CHAPTER VI

MODEL OUTPUTS

6.1 WATER BALANCE

Catchment water balance is controlled by climate variables and characteristics of the catchment. Thus, understanding individual hydrological processes and their relationships with climate and catchment characteristics is an important step in predicting catchment water balance (Zhang et al., 2008).

The distributed hydrologic coupled model of the Paya Indah wetland was used to estimate the total water balance for the modelled catchment in order to assess the anthropogenic impacts on the hydrologic system and propose the necessary restoration measures. However, other than addressing the impacts of the landuse and stress of groundwater abstraction on the hydrologic regime, the estimation of total water balance is a substantial issue to the Paya Indah wetland modelling since it can provide information on available water resources and demands in the catchment.

The total water balance for both calibration and validation periods are illustrated in Figures 6.1 and 6.2. Furthermore Table 6.1 shows the contribution of each water balance component. The model simulated all hydrological processes including evapotranspiration, recharge and runoff for both calibration and validation periods similarly both calibration and validation period. The water balance error was obtained by balancing all the major hydrologic components simulated in the model (precipitation, evapotranspiration, runoff, and changes in storage). This error was then divided by the precipitation and presented as a percent error. The water balance errors for the simulation during the calibration and validation period were less than 1% of the total precipitation for each, indicating a satisfactory model performance.

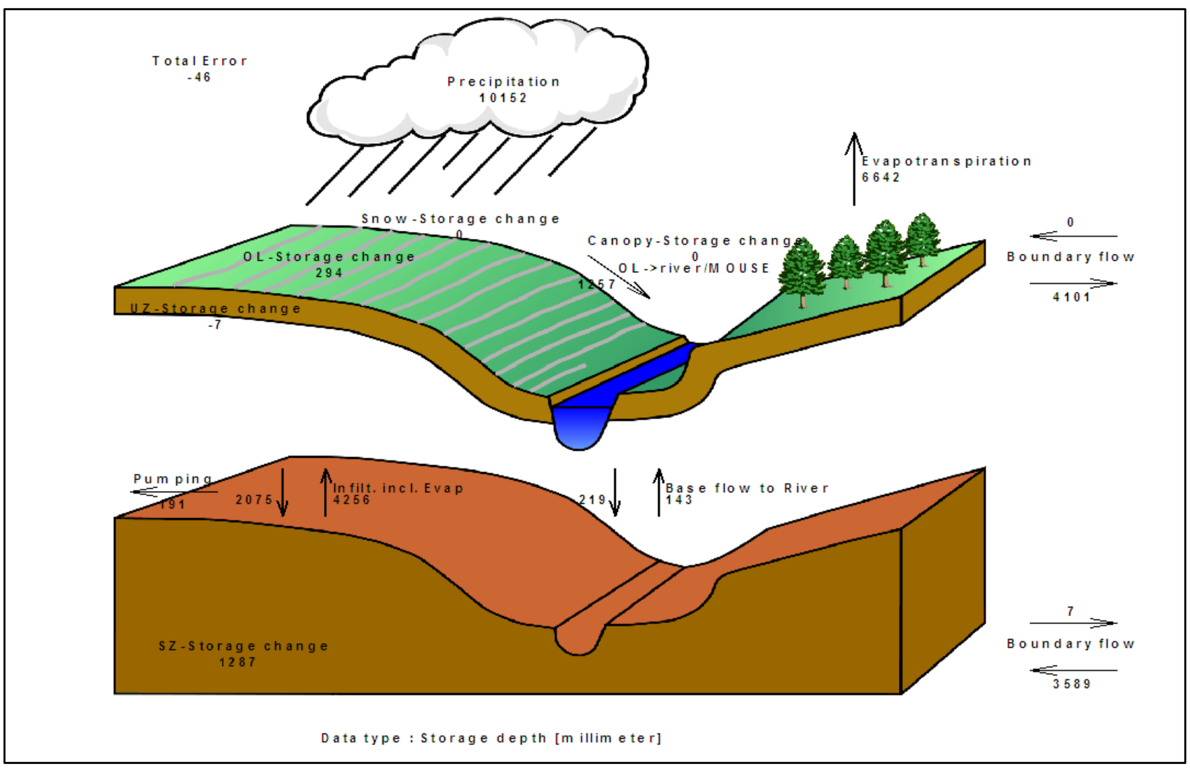

FIGURE 6.1
Water Balance for Paya Indah Wetlands Catchment (~ 242 km^2) for the Simulation Period 1/July/1999 to 31/October/2004

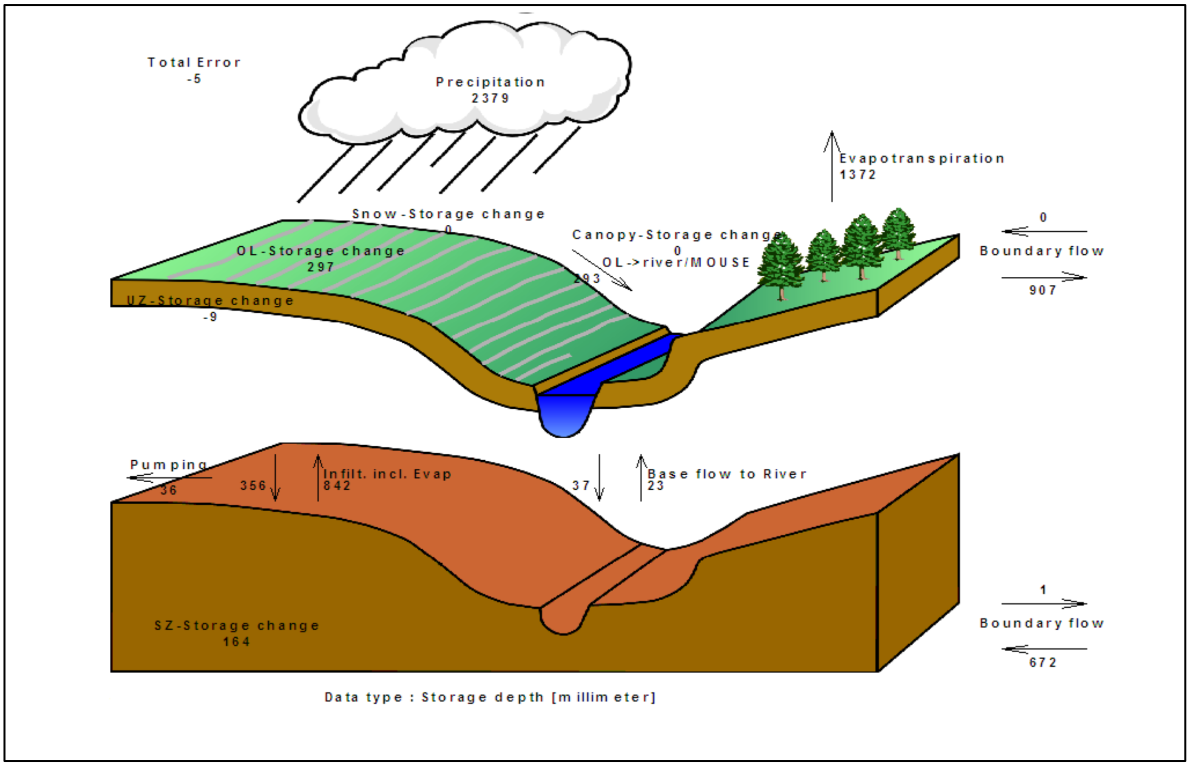

FIGURE 6.2
Water Balance for Paya Indah Wetlands Catchment (~ 242 km^2) for the Simulation Period 1/August/2007 to 2/August/2008

The results clearly show that a considerable portion of the rainfall was emitted through evapotranspiration losses in which represented approximately 65% and 58% of the total rainfall during calibration and validation periods respectively. Figures 6.3 and 6.4 illustrate the spatial distribution of the mean actual evapotranspiration across the catchment during wet and dry seasons respectively. It was evidenced that the greatest loss was from the lakes body and the ponded-water areas of the Kuala Langat swamp forest.

TABLE 6.1
Water Balance Estimation at the Paya Indah Wetland Catchment: Contribution of each Component

Component [a]	**Contribution** [b] (mm)			
	A		**B**	
Rainfall	-10151.92	(~ 38.39x10^6 m^3/month)	-2378.992	(~ 47.98x10^6 m^3/month)
Evapotranspiration	6642.422	(~ 25.1x10^6 m^3/month)	1371.626	(26.57x10^6 m^3/month)
OL-Storage Change	293.8065	(1.11x10^6 m^3/month)	296.7130	(5.98x10^6 m^3/month)
UZ-Storage Change [c]	-7.42357	(0.028x10^6 m^3/month)	-9.18930	(~ 0.19x10^6 m^3/month)
SZ-Storage Change [d]	1286.706	(~ 4.87x10^6 m^3/month)	164.4070	(~ 3.324x10^6 m^3/month)
OL-East Boundary Flow	4101.120	(~ 15.5x10^6 m^3/month)	907.3588	(~ 18.30x10^6 m^3/month)
SZ-East Boundary Flow	7.113633	(~ 0.03x10^6 m^3/month)	1.425129	(~ 0.03x10^6 m^3/month)
SZ-West Boundary Flow	3589.464	(13.57x10^6 m^3/month)	672.4775	(13.56x10^6 m^3/month)
OL-River flow	1257.136	(4.75x10^6 m^3/month)	292.6367	(5.90x10^6 m^3/month)
Groundwater Pumping	190.5930	(0.72x10^6 m^3/month)	35.77259	(0.72x10^6 m^3/month)
SZ-Infilt. Incl. Evap	2075.308	(~ 7.85x10^6 m^3/month)	356.3273	(~7.19x10^6 m^3/month)
SZ-exfilt. Incl. Evap	4256.417	(16.09x10^6 m^3/month)	841.7275	(16.97x10^6 m^3/month)
SZ- South Base Flow	218.9202	(~ 0.83x10^6 m^3/month)	37.41158	(0.75x10^6 m^3/month)
SZ- North Base Flow	142.9813	(0.54x10^6 m^3/month)	22.94681	(0.46x10^6 m^3/month)
Total Error	-46.0 (0.46%)	(0.17x10^6 m^3/month)	-5.0 (0.21%)	(0.10x10^6 m^3/month)

[a] OL: overland flow; UZ: unsaturated zone; SZ: saturated zone; Infilt: infiltration; Exfilt: exfiltration, Evap: evapotranspiration

[b] A: represents the period from July 1st, 1999 – October 31st, 2004 (64 months); B: represents the period from August1st, 2007 – August 2nd, 2008 (12 months)

[c] Negative sign indicates a relatively descending change of the water stored in the unsaturated zone

[d] Positive sign indicates a positive ascending change of the overland water stored in the pond.

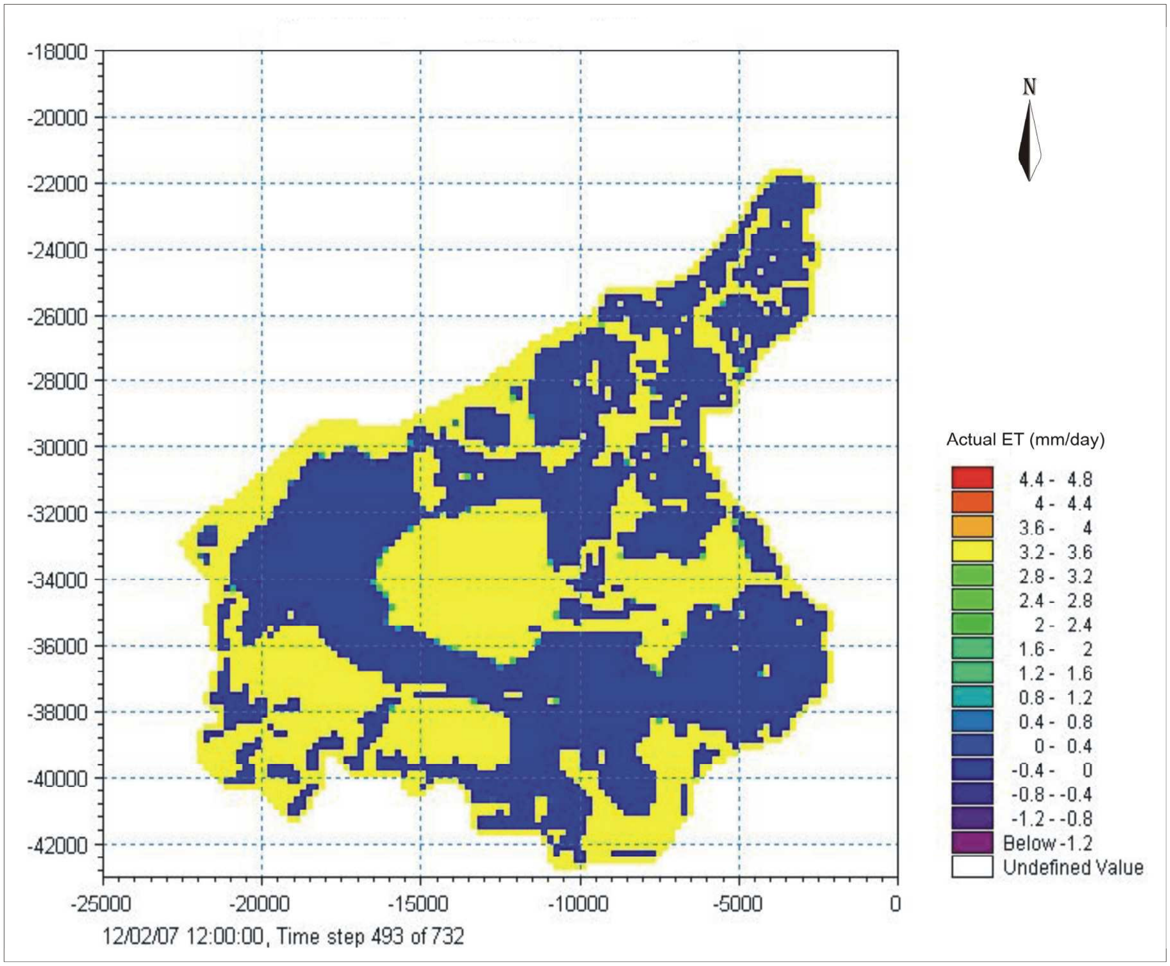

FIGURE 6.3
Distribution of Actual evapotranspiration at Paya Indah Wetland Catchment during a Normal Day in the Wet Season (September to March)

Furthermore during the simulations periods, the huge cumulative water loss of ~ 0.53×10^6 and ~ 0.57×10^6 m^3/day by exfiltration process across the catchment, considerably influenced groundwater recharge and dynamics by deepening the groundwater head. In fact, while the observation data are normally point-values that are measured at specific locations within the catchment, the model simulations represent the mean groundwater head within ~ 242 km^2 area. This result strengthened the linkage between the recent dropping of surface water level of the Paya Indah Lakes system and to the elevated levels of the evapotranspiration rates, (e.g. ~ 5 mm/day during dry seasons; and 3.7 during wet seasons) in the last four years. Overall, the model somehow underestimated the total water balance during the calibration and validation periods by 0.45% (~2.09×10^6 m^3/year) and 0.21% (~1.21×10^6 m^3/year) respectively.

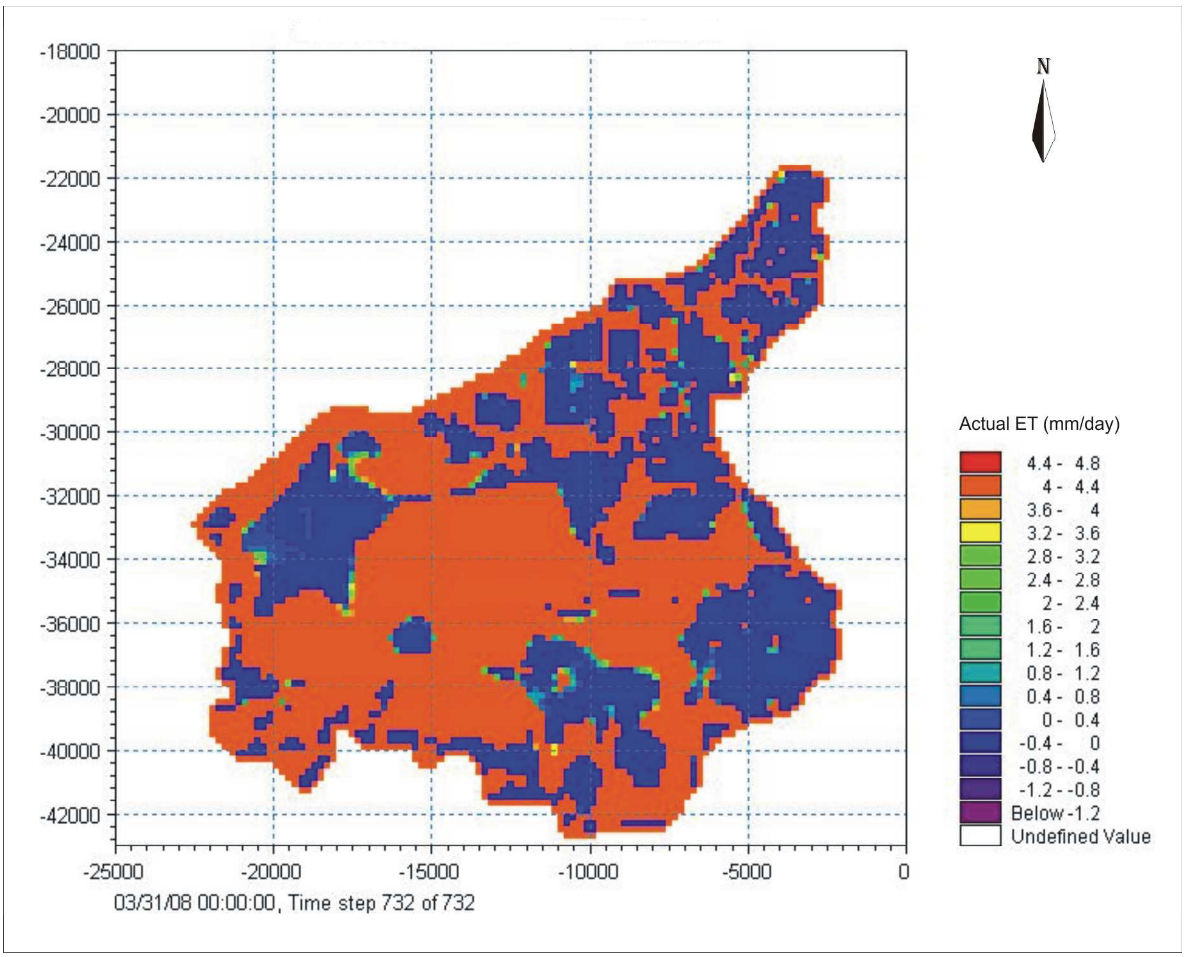

FIGURE 6.4
Distribution of Actual evapotranspiration at Paya Indah Wetland Catchment during a Normal Day in the Dry Season (April to August)

6.2 SATURATED AND UNSATURATED FLOW INTERACTIONS

The interaction between surface water including over land water and groundwater within the catchment of Paya Indah wetland takes place in three basic ways. These include seepage of overland flow (layer1), deep aquifer recharge from unsaturated zone (layer 2), and saturated zone and river lateral flow (layer3).

6.2.1 Overland flow

The relatively low Manning Number of 5.0 (five) resulted in occurrence of a large amount of accumulating water mainly in Kuala Langat peat swamp forest and the lowland downstream south of the catchment. Figure 6.5 illustrate the spatial distribution of the mean water level on the top layer in each grid point over one year of simulation, as well as the overland water depth. During storm event when high runoff occurs, a mean water level of about 0.8m initiates and, depending on the developed gradient, flows to the nearest lower grid points. Bearing in mind the nearly flat topography especially at the peat, this situation results in occurrence of water pressure gradient which affects the groundwater head elevations and most possibly developed some recharge zones (for the deep aquifer) at upstream in the northern part of the catchment where normally the unsaturated zone is thinner, and downstream areas which currently are located within the discharge zone of the Megasteel production wells.

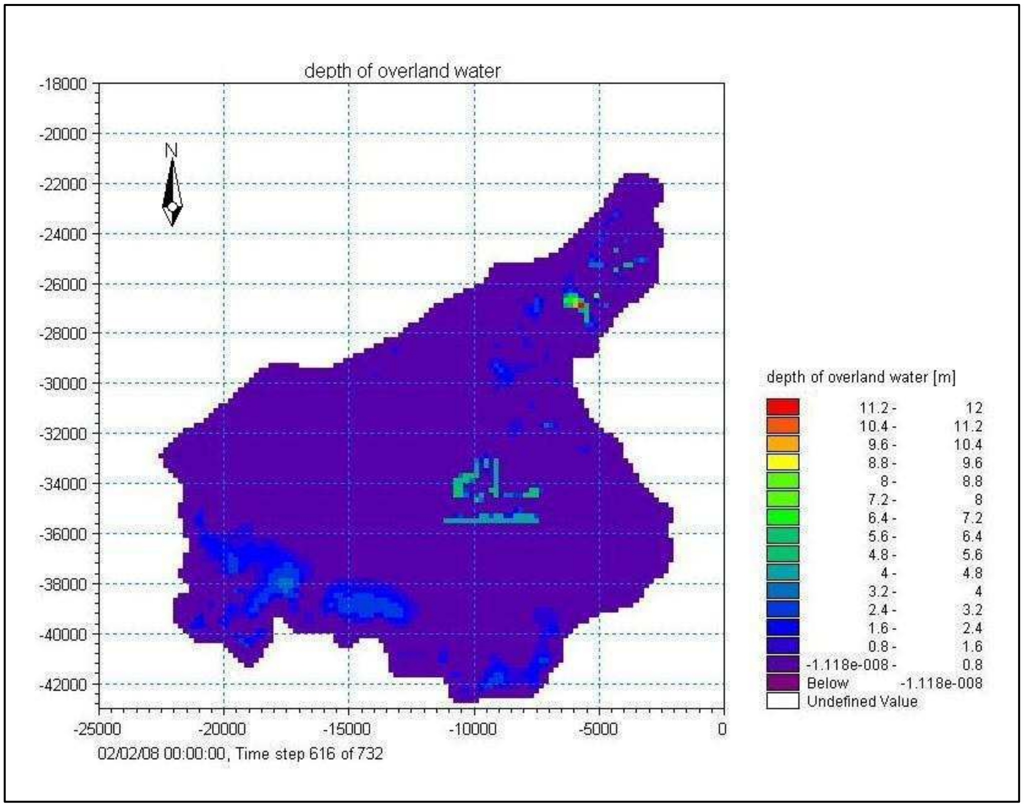

FIGURE 6.5
Depth of Overland Water during a Normal Day in Wet season (September to March)

6.2.2 Flow exchange between unsaturated and saturated zones

Upward flow from the water table is triggered once moisture depletion has reached the groundwater body. This feedback to evapotranspiration is termed capillary rise (Schroder and Rosbjerg, 2004). In a tropical area with excess rainfall the actual evapotranspiration is nearly to the potential evapotranspiration i.e. if a sufficient volume of water is available within the root zone or in the capillary fringe the simulated actual evapotranspiration will equal the potential rate. Conversely, in water shortage situation the potential rate will be reduced accordingly as a function of the available soil moisture in the root zone. In the Paya Indah wetland catchment the unsaturated zone is very shallow during wet seasons, thus infiltration and evapotranspiration are the essential processes that control simulation of the rate of recharge. Results revealed that the saturated zone gained a great deal of recharge water. About 15 % of the rainfall however, seemed to be lost by the exfiltration process which represents two magnitudes of the recharge (Table 6.1). Figures 6.6 – 6.7 illustrate the vertical fluctuations of the groundwater head in the unsaturated zone during wet and dry seasons respectively. The three distinguishable arrows represent 2D rotated orthogonal vector overlay while the smaller ones represent the groundwater flow in x-direction.

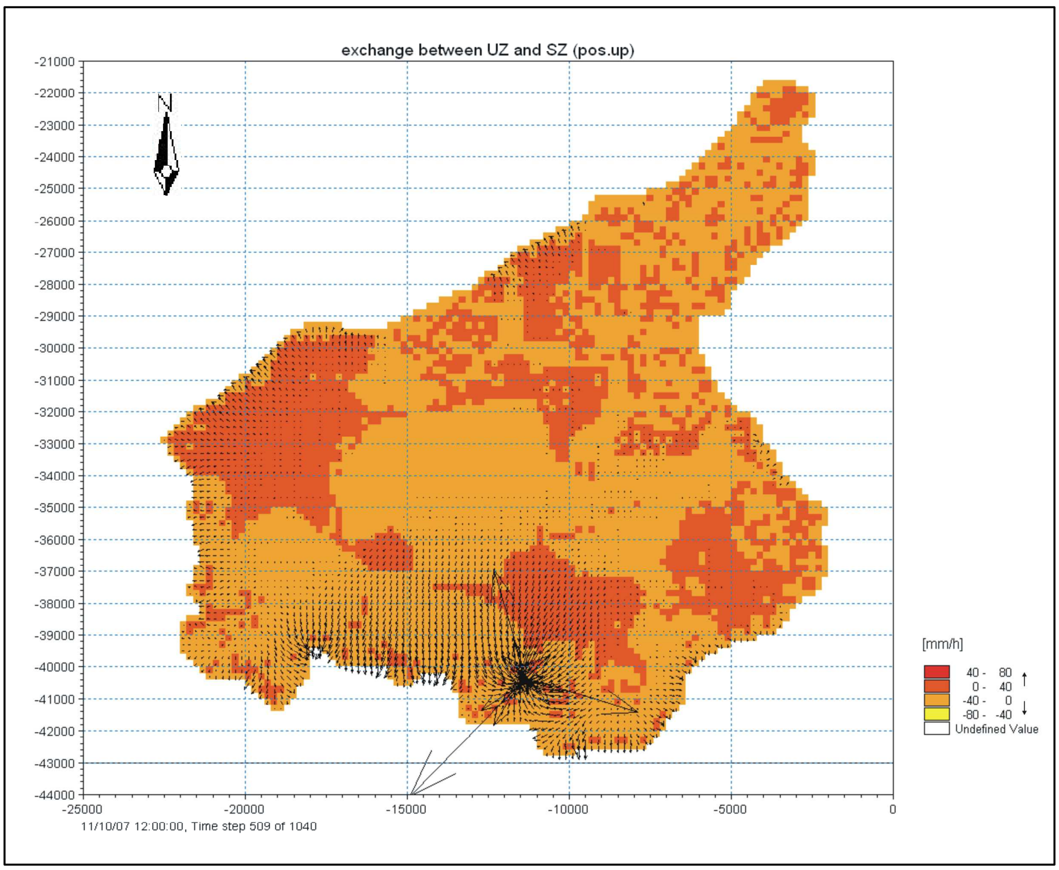

FIGURE 6.6
Unsaturated-Saturated Zones Flow Exchange during a Normal Day during Wet Season (September to March)

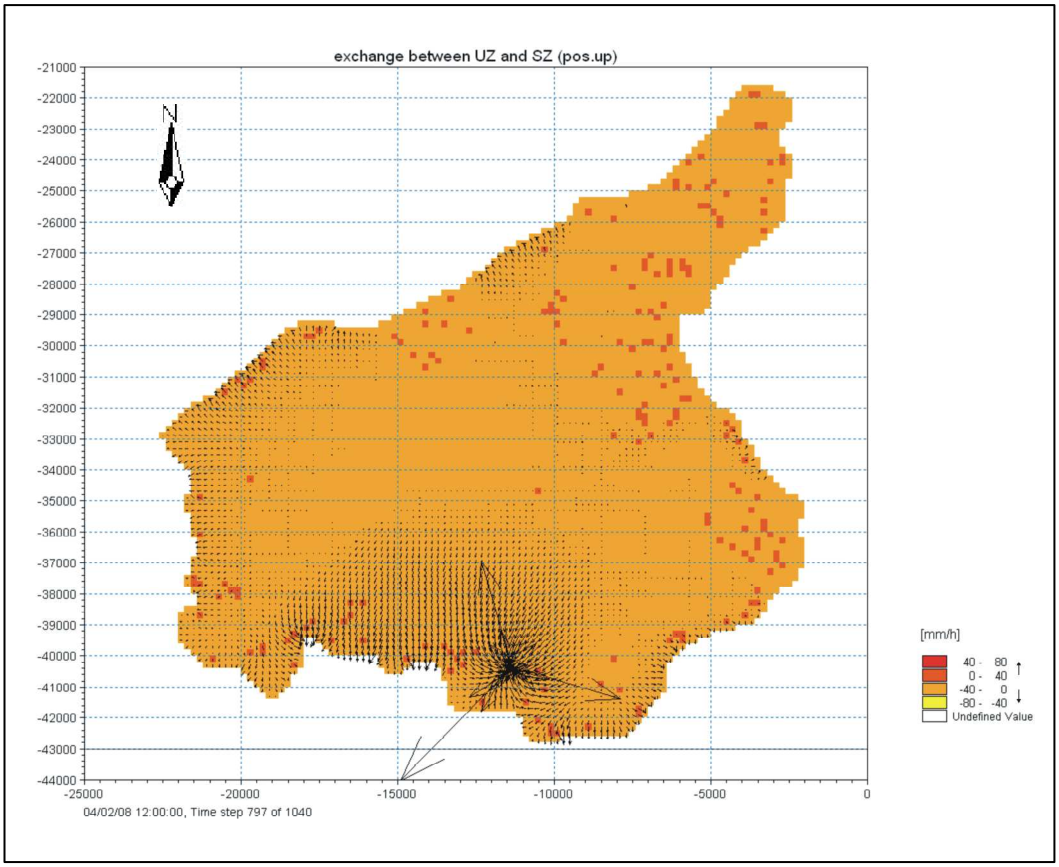

FIGURE 6.7
Unsaturated-Saturated Zones Flow Exchange during a Normal Day during Dry Season (April to August)

It is clear that the extensive discharge zone at the Megasteel wells at the south east corner of the catchment has developed a recharge area which influenced the adjacent lower part of the unsaturated zone. Another major recharge area occurred at the south west part as a result of groundwater outflow across the model boundary. It seemed that the stress caused by the load of overland water head on the peat surface at the east and Kuala Langat swamp forest at northwest parts of the catchment resulted in the elevated recharge rates at these areas. While as the central part including the area of the Paya Indah Lakes system showed a very little recharge.

6.2.3 Saturated zone and river lateral flow

Groundwater inflows that entered the model (baseflow) were calculated, using Darcy's equation, as a function of the head gradient between the canal water level and the adjacent groundwater level and a hydraulic resistence (leakage coefficient) which control the surface water and groundwater interaction. The Paya Indah Lakes are modelled as normal branches in MIKE11. The lakes do however appear with a spatial distribution on the ground surface and thus receives direct rainfall as well as depletion by open water evaporation. The lakes are rested on a very low permeability clayey layer which seals the bottom of the lake. Accordingly, the interaction between the lakes system and the saturated zone flow is very limited. Unlike the lakes system, the Langat River and the downstream reaches of the Lotus-Outlet and North Canal showed a constant lateral flow with the deep aquifer as illustrated in Figure 6.8. The overall baseflow of the modelled catchment ranges from 2.2% to 1.5 % of the total rainfall (Table 6.1).

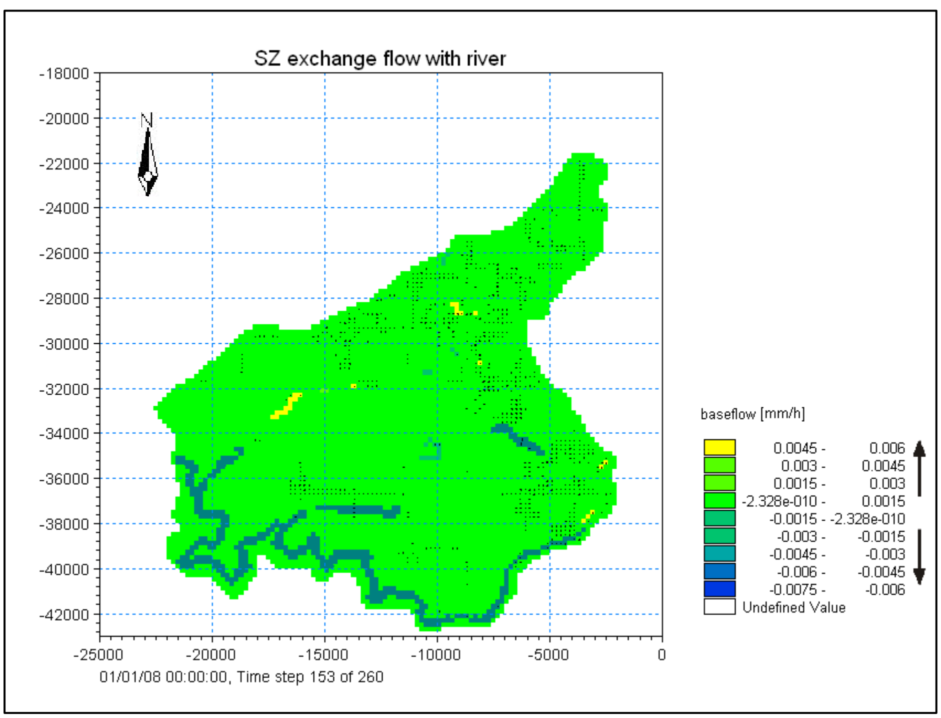

FIGURE 6.8
Flow Exchange between Saturated Zone and Channel Flow

6.3 HYDROLOGICAL IMPACT OF GROUNDWATER ABSTRACTION

The impact of the stressful groundwater abstraction at the Megasteel property (four production wells of 55 m to 60 m depth) on the Paya Indah lakes system and the shallow aquifer of the peat layer were investigated. It found that the estimated amount of the abstracted groundwater by Megasteel represented 8.3% of the effective recharge; and the latter represents 18.3 % of the total rainfall (Table 6.1). Consequently it was found that the area occupies the bottom (southern) part of catchment was adversely influenced by the pumping. Based on the sea level, the water table dropped between -12.0 m to 0.0 m depending on how far the location is from pumping well (Figure 6.9). The groundwater flow on the other hand, was extremely affected; and due to development of lateral flow, a portion of the groundwater was pushed across the model boundary and illustrated in Figure 6.10.

Unlike the major drainages, the Paya Indah Lakes rest on the top of a very low vertical permeability layer of silty clay constituents of 9.95E-7 $m.s^{-1}$ to 1.2 e-8 $m.s^{-1}$ (Minerals and Geoscience Department of Malaysia, 2002). This situation makes this layer act as a barrier preventing, in most cases, vertical flow between the top layer and the aquifer at the bottom layer. However, in certain conditions the vertical flow might develop as discussed earlier in this Chapter. Thus one can conclude here that the groundwater abstraction at the Megasteel property seriously affected the downstream part of the catchment. Furthermore, the fact that the pumping caused the groundwater head to drop about 4 – 12 m below the sea level, should be taken as an alert to avoid an anticipating seawater intrusion that might occur as consequence of long-term pumping.

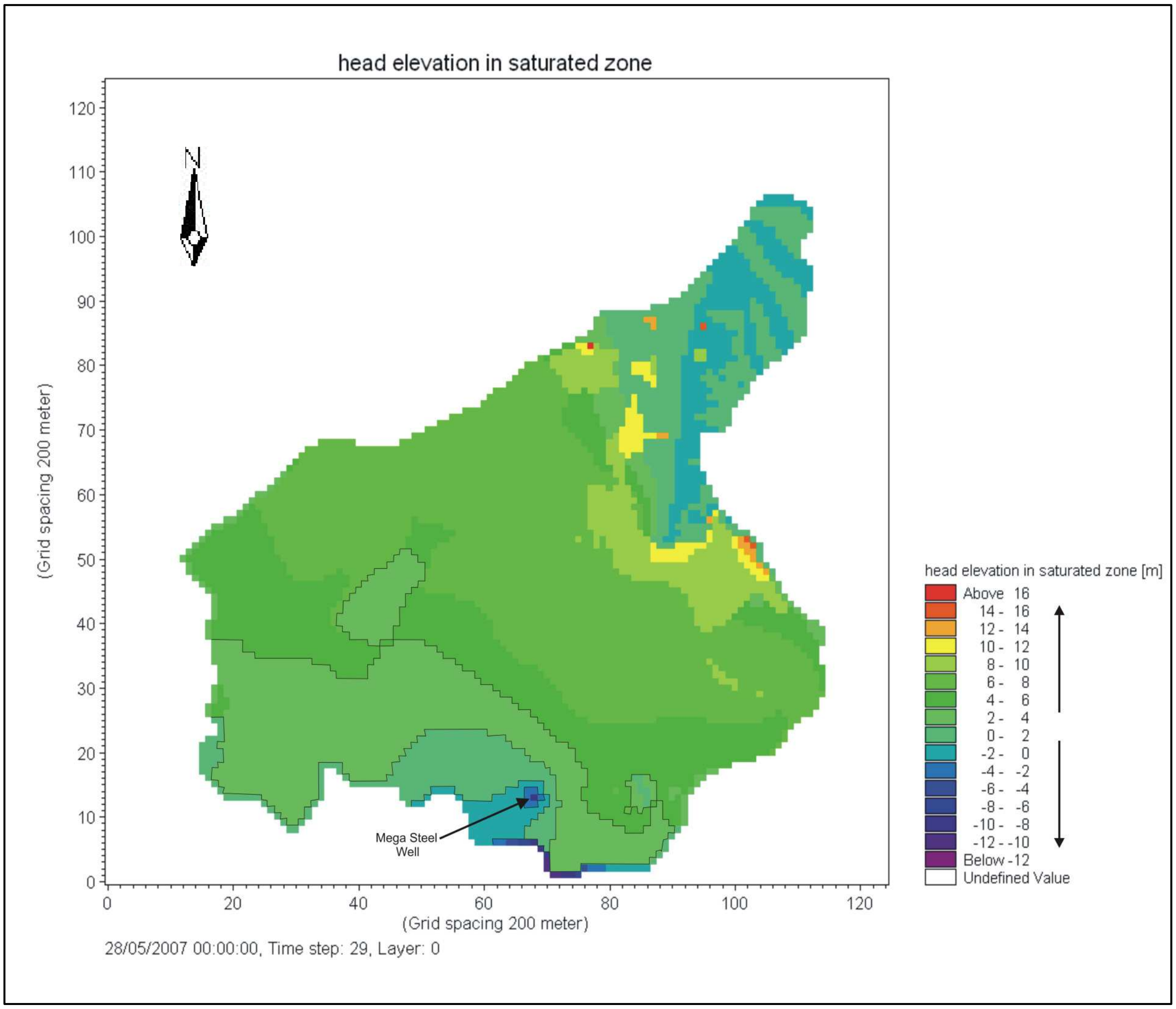

FIGURE 6.9
Impact of Groundwater Pumping at the Megasteel Wells on the Groundwater Head Elevation

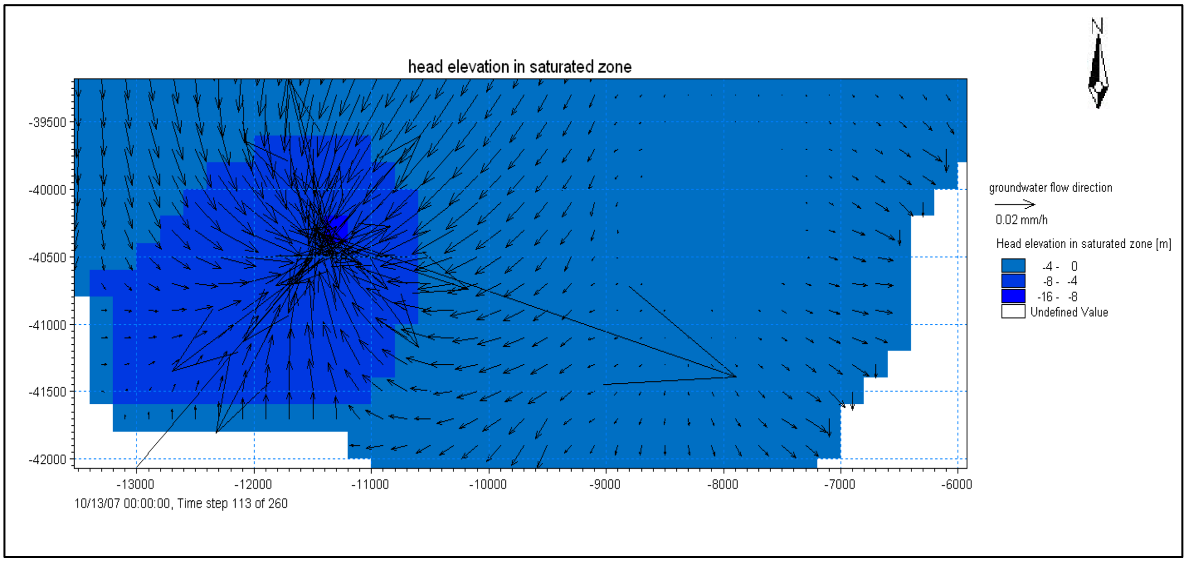

FIGURE 6.10
Impact of Groundwater Pumping at the Megasteel on the Groundwater Flow Direction

Apart from that, occurrence of land subsidence around the area of Megasteel property was an inevitable adverse, but expected, consequence of the groundwater pumping. Likewise the uncertainty associated with the rate of groundwater abstraction, the maximum level of subsidence in the area recorded by the Megasteel Co. Ltd. since 2000 to 2007 was 02 cm to 59 cm (Smart Survey Consultant, 2007); while as the survey that was conducted by Minerals and Geoscience Department of Malaysia from the year 2001 – 2006 indicated that the land surface around the pumping area was subsidizing to a level ranges between 0.9 cm to 48.1 cm depending on the location of measurement from the Megasteel wells (Minerals and Geoscience Department of Malaysia, 2007). Nonetheless, the results of both surveys (Tables J.6 and J.7 in Appendix J) evidenced that the aquifer started losing its pore water pressure due dropping of the groundwater associated with withdrawal of large amount of water with irregular abstraction rate which in turn might have led to an occurrence of a compressive deformation of the aquifer material. Based on the finding that the compaction of the aquifer is directly proportional to the water level drop in the aquifer (Sun et al., 1999) these results were in a good consistence with the recent dropping of groundwater head of ~ 0.75 m compared to a few years back (Figures 5.17 and 5.37). This finding was similar to the results obtained by Phien-wej et al. (2006) who investigated the Land subsidence in Bangkok City and found that the monitoring data showed a clear correlation between the subsidence and piezometric drawdown. They suggested that for 1 m^3 of groundwater pumped out in Bangkok Plain, approximately 0.10 m^3 of ground loss occurred at the surface.

The above discussion demonstrates that the groundwater abstraction at the Megasteel Co. Ltd. area might not be responsible of surface water dropping in the Paya Indah Lakes system; however, it is definitely responsible of occurrence of at least partial collapse of the deep aquifer which caused the ground subsidence.