0E-04	10	0.079	0.140	0.722	0.0044	0.2420
PIWc3	0.3	0.2	20	0.005	0.25	4.8E-05	1.0E-04	05	0.314	0.210	0.701	0.0117	0.2670
PIWc4	0.3	0.2	20	0	0.50	4.8E-05	1.0E-04	10	0.118	0.170	0.697	0.0088	0.2307
PIWc5	0.3	0.2	30	0	0.25	4.8E-05	4.0E-04	10	0.066	0.109	0.726	0.0058	0.2155
PIWc6	0.3	0.2	30	0.005	0.50	4.8E-05	4.0E-04	05	0.092	0.162	0.726	0.0058	0.2155
PIWc7	0.3	0.2	30	0	0.50	4.8E-05	7.0E-04	05	0.192	0.284	0.726	0.0058	0.2155
PIWc8	0.3	0.2	30	0	0.50	4.8E-05	7.0E-04	05	0.231	0.293	0.726	0.0058	0.2155
PIWc9	0.3	0.2	30	0	0.25	4.8E-05	7.0E-04	10	0.581	0.519	0.754	0.0118	0.2141
PIWc10	0.3	0.2	30	0.005	0.25	4.8E-05	7.0E-04	05	0.480	0.576	0.688	0.0361	0.2548
PIWc11	0.3	0.2	30	0.05	0.25	3.1E-05	4.0E-04	10	0.467	0.528	0.685	0.0603	0.6964
PIWc12	0.3	0.2	30	0	0.25	3.1E-05	4.0E-04	10	0.170	0.231	0.653	0.0151	0.2218
PIWc13	0.3	0.2	30	0	0.25	3.1E-05	7.0E-04	10	0.153	0.192	0.674	-0.3840	0.7545
PIWc14	0.3	0.2	30	0	0.25	3.1E-05	4.0E-04	10	0.118	0.175	0.677	0.0300	0.2227
PIWc15	0.3	0.2	30	0	0.25	3.1E-05	4.0E-04	10	0.240	0.300	0.688	0.0993	0.7306

TABLE 5.5 (Continued)

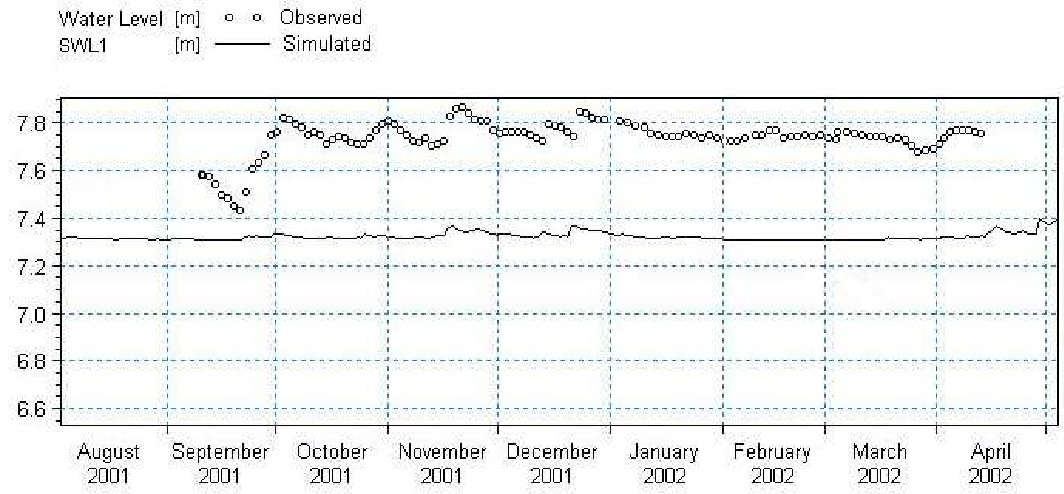
Validation													
PIWv1	0.3	0.2	20	0	0.05	3.1E-05	4.0E-04	10	0.137	0.145	0.715	0.0178	0.101
PIWv2	0.3	0.2	20	0	0.25	3.1E-05	4.0E-04	10	0.151	0.148	0.616	0.0139	0.127
PIWv3	0.3	0.2	30	0	0.50	3.1E-05	4.0E-04	10	0.043	0.056	0.716	0.0174	0.101
PIWv4	0.3	0.2	30	0	0.25	3.1E-05	4.0E-04	10	0.047	0.057	0.716	0.0174	0.060
PIWv5	0.3	0.2	30	0	0.25	3.1E-05	4.0E-04	10	0.051	0.059	0.680	0.0201	0.050
PIWv6	0.3	0.2	30	0	0.25	3.1E-05	4.0E-04	10	0.044	0.045	0.627	0.0064	0.133
PIWv7	0.3	0.2	30	0	0.25	3.1E-05	4.0E-04	10	0.053	0.055	0.571	0.0008	0.082

C1 , C2, C3 (mm/day), Cint, Aroot = actual evapotranspiration parameters of the Kristensen and Jensen model (1975);
K_v= horizontal hydraulic conductivity of the aquifer;
K_h = vertical hydraulic conductivity of the aquifer; M = Manning's number (reciprocal of Manning roughness coefficient);
Qo,ave = average value of observed streamflow;
Qs,ave = average value of MIKE SHE-simulated stream flows.

One of the main required implementations from the Paya Indah wetland model is estimation of the water balance for the modelled catchment and the stress on the water resource caused by adjacent development of Cyberjaya and groundwater abstraction at Megasteel Company's property. Looking at the overall water balance components it is clear that evapotranspiration accounts for the largest water loss from the model area, bearing in mind the tropical climate conditions of the area. It was thus essential to test the sensitivity of the actual evapotranspiration. The sensitivity runs were performed on different input variables mainly potential evapotranspiration, inflow depletion at SWL1, and groundwater abstraction. The latter was discussed comprehensively in Chapter 7.3 of this thesis. The test also included some other inputs parameter such as hydraulic conductivity and storage coefficient however, they were found of insignificant sensitivity thus excluded from the discussion. Generally, the calibrated model values and statistics represented the control run for all the sensitivity runs.

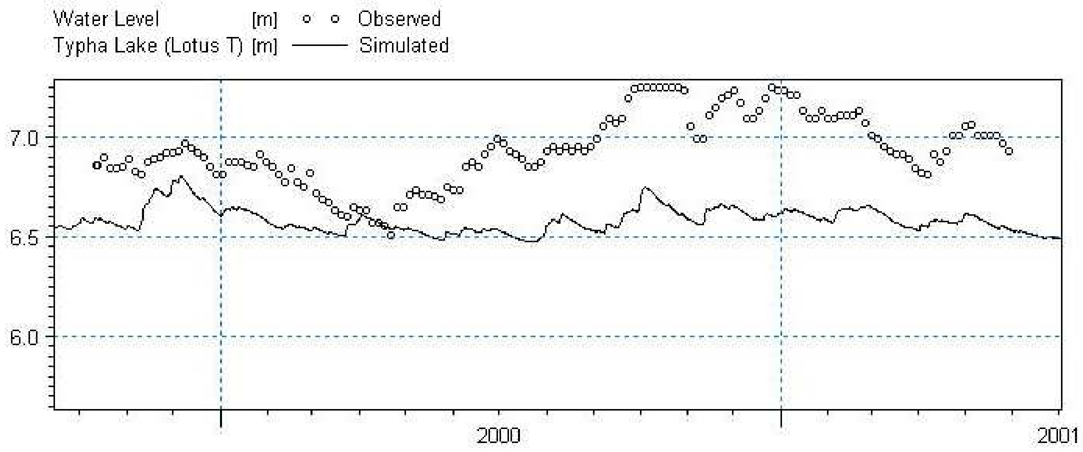
5.6.1 Effect of increment of evapotranspiration rate

In a confirmatory test aimed at investigating the degree of response of the validated model, the potential evapotranspiration was slightly increased to a uniform value of 5 mm/day for the whole catchment. Accordingly this modification resulted in a noticeable increase in the contrast in the actual evapotranspiration losses which in turn caused a dramatic drop of both surface water level and groundwater head. The water level declined within the ranges of 0.25m – 0.65m (average is 0.4m) and 0.20 m – 0.30m (average is 0.25m) in surface water and groundwater respectively (Figures 5.43 – 5.46).



ME=0.0492143
MAE=0.186628
RMSE=0.213678
STDres=0.207933
R(Correlation)=0.692257

FIGURE 5.43
Sensitivity Run for Assessing the Effect of ET Increment on Surface water Level at SWL1. Average drop of water level is about 40 cm



ME=0.346044
MAE=0.349422
RMSE=0.382968
STDres=0.164066
R(Correlation)=0.4741

FIGURE 5.44
Sensitivity Run for Assessing the Effect of ET Increment on Surface water Level at Typha Lake. Average drop of water level is about 40 cm

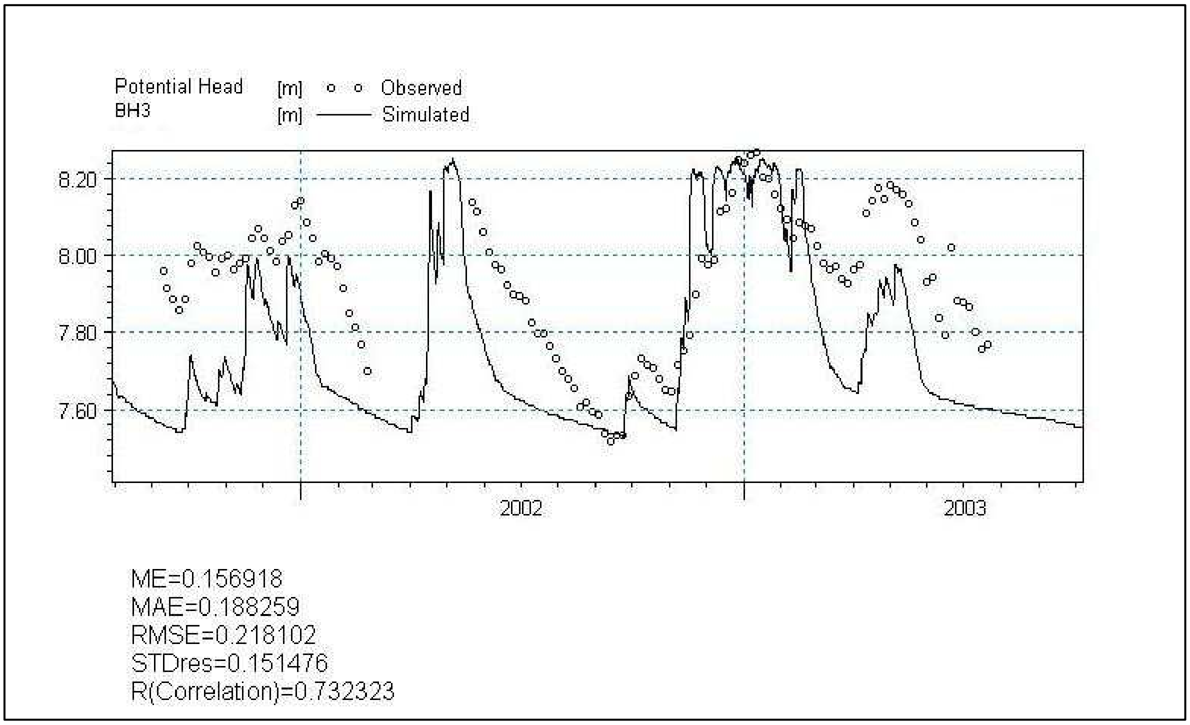


FIGURE 5.45
Sensitivity Run for Assessing the Effect of ET Increment on Groundwater Head at BH3. Average drop of groundwater table is about about 25 cm

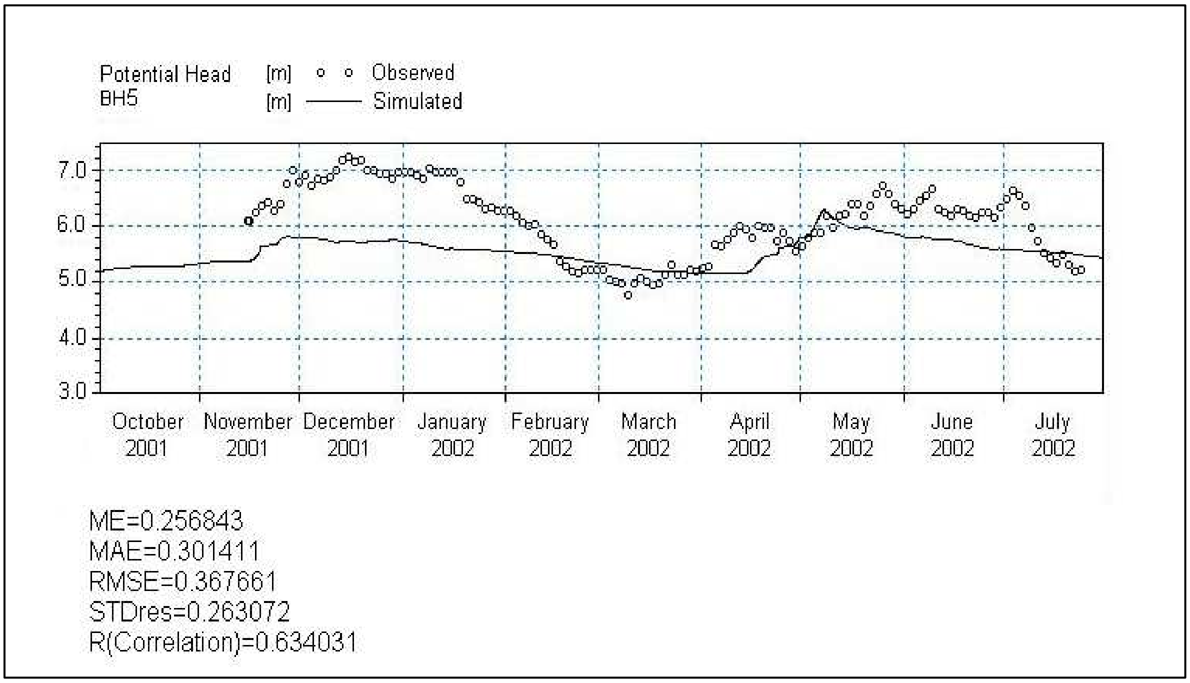


FIGURE 5.46
Sensitivity Run for Assessing the Effect of ET Increment on Groundwater Head at BH5. Average drop of groundwater table is about about 25 cm

The model demonstrated that increment and uniform distribution of the potential evapotranspiration had a greater effect on the surface water level and, surprisingly, the groundwater head as well. This phenomenon was observed at the Kuala Langat peat swamp forest upstream of the modelled catchment where the water table normally is close to or rises above the surface depending on the season (i.e. wet and dry). However, it seemed that this modification of evapotranspiration input did not affect the capability of the model to adequately simulate the dynamics in both surface water and groundwater. In fact it was found that assigning the reference evapotranspiration rate in a form of an actual daily timeseries that distributed evenly over the year; improve the model performance much better than the uniform value of 4 mm/day does. This finding efficienctly improved the simulation accuracy in both calibration or validation periods.

5.6.2 Effect of depletion of the inflow

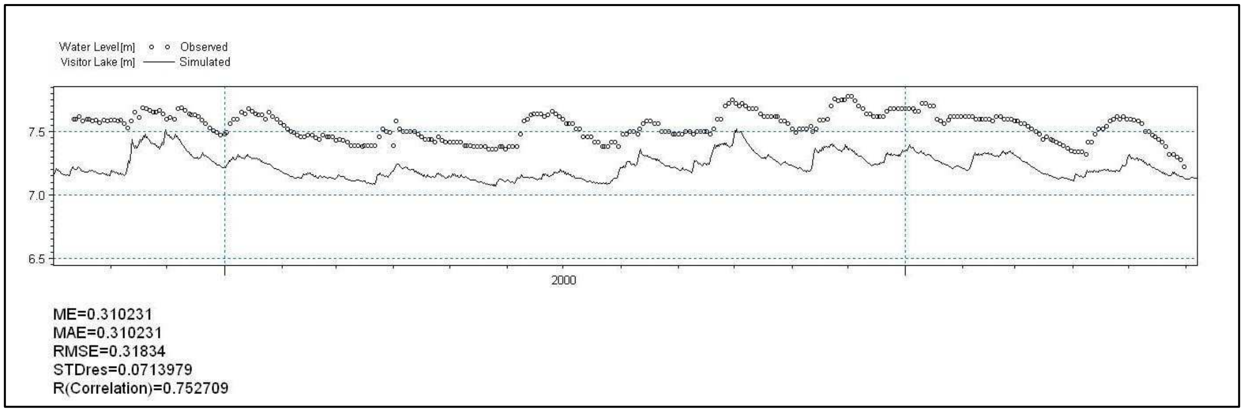
The sensitivity runs were performed to examine the change of the model upon depletion of inflow at SWL1. No significant difference was observed due to reduction of the flow rate by 10% however by 20 % and 50 % it dropped 0.10 to 0.15 m and 0.20 m to 0.25 m respectively (Table 5.6). While as 100 % depletion of the incoming flow to the system caused a drop within a range of 0.3 m to 0.60 m (Figures 5.47 – 5.52). However the water level at Driftwood, Tin, Perch and Marsh Lakes did not response to these modifications. Despite the seepage from overland flow, the fact that outer boundary of the Tin Lake extends some 2.5 km adjacent to the Kuala Langat swamp forest indicates of inflow from the shallow peat aquifer. This observation explained the tendency of these lakes to act as a sub-catchment within the Paya Indah Lakes system. In contrast the deep aquifer groundwater head showed insignificant response to the flow modifications. This result masked the assumption of occurrence of direct connectivity between the lakes system and the deep aquifer.

The above discussion demonstrated clearly that the model is very sensitive to evapotranspiration, overland flow diversion, and groundwater pumping (Chapter 7.3). However while the groundwater pumping influenced downstream of the catchment, the serious impact of both evapotranspiration and inflow dominated the whole catchment.

TABLE 5.6
Sensitivity of Different Flow Rate Modifications at SWL1

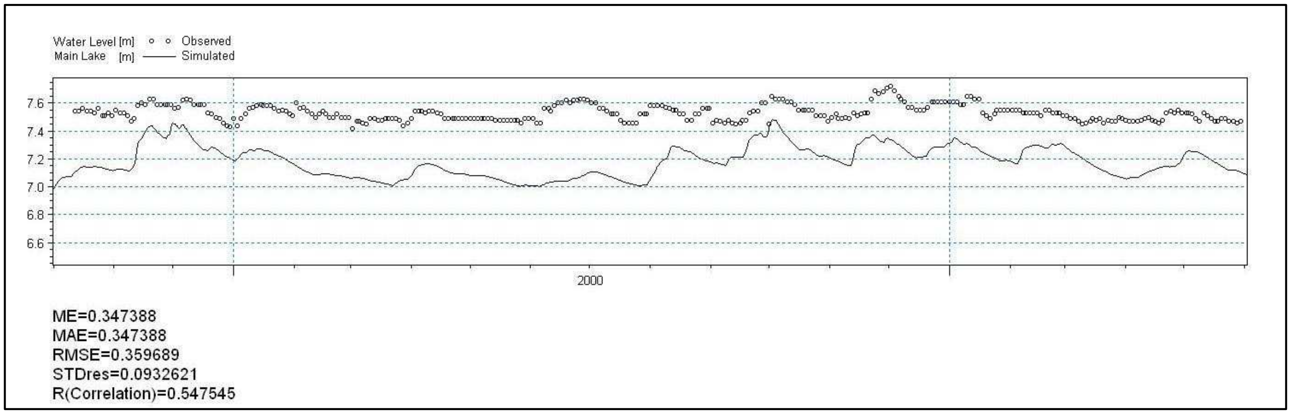
Reduction of Flow Rate (%)	**Water Level** (m)	**RMSE**
10	INS [a]	0.057 – 0.22
20	0.10 – 0.15	0.082 – 0.28
50	0.20 – 0.25	0.11 – 0.31
100	0.30 – 0.65	0.31 – 0.62

[a] INS: insignificant



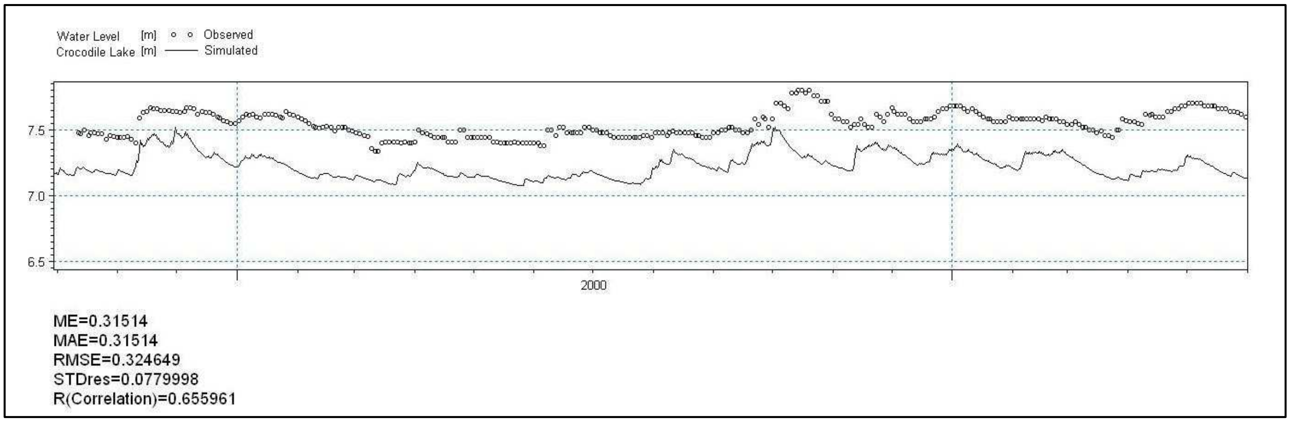
ME=0.310231
MAE=0.310231
RMSE=0.31834
STDres=0.0713979
R(Correlation)=0.752709

FIGURE 5.47
Sensitivity Run for Assessing the Effect of Flow Depletion at Visitor Lake



ME=0.347388
MAE=0.347388
RMSE=0.359689
STDres=0.0932621
R(Correlation)=0.547545

FIGURE 5.48
Sensitivity Run for Assessing the Effect of Flow Depletion at Main Lake



ME=0.31514
MAE=0.31514
RMSE=0.324649
STDres=0.0779998
R(Correlation)=0.655961

FIGURE 5.49
Sensitivity Run for Assessing the Effect of Flow Depletion at Crocodile Lake

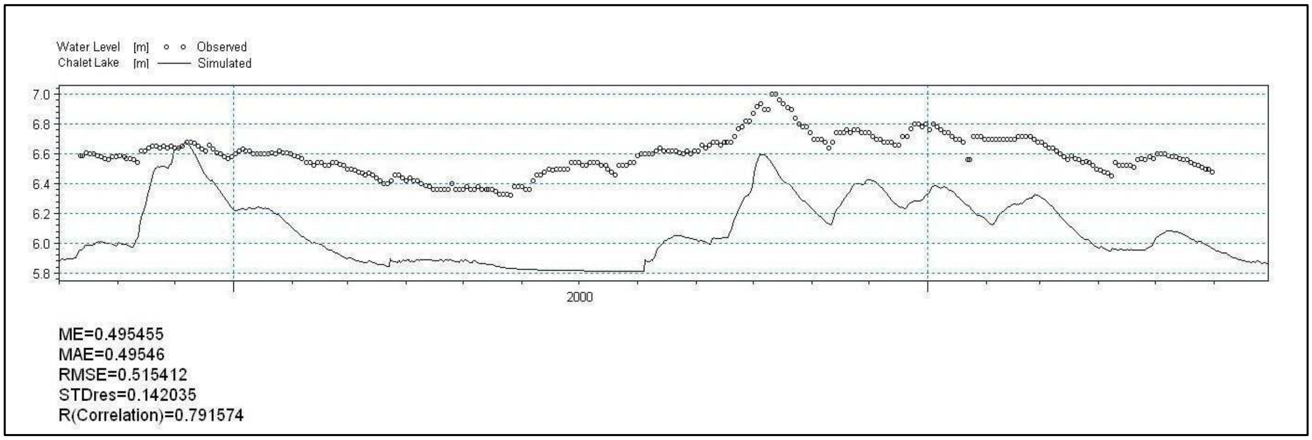


FIGURE 5.50
Sensitivity Run for Assessing the Effect of Flow Depletion at Chalet Lake

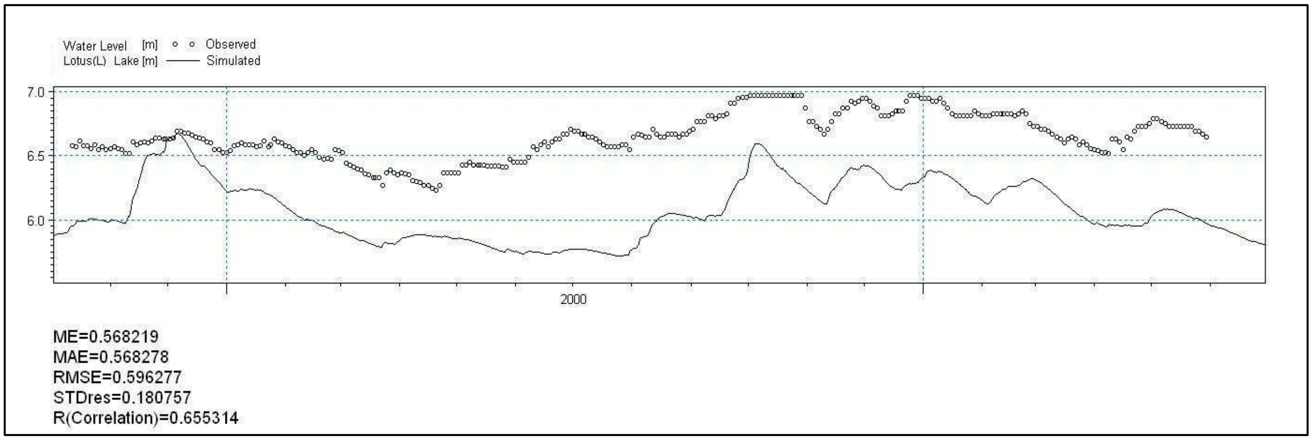


FIGURE 5.51
Sensitivity Run for Assessing the Effect of Flow Depletion at Lotus Lake

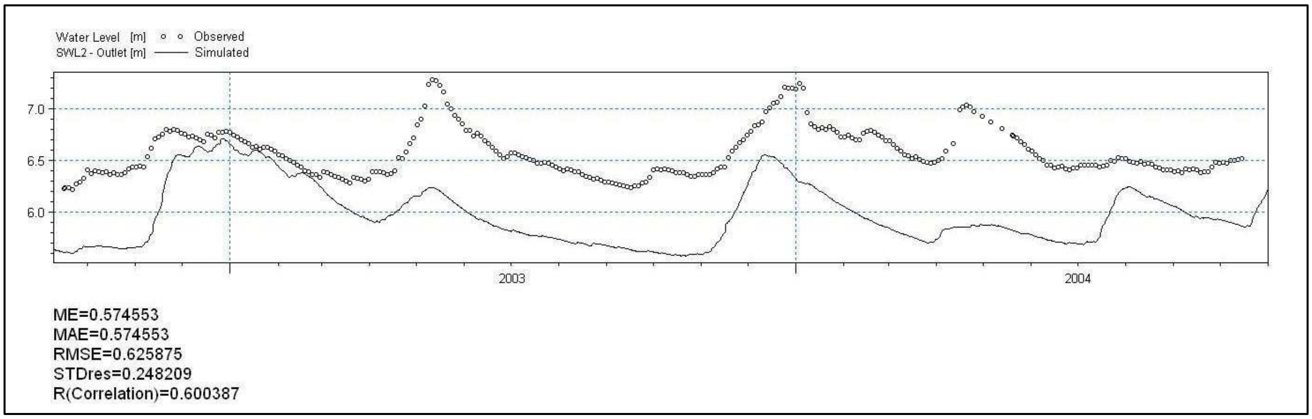


FIGURE 5.52
Sensitivity Run for Assessing the Effect of Flow Depletion at SWL2