Example: Rainfall-runoff modeling

October 10, 2021

In this example we will walk you through how to make a very simple rainfall-runoff model over a small sub-catchment using the built-in plugins of *OpenHydroQual*. We will start from a very simple model without infiltration and then we will add complexity on a step by step fashion by adding soil and infiltration, then groundwater component, stream and then we will include groundwater surface water interactions.

1 Step 1: A single impervious catchment

At this step we assume a single impervious sub-catchment with an area of $12000m^2$ discharging into a nearby stream. In the next steps, we will add infiltration to the model. The diagram of the model is shown in figure 1.

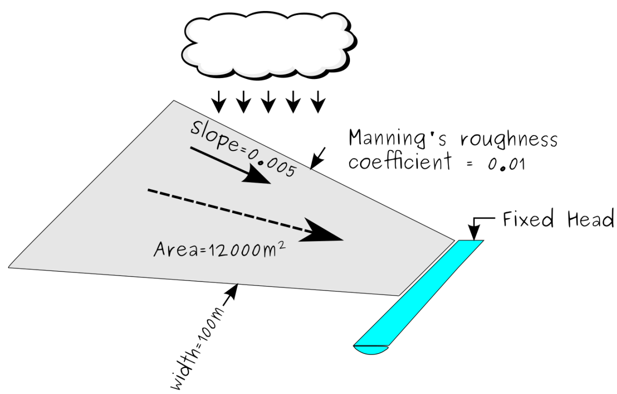


Figure 1: The conceptual model of the simple sub-catchment

Follow the following steps to create the model:

1. Start OpenHydroQual
2. Add a catchment component by clicking on the catchment icon  on the top toolbox.
3. **Setting the properties of the catchment:** Select the catchment block by clicking on it and then set the properties of the catchment as follows through the *properties* window:
    - *Manning's roughness coefficient:* 0.01
    - *Catchment slope in the direction of flow:* 0.005
    - *The width of the catchment:* 100 [m]

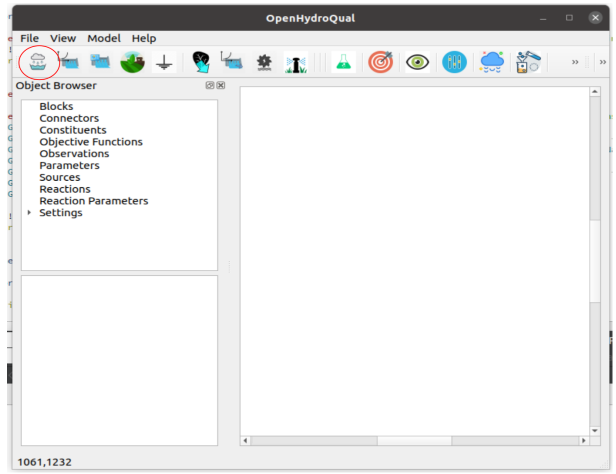


Figure 2: Adding a catchment

- *Catchment area:* 12000 [m^2]

4. We are going to use a fixed head component to represent the receiving stream since all we are interested is the flow rate going to the stream. Add a "Fixed head" component by clicking on the "Fixed head" on the top toolbar.

5. **Connecting the catchment to the fixed head boundary:** Select the catchment to fixed head link from the top and toolbar and then drag your mouse from the catchment to the fixed head boundary. Your screen should look like figure 4.

6. **Adding precipitation:** Now we are going to add precipitation to the catchment. Download an example precipitation data file from `https://openhydroqual.com/wp-content/Data/Sample_Rain_Data.txt` and save it somewhere on your hard-drive.

   From the top toolbar add a precipitation item by clicking on the precipitation icon . From the *Object Browser* window expand *Sources* and then select the *Precipitation (1)* item (figure 5). You may now change the name of the precipitation item from the properties window.

   In the properties window click on the box in front of "Precipitation intensity" and then choose the precipitation data file you just down-

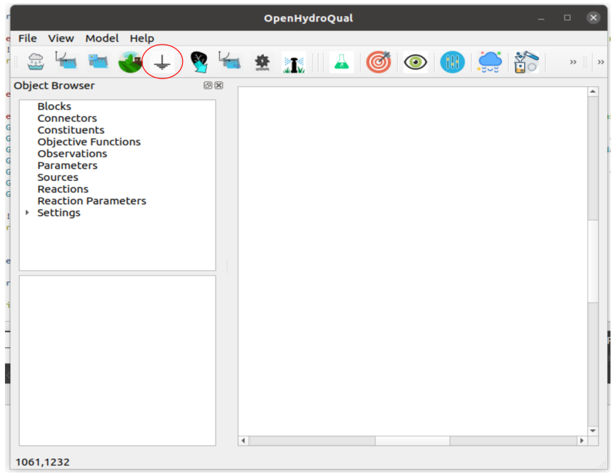


Figure 3: Adding a fixed-head block

loaded using the file browser. Right-click on the filename in the value column and choose plot from the drop-down menu. You should see a graph similar to figure 6. Please note that you can open the precipitation data file using any text editor and inspect its format. The first two columns in the file contain the start and end time of a "bin" and the third column contains the total rain volume in meters (per m^2) occurred within that time bin.

Note that the date range of precipitation data is from January, 2010 to December 2012. This is going to be our simulation period.

7. **Apply the precipitation to the catchment:** Now we have to tell the program that the precipitation data we just added falls on our catchment. In order to do this select the catchment either by clicking on the catchment block in the graphics view panel or through the object browser. In the properties window click on the box in front of "Precipitation timeseries" item and select "Precipitation (1)" from the drop-down menu (Figure 7).

8. **Setting the period of simulation:** From *object browser*, choose **Settings→General Settings**. In the properties window set the simulation start time to 01.01.2010 and simulation end time to 12.30.2012.

9. Save the model.

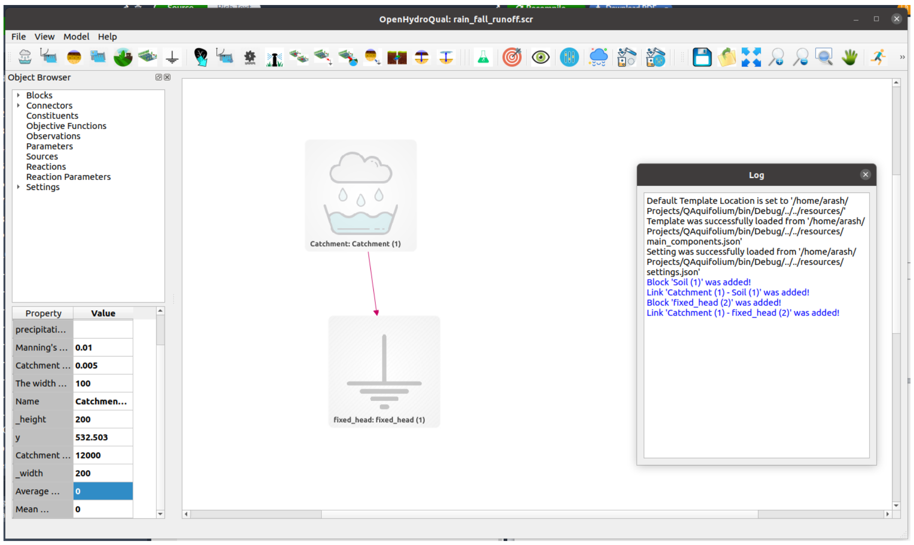


Figure 4: Rainfall-runoff model with impervious surface in OpenHydroQual GUI

10. Now your first model is ready to be run. Click in run button  and wait for the simulation to end.

11. **Inspecting the results:** Now is the time to inspect the results. Right-click on the connector connecting the catchment to the fixed-head boundary in the graphics view panel and select Results→flow. This shows the flow time-series from the catchment to the fixed-head boundary (Figure 8). Right-click on the catchment and the fixed head and see what other results are available.

2 Step 2: Incorporating infiltration

In this step, we are going to add soil layers and groundwater to allow infiltration to occur (Figure 9). For this purpose we need to add one or more soil layers and a groundwater layer.

Initially we assume that the hydraulic head of the groundwater is fixed and not affected by the infiltration so we use a fixed head boundary condition to represent the groundwater layer. In the next step, our intention will be to include surface water-groundwater interaction by allowing flow from the stream to the groundwater and vise-versa. For this purpose, we will replace

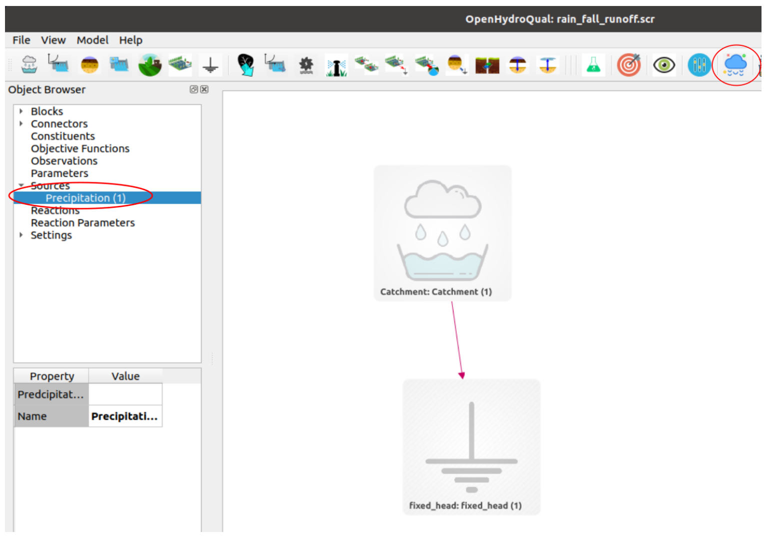


Figure 5: Adding precipitation

the fixed-head object representing the groundwater by a groundwater block. We assume that the average depth of the water table is 1.5 m below the ground surface. In other words the average depth of the unsaturated soil layer is assumed to be 1.5 m. We will also assume the soil is silty-clay-loam with the soil water retention parameters shown in table 1.

Parameters name	value
Saturated moisture content (θ_s)	0.43
Residual moisture content (θ_r)	0.089
van Genutchten parameter n	1.23
van Genutchten parameter α	$1m^{-1}$
Saturated hydraulic conductivity (K_s)	0.0168 m/day
Initial moisture content (θ_{ini})	0.2

Table 1: Soil water retention parameters for the tutorial example

To create the model, follow the following steps:

1. **Adding the "unsaturated soil" plugin** In order to make the soil plugin available to be used it needs to be added to the model. For this purpose go to **File→Preferences→Add Plugin**. From the dialog that appears, select *Unsaturated soil* item and press the *Ok* button at the bottom of the window. You should see a soil component  and

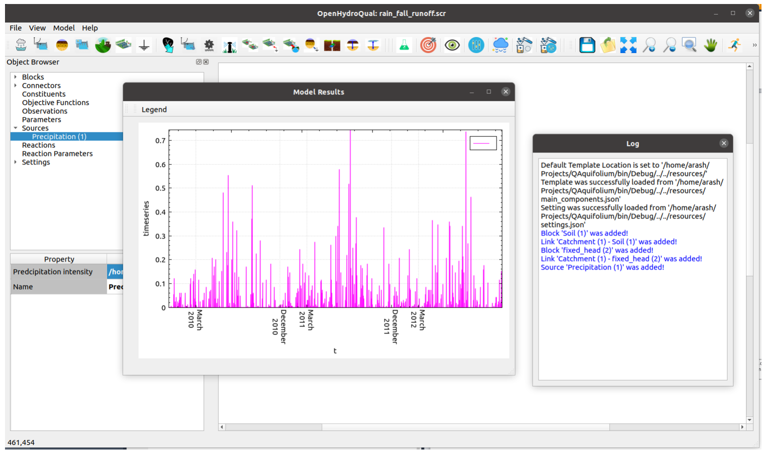
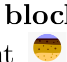


Figure 6: Precipitating graph

some soil-related connectors to be added to the component toolbox.

2. **Add a soil block and a fixed-head block to your model:** Click on the tool button for soil component  from the top toolbox to add a soil block to the model. Also add another fixed head  to represent the groundwater. You can rearrange your model blocks so the soil layer and "groundwater" blocks are visually placed under the catchment (Figure 10).

3. **Assign the properties of the soil block:** Select the soil block just added and then from the property window assign the following parameters:

   - *Saturated moisture content:* 0.43
   - *Residual moisture content:* 0.089
   - *Van Genuchten's n parameter:* 1.23
   - *Bottom area of the soil block:* 12000
   - *Moisture content:* 0.2
   - *Saturated hydraulic conductivity:* 0.0168
   - *Van Genuchten's alpha parameter:* 1
   - *Bottom elevation of the soil block:* -1.5
   - *Depth of the soil block:* 1.5

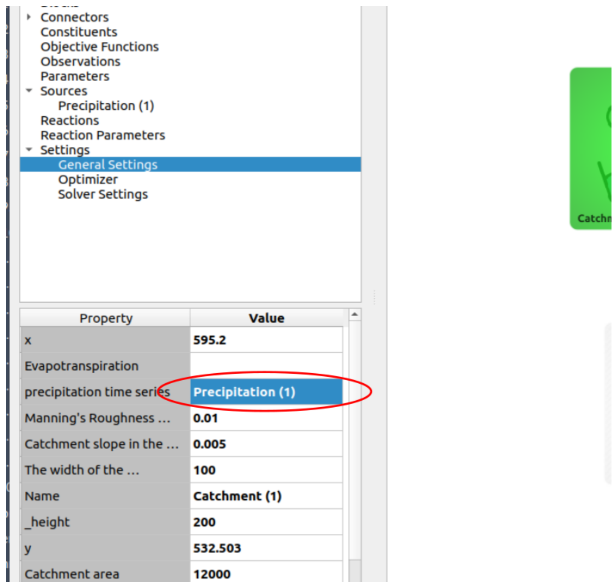


Figure 7: Applying precipitation to a catchment

For the fixed-head block that was just added only set the value of *Head* to -1.5.

4. **Connecting the catchment to the soil layer:** Using the *Surface-water to soil connector* connect the catchment to the soil block. Also using the *Soil to fixed head connector*, connect the soil layer to the fixed_head (2) block.

5. **Save the model**

6. **Run the model** and wait for the simulation to end.

7. **Inspect the results:** Now is the time to inspect the results. Similar to the previous step, look at the flow time series from the catchment to the fixed-head block representing the stream. You can also right-click on the connector from the catchment to the soil block to see the infiltration to the soil or right-click on the connector from the soil block to the fixed-head block representing the groundwater to see groundwater recharge (Figure 11. As you can see initially the infiltration is higher and the groundwater recharge is lower. Why do you think the reason for this phenomena is? confirm your speculation by looking at the variation of soil moisture (θ) of the soil block.

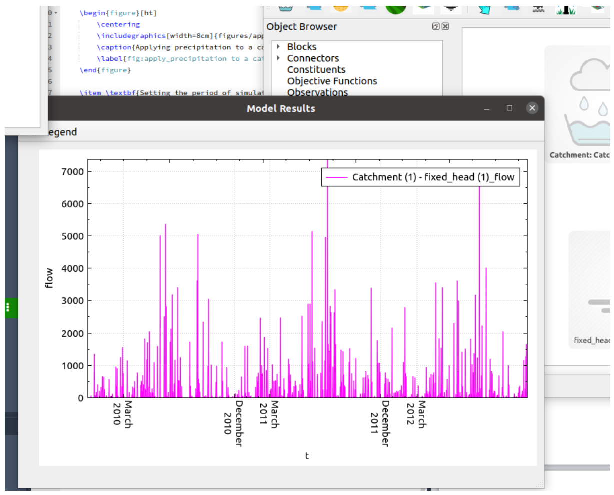


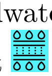
Figure 8: Model results: flow from the catchment to the stream

8. Increase the soil saturated hydraulic conductivity by a factor of 10 (i.e. $0.168 m/day$) and see how that will affect infiltration and recharge rates and the surface runoff.

3 Step 3: Implementing surface water-groundwater interaction

In this step we will allow water exchange between the groundwater and surface water. For this purpose we should allow the head of the groundwater to change as a result of the recharge process (Figure 12.)

The first step is to replace the fixed-head block representing groundwater with an actual groundwater block. This will allow the hydraulic head of the groundwater to vary in response to the change of its storage. In order to add a groundwater block to the model, we need to add the *Groundwater* plugin. Follow the following steps to incorporate groundwater-surface water interactions into your model.

1. **Add the Groundwater plugin:** From File→Preferences→ Add plugin, add the Groundwater plugin . A new tool button for the groundwater component  will be added to the components tool bar.
2. **Delete the fixed-head block representing groundwater:** Right-click on the existing fixed-head block representing the groundwater and

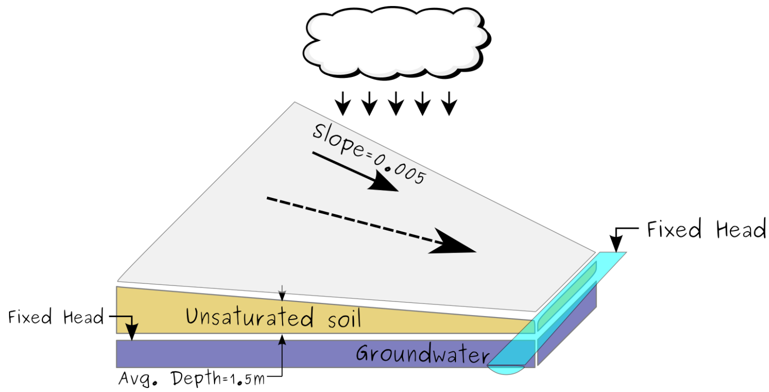


Figure 9: Rainfall-runoff system with infiltration

choose *Delete*. This will delete both the *fixed-head (2)* block and the link connecting the soil block to it.

3. **Add a groundwater block:** Click on the groundwater button from the components toolbar to add a groundwater block to your model.

4. **Assigning properties to the groundwater block:** We are going to assume the aquifer depth to be 2 meters. We will also assume the hydraulic conductivity of the groundwater is 0.1 m/day. Select the newly added groundwater block and assign the following properties to it:

   - *Cell Depth:* 2.5
   - *Cell area:* 12000
   - *Moisture content:* 0.4
   - *Bottom Elevation:* -3.5
   - *Hydraulic conductivity* 0.1

5. **Connecting the soil block to the groundwater block:** Select the *soil to groundwater link* from the components toolbar and then connect the soil block to the newly added groundwater block. Select the link and assign a value of 12000 to the *interface area* property.

6. **Connecting groundwater to stream:** Select the *Groundwater to fixed-head* link from the components toolbar and connect the groundwater block to the fixed-head block representing the stream.

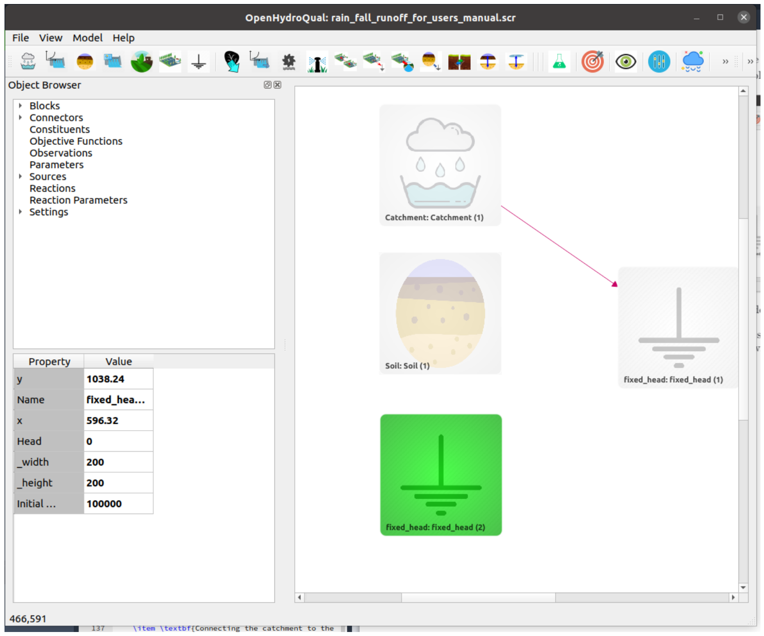


Figure 10: Model with the soil layer added

7. **Assigning the properties of the link between groundwater and stream:** We need to specify two parameters for the link between groundwater and the "stream". They include a length which represent the length between the centroid of the groundwater block and the stream and an interface area which represents the interface area between the two blocks over which the water exchange occurs. We will assume that the distance between the centroid of the groundwater block and the stream is the same as the distance between the centroid of the watershed and the stream (i.e. $12000m^2/100m/2 = 60m$) and the area is the area of the interface is the bottom area of the stream segment assuming the width of the stream being 1m. So the interface area will be $100m \times 1m = 100m^2$. Select the connector from the groundwater block to the stream and assign the following properties:

   - *Length:* 60
   - *Interface Area:* 100

   Your GUI should look like figure 13.

8. **Save the model:** You can save the model with a new name so you

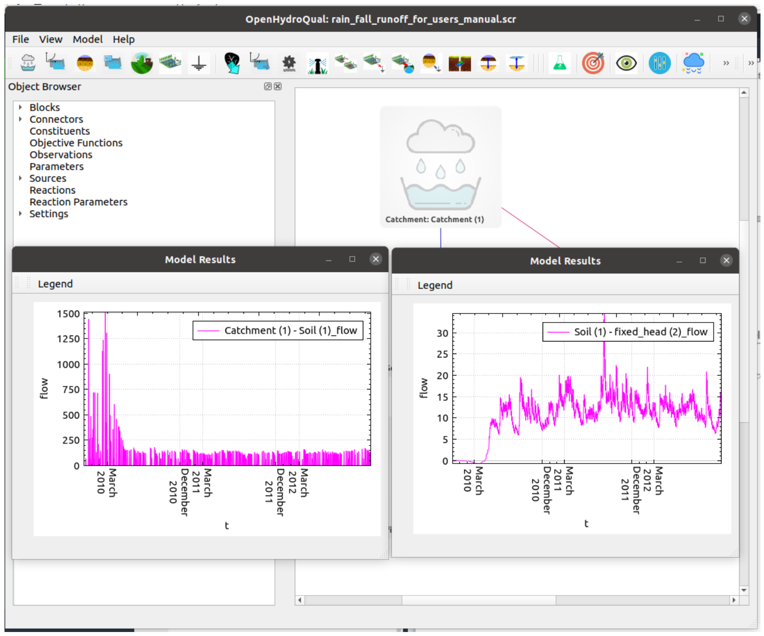


Figure 11: The results for infiltration and groundwater recharge

preserve the previous version.

9. **Run the model:** Now is the time to run the model. Wait for the simulation to finish.

10. **Inspect the results:** Look at the flow between groundwater and surface water, groundwater recharge and the hydraulic head of the groundwater block. Why the flow from groundwater to the stream is negative at early times? Why the flow from soil to the groundwater is negative at early times? Answer these questions by checking the hydraulic head variation in the soil and groundwater blocks.

11. **Challenge:** Try to discretize the unsaturated soil layer into three layers each of them having a depth of 0.5m. This will result in a much more realistic results because of the fact that with multiple soil layers, the vertical variation of soil moisture and its impact on the groundwater recharge rates will be accounted for.

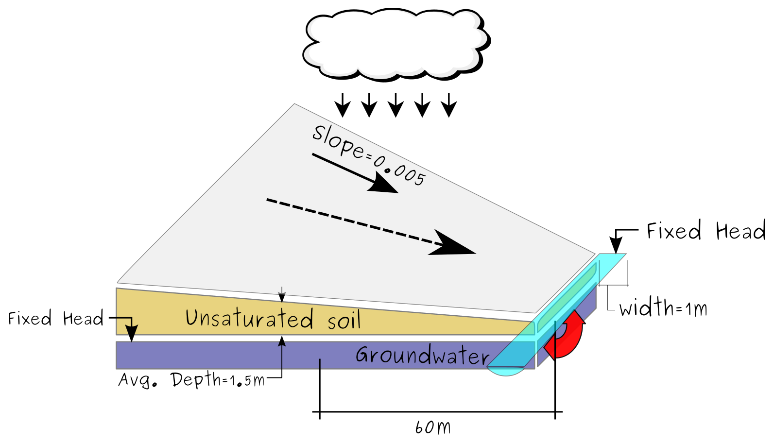


Figure 12: Conceptual model with GW-SW interaction

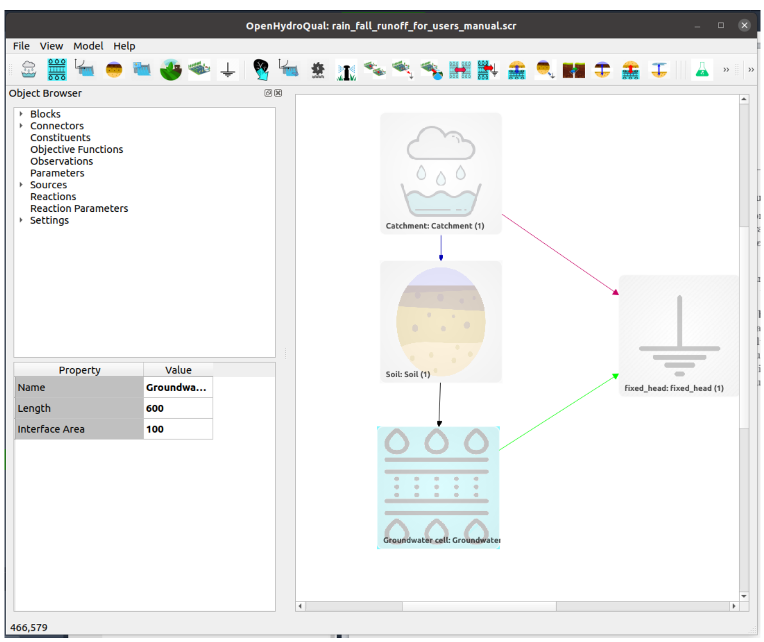


Figure 13: Screenshot of the model with GW-SW interaction