Catchment modelling

Module 7 WSE - HI River basin modelling

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1. Q2

Consider model Integrated_2a (in which land use changes were introduced). Its analyses are presented on pages 21-23 of the Catchment Modelling exercise report (please revise this part). Make accumulated water balance for the overland (OL) and unsaturated zone (UZ) components. Compare these results with the same water balances of model Integrated_1, presented on pages 7-10 of the Catchment Modelling exercise report ,and explain the differences. Use whatever additional results you find appropriate to support your explanations.

1.1 Water balance for the overland (OL)

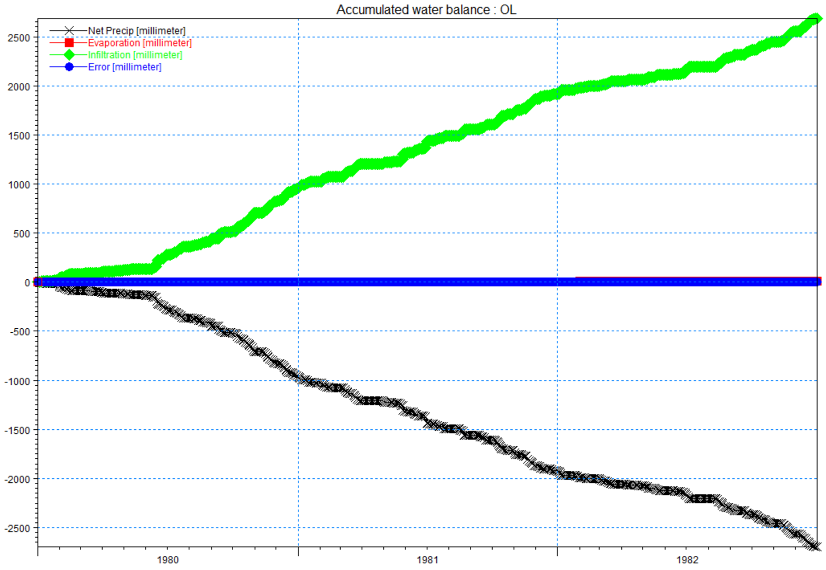

Figure 1. The accumulated water balance: OL in Integtrated_1

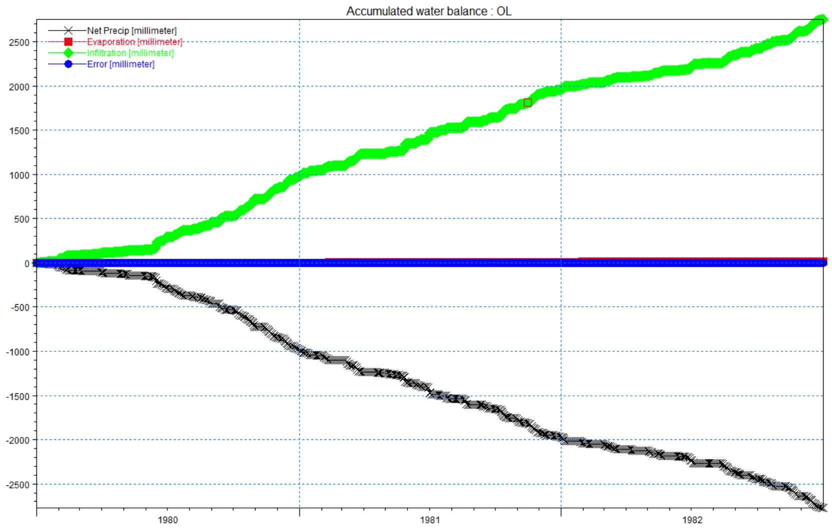

Figure 2. The accumulated water balance: OL in Integtrated_2a

Table 1. The final results of the accumulated water balance: OL

	Time	1-Net Precip (mm)	2-Drip Irrigation (mm)	3-Evaporation (mm)	4-Infiltration (mm)
Integrated_1	1/1/1983 00:00:00	-2695.37	0	10.9839	2684.39
Integrated_2a	1/1/1983 00:00:00	-2771.66	0	19.0557	2752.61

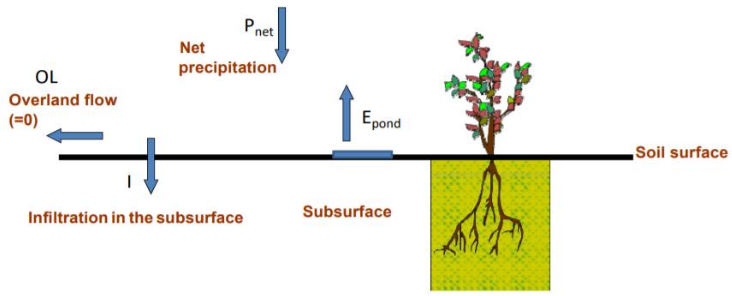

Figure 3. Schematic representation of the Overland Flow (OL) component

Since we set the Manning roughness coefficient is 0, the overland flow can be ignored. The formula for the overland component is as follows:

$$\mathrm{P}_{net} + I + E_{pond} = 0 \tag{1}$$

Through comparison, all three absolute values of the net precipitation decline, evaporation and infiltration increase in Integrated_2a model. I will analyse the changes in the three variables separately.

1.1.1 More net precipitation

The net precipitation is the outflow from the canopy interception component. Two models have the same precipitation condition, but the Integrated_2a model has a larger interception (2771 mm compared to 2695 mm of the original model) due to the difference in land use. According to the formula calculating the max interception storage capacity (I_{max}) and Interception of rainfall by the canopy (ET_{canopy}):

$$\mathrm{I}_{max} = C_{int} \times LAI \tag{2}$$

$$\mathrm{ET}_{canopy} = \min(I_{max}, E_p \times \Delta t) \tag{3}$$

LAI refers to leaf area index, and the forest and wetland own higher LAI compared to the agriculture. Therefore, the precipitation loss total 76 mm reduction before reaching the overland.

1.1.2 More evaporation

Although most of the throughfall is expected to infiltrate, some water may also evaporate through OL ponding on the soil surface. As shown in Figure 4 below, there is indeed more OL ponding accumulation in the Integrated model. This is a phenomenon occurring in most cases, while a small part is just the opposite. Overall, OL ponding has improved compared to the original model.

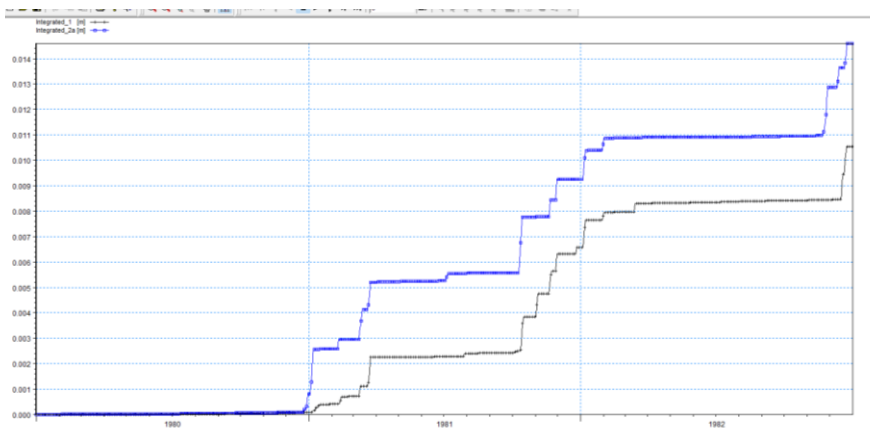

Figure 4. OL ponding accumulation in one cell of two cases

Integrated_2a declines the root depth, that is to say, the infiltration capacity of the soil. The change in land use has led to aggravate the phenomenon that the net rainfall rate exceeds this capacity, which is easy to pond water on the groundwater surface. Since the overland flow cannot be formed, more water sources gather together to form OL ponding and produce more evaporation. (from 11mm to 19mm)

1.1.3 More infiltration

Infiltration is governed by two forces, gravity, and capillary action. Among them, the capillary is affected by the root depth. Forest and wetland vegetation types have a larger root depth compared to agriculture. Their reduction gives the infiltration process less resistance, so this value of Integrated_2a goes up from 2684 mm to 2753 mm.

1.2 Water balance for the unsaturated zone (UZ)

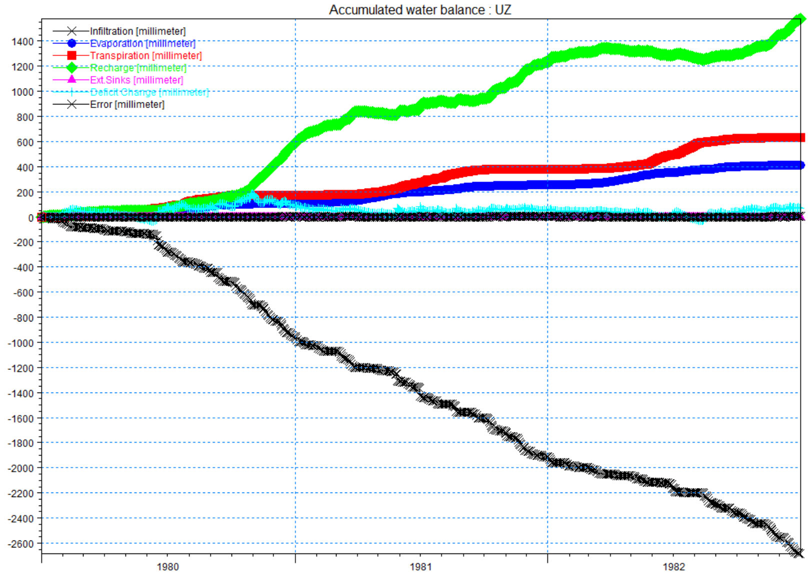

Figure 5. The accumulated water balance: UZ in Integtrated_1

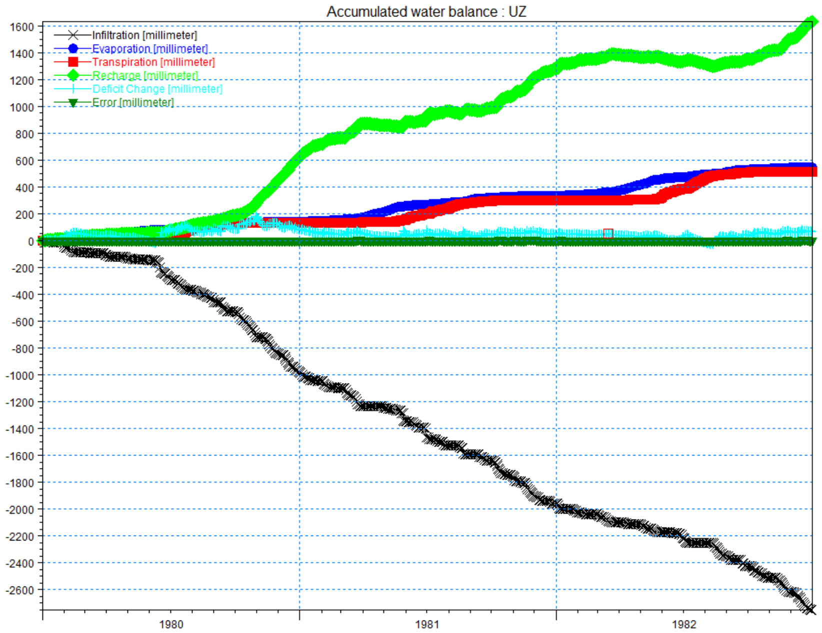

Figure 6. The accumulated water balance: UZ in Integtrated_2a

Table 2. The final results of the accumulated water balance: UZ

	Time	1-Infiltration (mm)	2-Evaporation (mm)	3-Transpiration (mm)	4-Recharge (mm)	5-Ext.Sinks (mm)	6-Deficit Change (mm)	7-Error (mm)
Integrated_1	1/1/1983 00:00:00	-2684.37	411.831	630.157	1578.01	0	65.9899	1.61709
Integrated_2a	1/1/1983 00:00:00	-2752.61	545.069	512.131	1631.91	0	65.165	1.67382

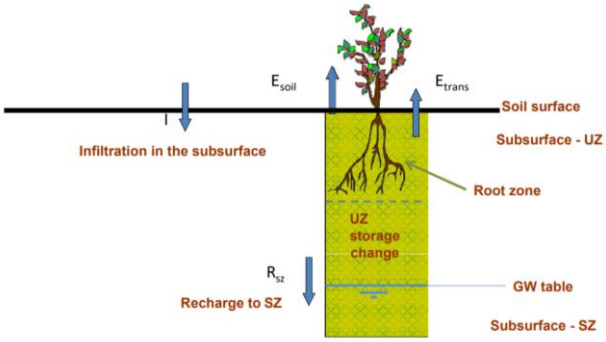

Figure 7. Schematic representation of the Unsaturated Zone (UZ) component

The accumulated water balance of the UZ is shown in Figure 7. It shows the following balance among the five components:

$$\mathrm{I} + \mathrm{E}_{soil} + \mathrm{E}_{trans} + UZ_{SC} + R_{sz} = \mathrm{Error} \qquad (4)$$

The infiltration which was an outflow from the OL component is now inflow to the UZ component. In addition to this, the soil evaporation and the recharge to the SZ component increase, the transportation decreases, and the UZ storage change are almost the same (65 mm in model 2a and 66 mm in the original model). I will analyse the changes in the four variables separately.

1.2.1 More soil evaporation

The soil evaporation takes from the first node in the UZ, just below the soil surface. This process is affected by the LAI variable, and the change in land use causes more land to be exposed to the sun without leaves blocking it. Thus, the amount of soil evaporation increases to 545 mm from 412mm.

1.2.2 Less transpiration

The root uptake for transpiration happens from several nodes, depending on the defined depth in the root zone. The forest and wetland own higher root depth value compared to agriculture. The change in land use causes fewer nodes and less area to generate this component. Thus, the amount of soil evaporation decline to 512 mm.

1.2.3 More recharge

The phenomenon that the recharge has increased to 1631mm from 1578mm is due to the decreased size of the UZ. This is because of the higher groundwater tables, which are shown in Figure 8 below. It shows the time series of depth to the phreatic surface for one cell as an example. Note that Integrated_2a has a higher groundwater table (smaller UZ size). That prompts UZ flow taking place over a smaller portion of unsaturated conditions. Thus, water that would be stored in the UZ now recharges the SZ.

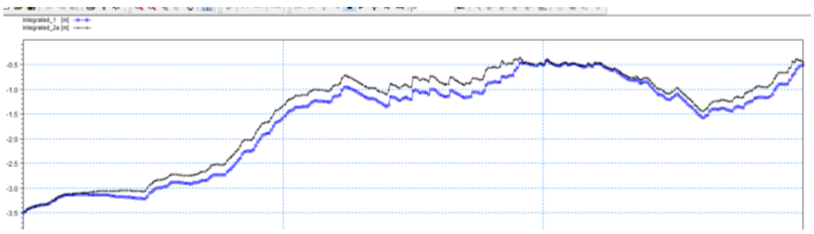

Figure 8.Depth to phreatic surface in the cell (22, 12) of two cases

1.2.4 Almost constant for UZ storage

Normally, the UZ storage change is determined by two terms: the UZ volume and the water content. As discussed earlier, Integrated_2a has a smaller UZ volume due to higher groundwater tables. However, it owns higher amounts of water content in the UZ due to less water being lost to ET (from 1410 mm to 1476 mm). This can be proved by Figure 9, which indicates water content in the first point of the UZ discretion. These two conditions compensate each other, resulting in approximately the same Deficit Change.

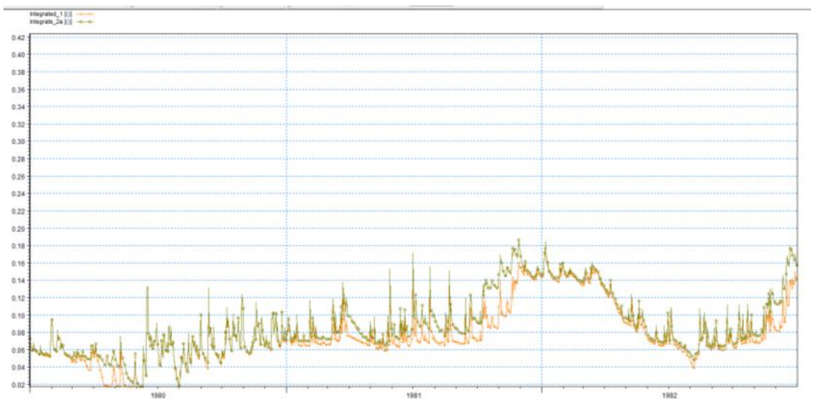

Figure 9. Water content in the unsaturated zone (22, 12, 1) of two cases

1. Q5

Consider models Integrated_1 (the first integrated model developed), Integrated_2a (in which land use changes were introduced), and Integrated_2b (in which river-aquifer exchange was modified). Generate the river flow hydrographs at the outlet of the catchment for these three models and explain their differences. For clearer explanations you can also present a zoomed-in graph of these hydrographs for a shorter part of the simulation period (for example, the last six months of the simulation). Explain and support your answers with additional results, as you find appropriate.

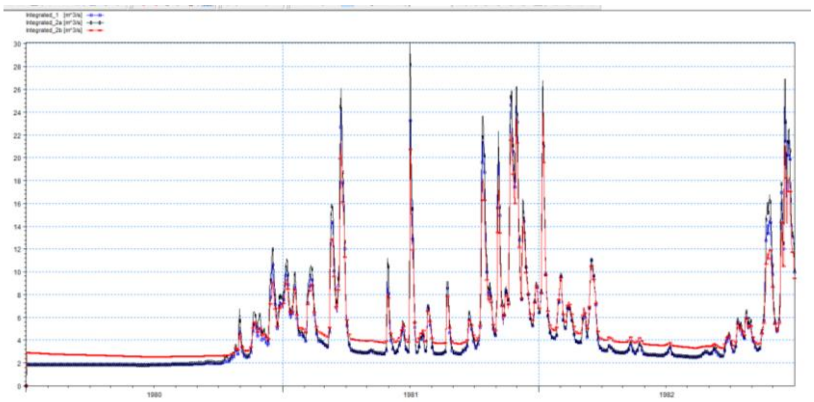

Figure 10. The river flow hydrograph at the outlet

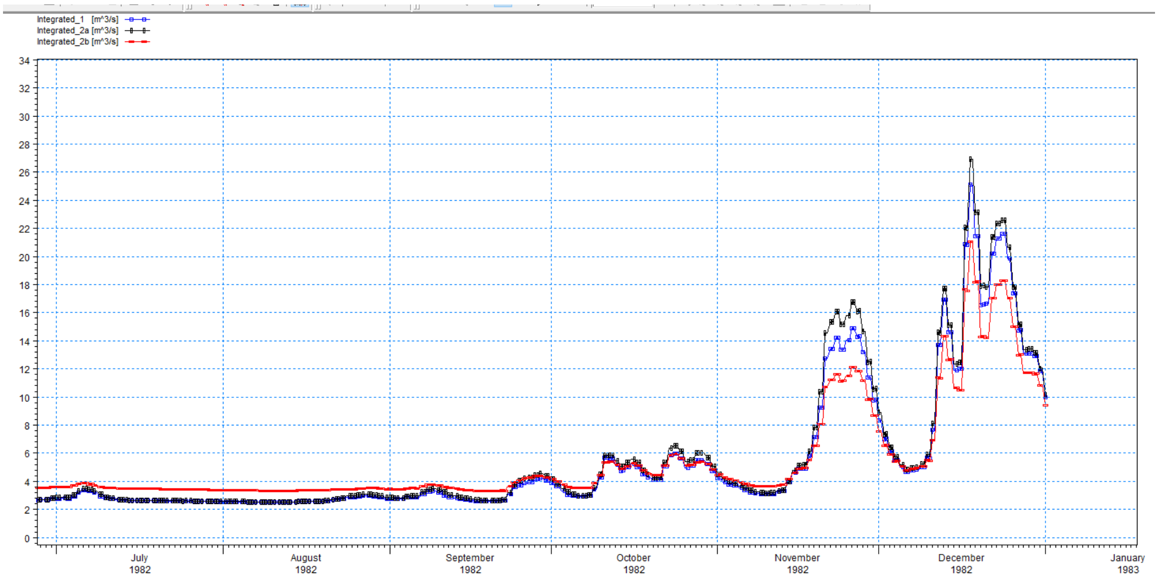

Figure 11. A zoomed-in graph of the hydrograph

Figure 10 illustrates the hydrograph at the catchment outlet for the three models: Integrated_1, Integrated_2a, and Integrated_2b. A zoomed in representation of these three for the period from July 1982 to the end of December 1982 is presented in Figure 11. From this figure, it is obvious to separate two parts to analyse: the low rainfall period and the high rainfall period. Besides, we need to analyse the period from January 1980 to October 1980.

2.1 The low rainfall period

Integraeted_2b has the highest discharges among three models during periods of low rainfall. The discharge of Integrated_2a is slightly higher than the original model. The reason for the result is that the periods of the low rainfall are baseflow-dominated (slow component). Integrated_2b has larger conductance due to using 'Aquifer only' for the river aquifer exchange. Whereas in the original model, it should consider both the conductance of the river bed and the aquifer materials. The calculation formula for the two cases is as follows:

$$C = \frac{K d_a d_x}{d_s} \tag{5}$$

$$C = \frac{1}{\frac{d_s}{K d_a d_x} + \frac{1}{L_c w d_x}} \tag{6}$$

Eq5 and Eq6 are for 'Aquifer only' and 'Aquifer + River' separately. Integrated_2b has less resistance to generate the baseflow component. According to the exchange flow calculation (Eq7), we need to plot the groundwater level for one cell. (Figure 12) Its coordinate is (6, 30) located the side of the outlet of the catchment. Since the difference between the groundwater head in these cells and the water level in the river is relatively constant throughout the simulation period, the groundwater head always relatively high above the river head level. Through Figure 12, we can get that the groundwater level in Intgrated_2b reduces compared to Integrated_1. After the coordination of the two terms, Q of Integrated_2b is still larger than the original one.

$$Q = C \times \Delta h \tag{7}$$

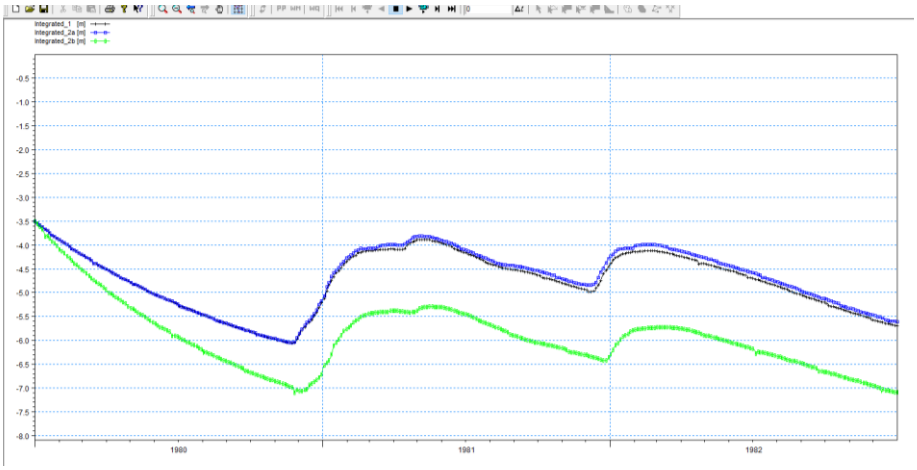

Figure 12. The groundwater level for cell (6, 30) among integrated_1, Integrated_2a, and Integrated_2b

For Integrated_2a in the low rainfall period, its baseflow is slightly larger than the original model. Only in the period from January 1980 to October 1980, its baseflow value coincides with the original model. Both have the same conductance, so the baseflow is controlled by the groundwater level beside the outlet of the catchment. Observing Figure 12, we can conclude that the depth to the phreatic surface has the same trend in the low rainfall period. This is because the vegetation value at this point (6077, 30888) is 1, representing agriculture, and it has not changed compared to the original one. That can explain why the early period data will coincide. For the period from July 1982 to the end of December 1982, Integrated_2a's groundwater level is higher than the original one. Similarly, the discharge of Integrated_2a is larger than Integrated_1.

2.2 The high rainfall period

In periods of high rainfall that produce the peaks of the hydrograph, Integrated_2b has the lowest value, and Integrated_2a has the highest one. This process is dominated by drainflow (fast component). When the groundwater level exceeds the drainage level (0.5m below the soil surface) in the summer, the catchment generates drainage flow to the river. Through the depth to phreatic surface graph (Figure 12), the groundwater level is sorted from large to small as Integrated_2a, Integrated_1, and Integrated_2b, which is also the order of discharge.

Figure 10 shows no peaks at the beginning of the simulation since the drainflow in the entire area is 0 in this period as the groundwater tables overall are still below the drain level.

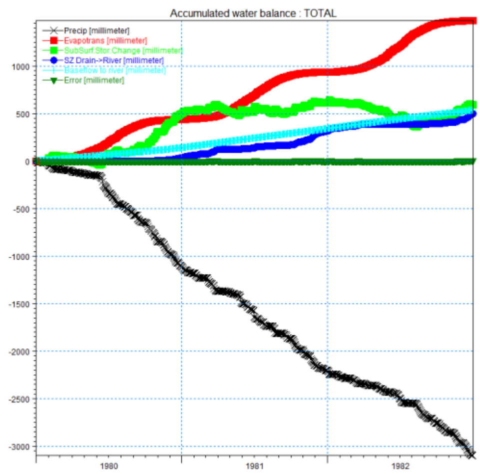

Figure 13. The accumulated water balance: TOTAL in Integtrated_1

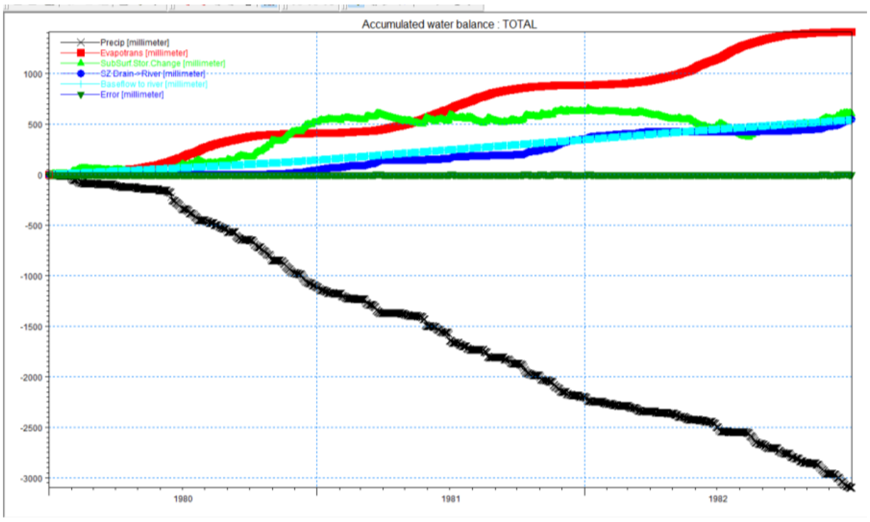

Figure 14. The accumulated water balance: TOTAL in Integtrated_2a

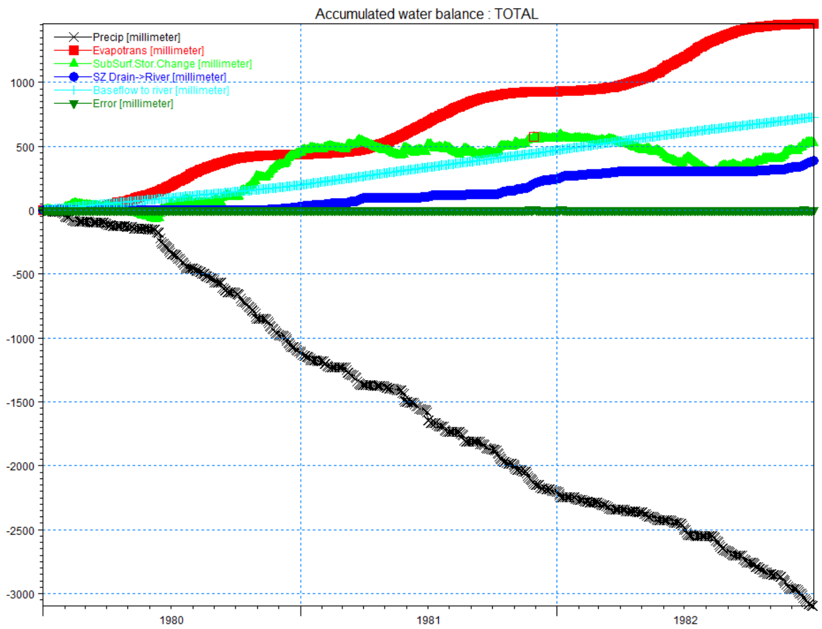

Figure 15. The accumulated water balance: TOTAL in Integtrated_2b

2. Q7

In the model Integrated_1 change the drain time constant from 5.6 x 10^{-7} to 1 x 10^{-7} 1/s. You can name this model Integrated1_B. Generate chart water balance results. Compare the water balance results of this new model (Integrated1_B) with those of Integrated1 and explain the differences. Generate the river flow hydrographs from the two models at the outlet of the catchment and explain the differences. Support all your explanations with additional results, as you find appropriate.

3.1 The water balance

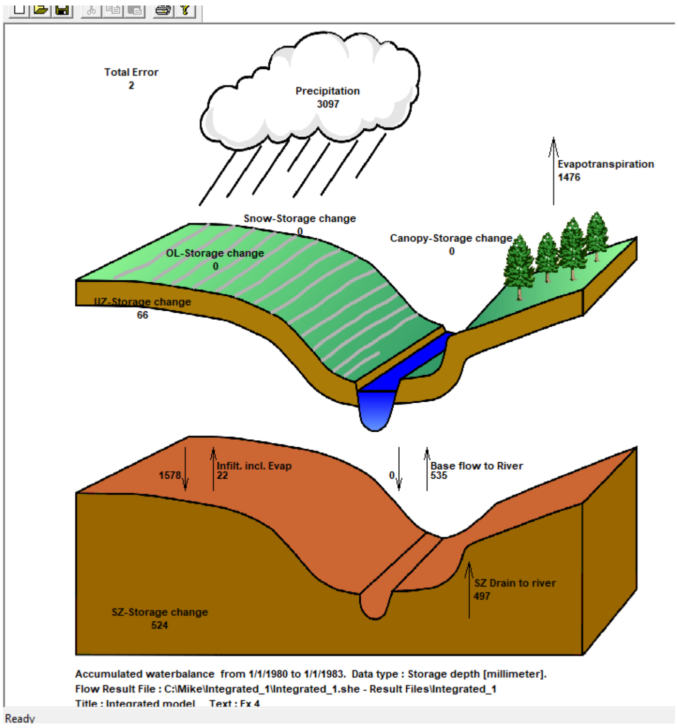

Figure 16. The water balance chart in Integrated_1

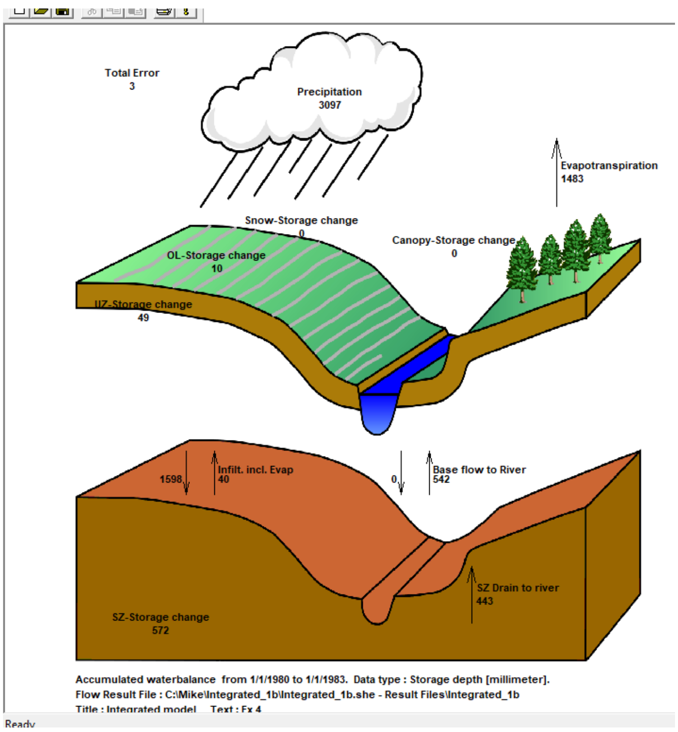

Figure 17. The water balance chart in Integrated_1b

The obvious change is the decrease in SZ Drain to the river (from 497mm to 443mm) due to the decline of drain time constant. (from 5.6×10^{-7} to 1×10^{-7} 1/s). This component has not changed much relating to the drain time constant multiple changes. This is because although the flood discharge capacity per unit time is reduced, the drainage is still the fastest way to solve the extra flow. However, during this treating time, the groundwater water level goes up compared to the original one. This phenomenon leads to other terms' change.

First, the entire recharge to SZ changes a few from 1556mm to 1558mm. The discharge of the Baseflow to River grow to 542m due to the groundwater level increasing. Next, the SZ-Storage change becomes larger due to variations in the groundwater table. (572mm in Integrated_1b from 524mm) To the opposite, the UZ-Storage change is smaller and OL-Storage change appears by 10mm. This is because the groundwater table rises above the ground surface, water is ponded on the ground surface, which can be proved by Figure 18. Last, evapotranspiration raise to 1483 mm due to the evaporation from ponded water. This term increases from 11mm to 23mm.

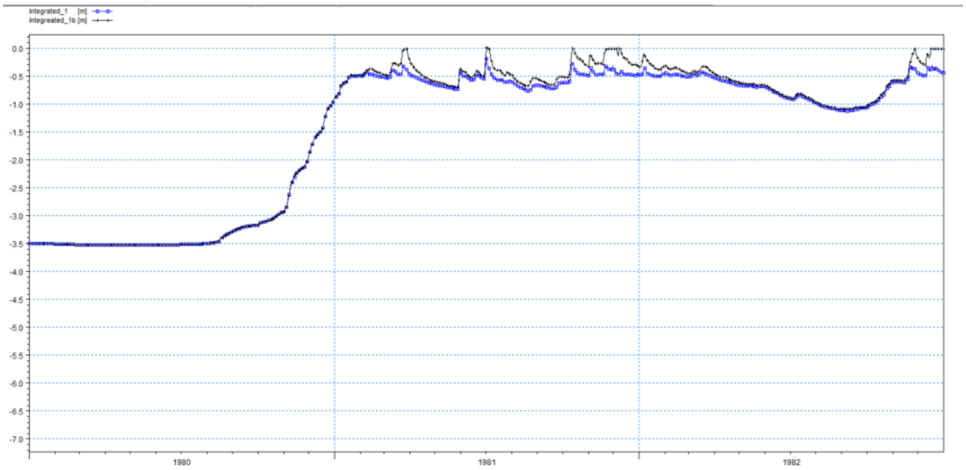

Figure 18. Depth to phreatic surface in one cell of two cases

3.2 Hydrograph at the outlet of the catchment

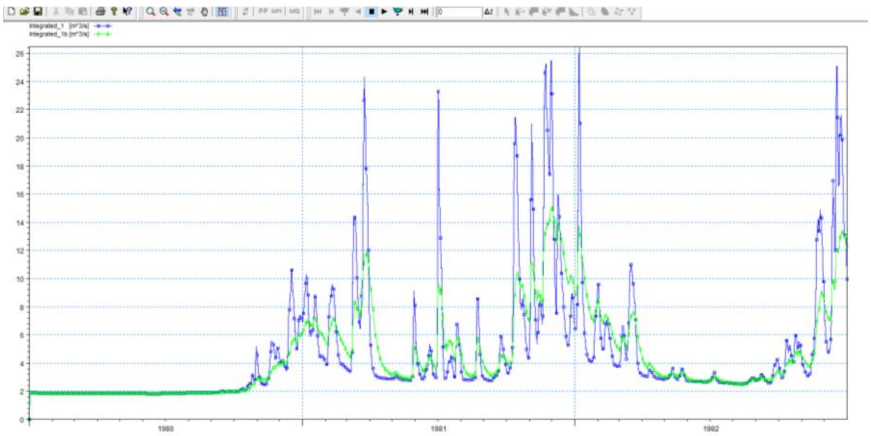

Figure 19. Hydrograph at the outlet of the catchment

This figure illustrates that the peak value decline sharply compared to the original one. This is also confirmed that a reduced time constant would reduce the speed (and consequently) of drainage routing. However the spike duration extends. A combination of two content, it can explain why the entire drainage flow reduces very little. Then during the low rainfall period, there is no difference between these two models. Since the groundwater level overall is lower than the drainage level in winter.

3. Q10

In the model Integrated_1 introduces higher Initial groundwater heads of -0.5 m below the soil surface, instead of -3.5 m below the soil surface. You can name this model Integrated1_E. Generate chart water balance results. Compare the water balance results of this new model (Integrated1_E) with those of Integrated1 and explain the differences. For cell (18, 19) generate the UZ plot (water content in UZ in time) from this model (Integrated1_E) and compare it with the UZ plot of the same cell from model Integrated1 and explain the differences (an example of this type of plot for another cell is in your exercise report on page 13). Generate the river flow hydrographs from the two models at the outlet of the catchment and explain the differences. Support all your explanations with additional results, if you find appropriate.

4.1 The water balance

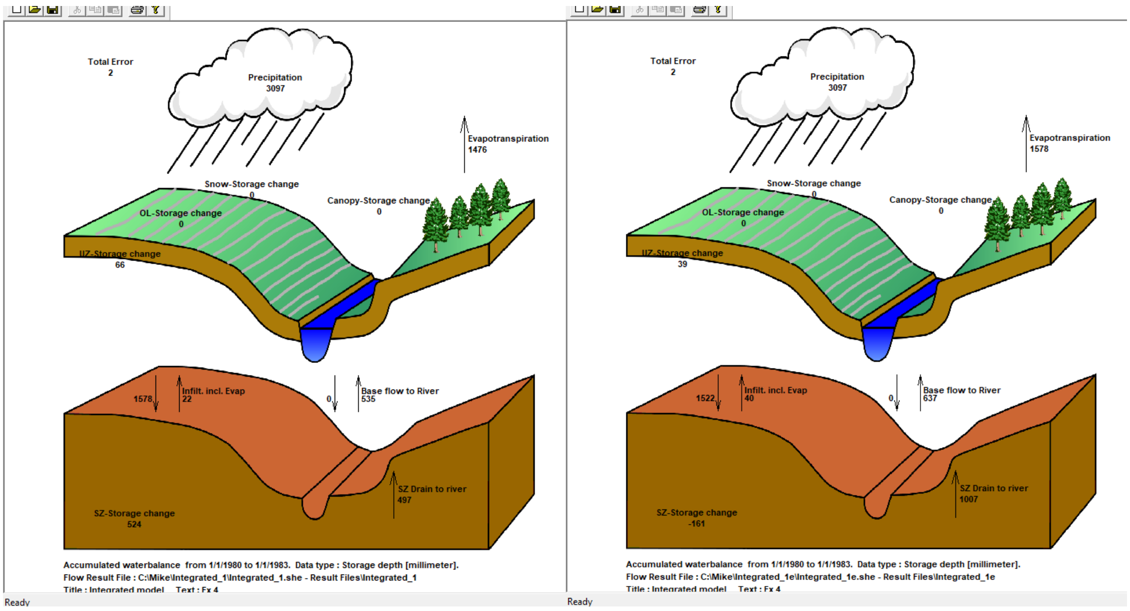

Figure 20. The water balance chart in Integrated_1 and Integrated_1e

As can be seen from the Water Balance Chart one significant change in this model is in the increase of the SZ Drain to the river. (1007mm compared to 497mm in the original model) The reason for this change is the change of the initial groundwater level. It is easy to exceed the drain level in the early stage, and generates more SZ Drain to river, occupying a large part in the water balance. Next, the increased initial groundwater level also leads to growth of Baseflow to River. Due to more water forming outflow, SZ-Storage change reduce from 524mm to -161mm. There is reduction of UZ-Storage change from 66mm to 39mm. In the end, the groundwater level of the two case (Integraed_1 and integrated_2e) tend to be the same. Thus, the only factor affecting the UZ-Storage change is the water content due to the available water. Since more water is lost to the evapotranspiration term, Integrated_1e has smaller amounts of water content in the UZ, causing the reduction of UZ-Storage change.

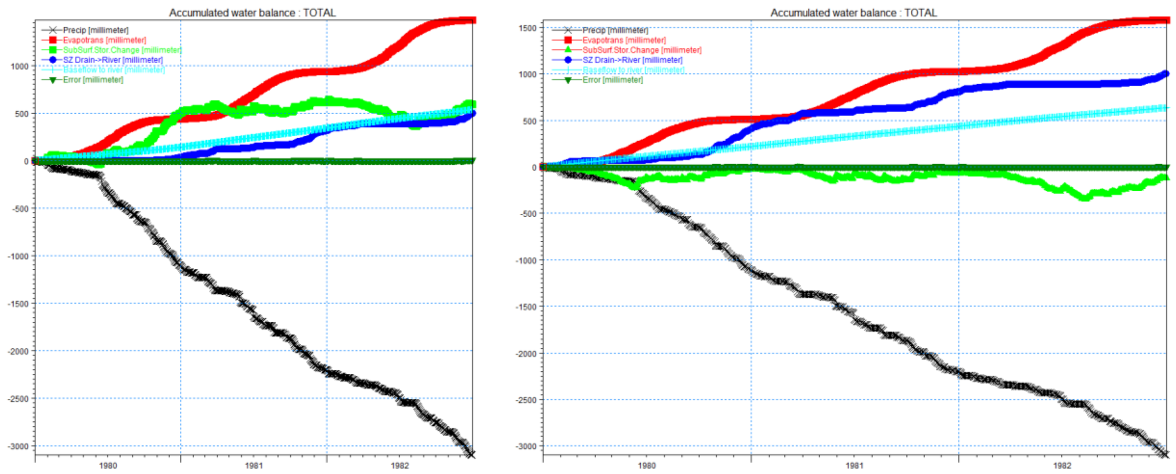

Figure 21. The accumulated water balance: TOTAL in Integtrated_1 and Integtrated_1e

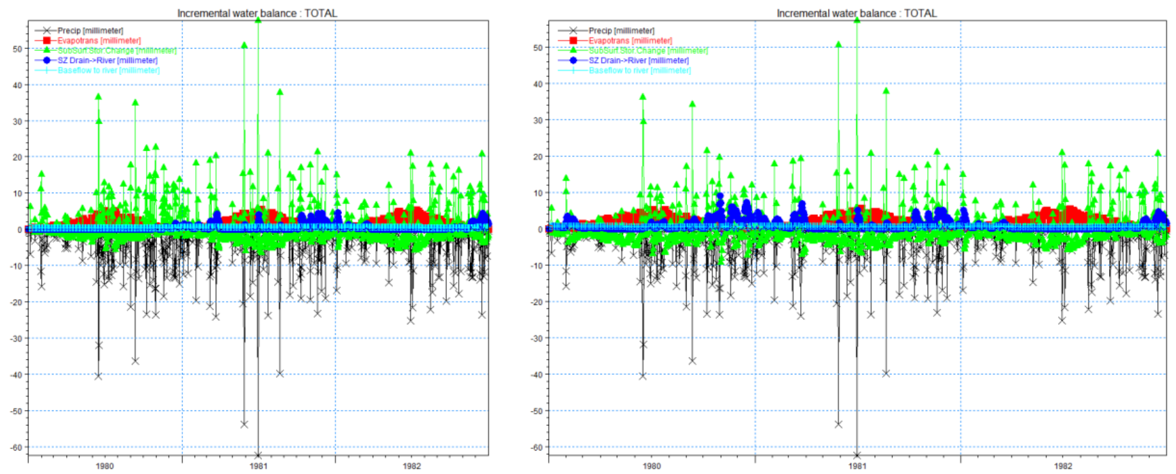

Figure 22. The increment water balance: TOTAL in Integtrated_1 and Integtrated_1e

These figures show evapotranspiration component has the similar trend and the difference between them is small. That's mainly caused by the increase of soil evaporation (from 412mm to 464mm). Then, the drainage flow happens in winter since there is less ET in this season. Observing the water Incremental water balance, we can conclude that in the first winter from January to March 1980, there is drain flow happening in Integrated_1e. In contrast, there is no drainflow in Integrated_1. The reason for this is that the initial conditions in the SZ are groundwater level at 0.5m below the soil surface, which is way equal to the drain level (0.5m below soil surface). The Sub-surface hold part not the whole precipitation, and the groundwater level exceeds the drain level. Thus, amount of water flow from the aquifer to the drainage. Also in December 1980, the drainage flow differs between the two models. Because during these summer months, the ET is significant. The groundwater level of Integrated_1e raises to the drain level, but it cannot store so much water. The rest water may flow into the drainage. For the original model, the groundwater level is far smaller than the drain level, so it cannot produce drainflow. After that, the drainage flow is almost the same. This is because the initial condition only affects the beginning of the simulation process.

4.2 the UZ plot

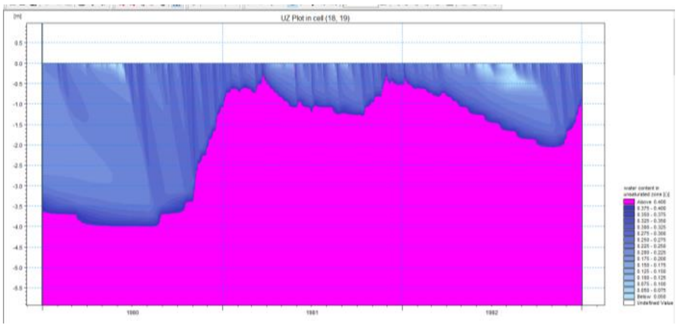

Figure 23. The UZ plot in cell (18,19) of Integrated_1

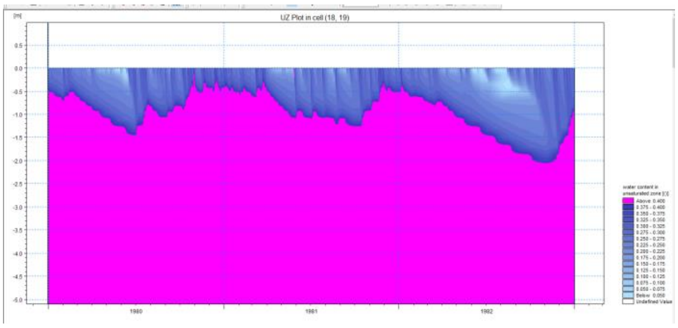

Figure 24. The UZ plot in cell (18,19) of Integrated_1e

The two graphs have the largest deviation in the first trough, because Integrated_2e changes the initial groundwater level to -0.5m without sufficient supply to keep this level, whereas the other two are hardly influenced. The first three months (January – March) show very little ET and few precipitation events. In Integrated_1, the groundwater level stay at a uniform level about -3.7m. For integrated_2d, the groundwater level decrease and reach an extreme value about -0.7m. In the period April-September, the groundwater level of Integrated_1e changes more largely (1m) than the Integrated_1 (0.5m). Since more water flow to the river as baseflow in Integrated_1e. For the original model, the groundwater level reaches a short-term equilibrium and maintained at -4.0m. Subsequently, both groundwater levels rise due to increased rainfall, and both of them exceed the drain level at a certain moment. Next, the two plans' results are basically the same

4.3 The river flow hydrograph

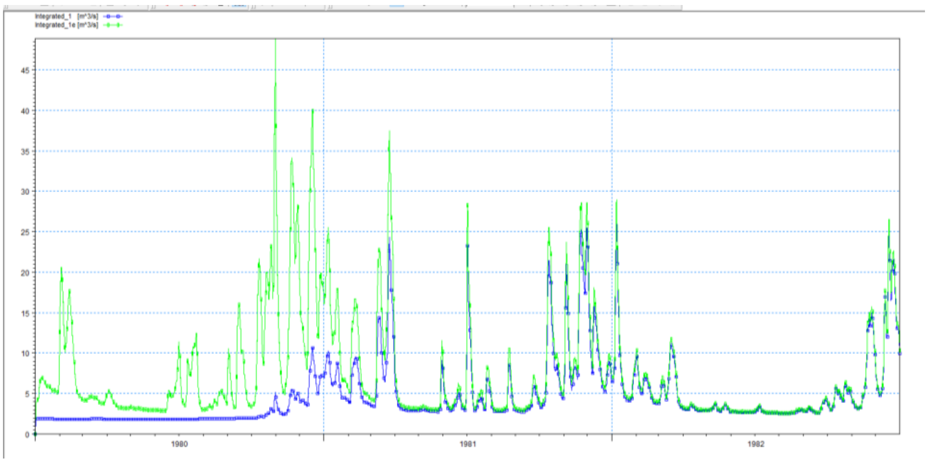

Figure 25. The river flow hydrograph of Integrated_1 and Integrated_1e

The difference happens from January 1980 to March 1981. The river discharge in Integrated_1e is always higher than the original model's discharge, which stays at $2m^3/s$ in most of the period. At the same time, the discharge shocks violently with multiple peaks. The reason for this result can be divided into two parts. For low discharge, it is mainly contributed by the baseflow. The initial groundwater level in Integrated_1e is higher than the one in Integrated_1. Thus the modified case can generate more baseflow making up the bottom in discharge. Next, for the peak values, the upper part of the discharge is dominated by the drainflow. In Integrated_1e, the drainflow happens at the most of the period. However, it only happens from October 1980 to March 1981 in Integrated_1, whose value is much smaller than the value of Integrated_1e. Also, Figure shows no peaks in the beginning of the simulation due to the groundwater level below the drain level. Since April 1981, the two case nearly coincide with each other. This further illustrates that the initial conditions only have an effect on the early simulation period of the model.