Example: Pipe-tank-pump system modeling

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In this example we will show how to build a model of a pipe-pump-tank system in *OpenHydroQual*. For this purpose, we will start from a very simple system composing of only two tanks connected via a pipe under a purely gravity-driven flow. Then in the second step, we will show how to model a network of pipes using junctions, and in the third step we will show how to add a pump with a given characteristic curve to the system.

1 Step 1: A simple system consisting of two tanks and a pipe with gravity flow

The diagram of the system to be modeled in this step is shown in Figure . As you can see, the system is composed of two tanks with elevations of respectively 15m and 10m which are connected to each other through a pipe with a length of 100m and a diameter of 10 cm. The Hazen-Williams roughness coefficient for the pipe will be assumed to be 90. We will assume the tanks each have a base area of $10m^2$ and there is 1m of water in the tank with a higher elevation at the beginning of the simulation.

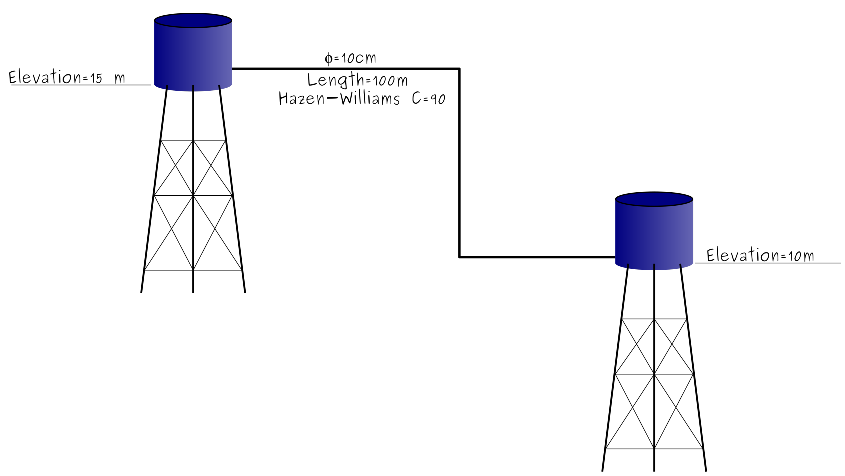

Figure 1: Simple pipe system

To create the model, follow the following steps:

1. **Start OpenHydroQual**

2. **Add the Pipe/Pump systems plugin:** From **File→Preferences→Add plugin** add the *Pipe/Pump systems* plugin to your model. As you

can see, several new components will be added to the components toolbar at the top of the OpenHydroQual window.

3. **Add two tanks:** Add two tanks by clicking on the tank button twice. Drag the tanks to the desired location on your screen.

4. **Assigning properties to the tanks:** Select *Tank (1)* and assign the following properties through the property window:

    - Bottom Elevation: *15* [m]
    - Base Area *10* [m^2]
    - Initial Storage *10* [m^3]

    Select the second tank and assign the following properties:

    - Bottom Elevation: *10* [m]
    - Base Area *10* [m^2]

5. **Connecting the two tanks via a pipe:** Click on the *Pipe, Hazen-Williams Equation, 2Way* button from the component toolbar and then drag from *Tank (1)* to *Tank (2)*. Your GUI should look like Figure 2. Please note that a "2-way" pipe allows the water to move in both direction depending on the hydraulic gradient while a "1-way" pipe allows the water to only flow from a source to a destination.

6. **Assign the properties of the pipe:** Select the pipe just added to the model. And assign the following properties via the properties window:

    - Pipe length: *100* [m]
    - Hazen-Williams coefficient: *90*
    - Diameter: *0.1* [m]

7. **Save the model:** Save the model with your desired name. Make sure to add a ".scr" at the end of the filename.

8. **Run the model:** Now the model is all set for execution. Run the model by clicking on the run button from the top window and wait for the simulation to end, then close the run model window that popped up.

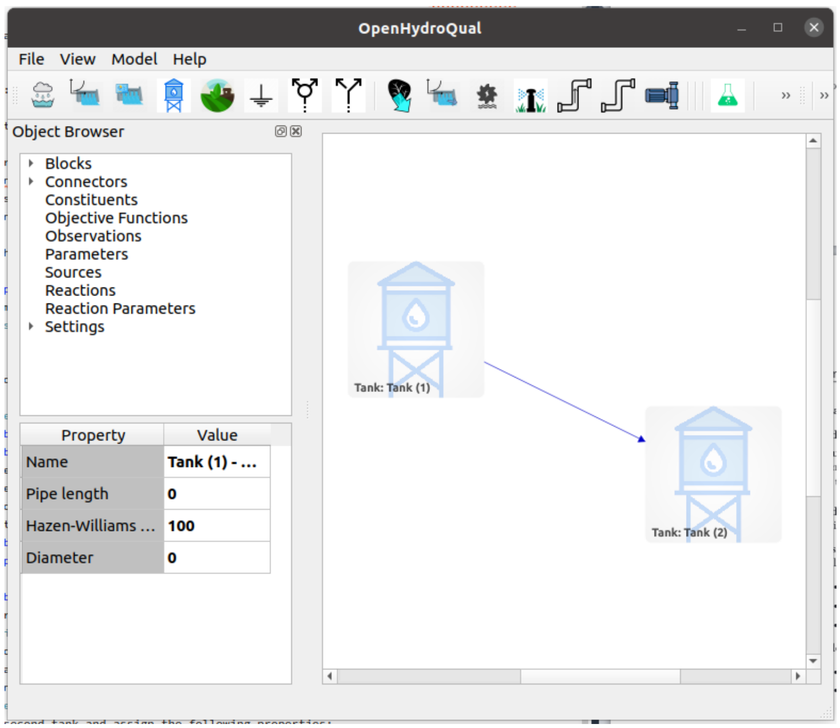

Figure 2: Screenshot for the simple pipe system example

9. **Inspect the results:** Right-click on Tank (1) and then go to **Results→Storage** to see how the storage changes throughout the simulation. As you can see the storage in Tank (1) runs out in less than one hour. Similarly, you can look at depth and head variation in Tank (1) and Tank (2) and flow and hydraulic gradient variation in the pipe.

10. **Change the time resolution of the model:** To see the variation of the model results more accurately, we are going to use a smaller time-step and a shorter simulation period. We are going to shorten the simulation period to 0.1 day instead of the default 1 day period. For this purpose from the *Object Browser* window go to **Settings→General Settings**. Then right-click on the value against the property *Simulation end time* and choose *Enter a numerical value* from the drop-down menu and then enter 0.1 in the input box that appears. To reduce the time-step at which the results are stored from Object Browser window select **Settings→Solver Settings** and the change the values of *Initial time-step* to 0.0001. Now run the model again.

11. **Inspect the results:** Now look how different state variables of each model component changes with time.

12. **Explore other scenarios:** Change the initial storage in the tank, the pipe length and other properties and elevations of the tanks and rerun the model and see how those changes affect the dynamics of the system.

2 Step II: A simple pipe network

Now, we will expand our model to a network by first adding a junction, then adding a parallel pipe and then adding more complexity to the model. As the first step, we would like to split the pipeline between the two tanks into two pipes each with a length of 100m but one with a diameter of 5 cm and the second with a diameter of 2.5 cm. The model diagram will look like figure 3.

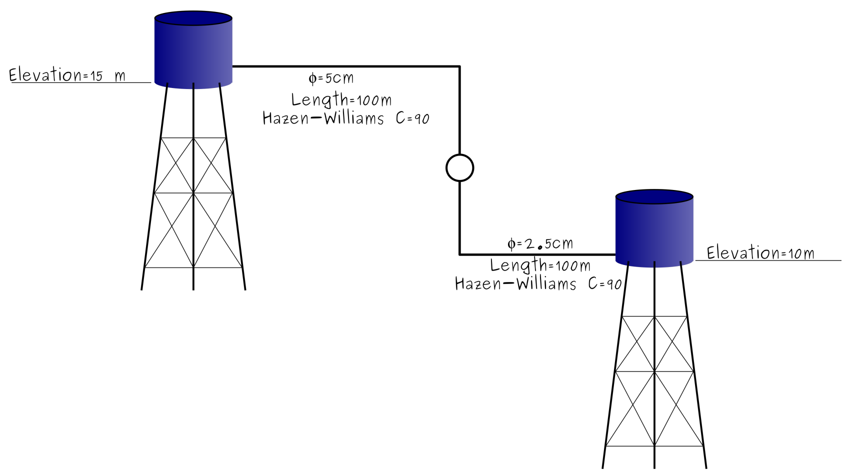

Figure 3: Pipes in series

Follow the following steps:

1. **Saving with a new name:** You may save your model with a new name it order to preserve your earlier model intact.

2. Delete the pipe from the model by right-clicking on the pipe and then selecting "Delete" from the drop-down menu.

3. **Add a rigid junction:** From the component toolbar add a rigid junction to your model.

4. **Add pipes:** Use two-way pipes to connect Tank (1) to the junction and another one to connect the junction to Tank (2). Your screen should look like what you see in figure 4.

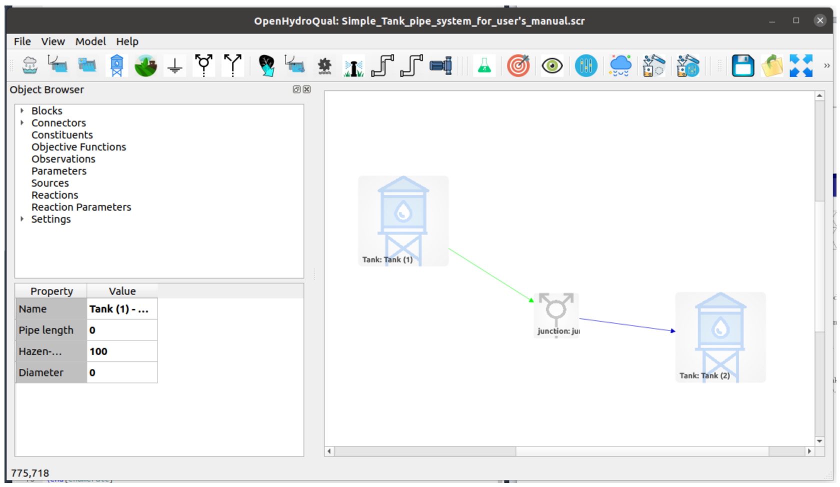

Figure 4: GUI screenshot for the pipes in series example

5. **Assigning properties to pipes:** Assign the following properties to the pipe connecting Tank (1) to the junction:

   - Pipe length: *100* [m]
   - Hazen-Williams coefficient: *90*
   - Diameter: *0.05* [m]

   and the following properties to the pipe connecting the junction to Tank (2).

   - Pipe length: *100* [m]
   - Hazen-Williams coefficient: *90*
   - Diameter: *0.025* [m]

6. **Run the model:** Save and then run the model and then inspect the results at each block and link (i.e. pipe). As you can see, and as it is expected, the flow rate is much smaller than the case with a single

pipe due to the fact that the pipeline is longer and the diameters are smaller overall. You can now change the simulation period back to 1 day via **Settings→General Settings**.

2.1 Adding a parallel pipe:

Now we would like to add a parallel pipe connecting Tank (1) to Tank (2). We will assume this pipe to have a length of 150 m and a diameter of 2.5cm (Figure 5).

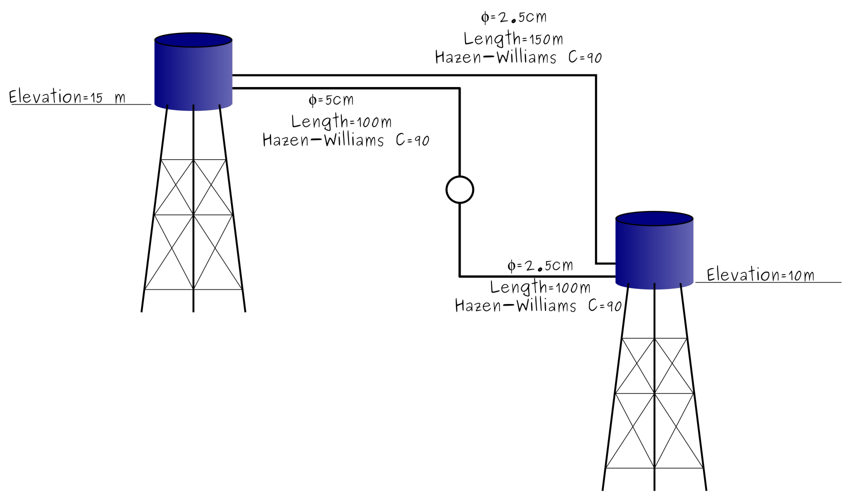

Figure 5: Pipes in parallel

1. Use another two-way pipe  to connect Tank (1) directly to Tank (2). The screenshot of your GUI should look like figure 6.

2. Assign the following properties to the newly added pipe:

   - Pipe length: *150* [m]
   - Hazen-Williams coefficient: *90*
   - Diameter: *0.025* [m]

3. **Run the model:** Save and then run the model and then inspect the results at each block and link (i.e. pipe).

4. **Inspect the results:** Inspect the flow rate in each of the pipes. Which pipeline carries more flow? Can you explain why?

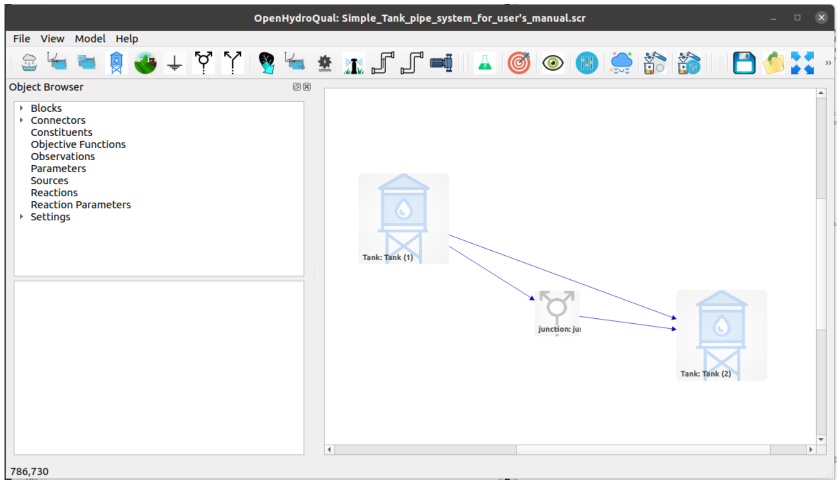

Figure 6: GUI screenshot for the pipes in parallel example

3 Step III: Adding a pump

In this section, we will show how to add a pump to the system. For this purpose we will add a source water block that we will model as a fixed head boundary and then we will add a pump to pump water from the source water to Tank (1). Please note that we could also use other components including pump, stream, reservoir, or groundwater as our source but that would make the example a bit more complex. To simplify the problem, we assume that the head-loss in the pipe connecting the water source to Tank (1) is negligible. This allows us not to include the pipe from the source to Tank (1) in the model. Follow the following steps:

1. **Add the source:** Add a fixed-head block by clicking on the fixed-head button on the components toolbox. We are going to assume that the hydraulic head of the source water is 5m. So assign a value of 5 to the *Head* property of the fixed-head component just added to the model. Also change the name of the fixed-head boundary to "Source".

2. **Connect the source to Tank(1) through a pump:** A pump is considered a connector in the default *pump-pond-tank* plugin. Click on the pump button and then drag from the newly added source block to Tank (1). Your GUI should look like figure 7.

3. Specifying the pump characteristic curve parameters: Now we have

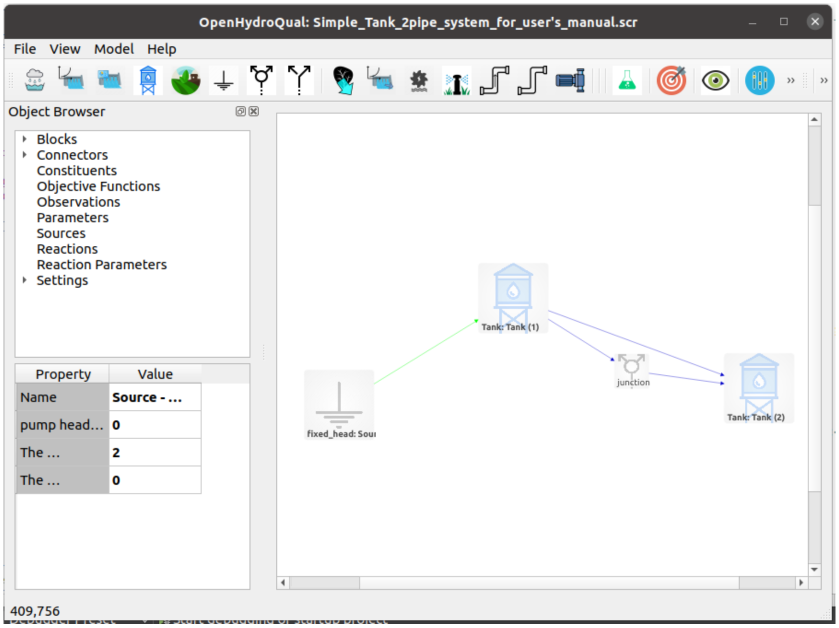

Figure 7: GUI screenshot for the pipe network and pump model

to specify the pump characteristic curve parameters. The equation that is used for pump characteristic curve looks like $h_p = h_0 - \alpha Q^{\beta}$. Here we assume an h_0 of 12, and α value of 0.002 and we will keep the value of β at 2.0. So the pump characteristic curve will be described as $h_p = 12 - 0.002Q^2$. Select the link representing the pump and from the properties window assign the following parameters:

- *pump head at zero flow (h_0):* 12 [m]
- *The coefficient alpha in $h = h_0 - \alpha Q^{\beta}$:* 0.002

4. Change the simulation end time to 10 [days] so you can better see the system's behaviour over long-run.

5. **Save and run the model**

6. **Inspect the results:** Look at flow through the pump, the storage of tanks (1) and (2) and flow through the pipes. Why do you think the flow stops after sometime? Verify your speculation by looking at the hydraulic head of Tank (1) and Tank (2).

7. **Allow water to be withdrawn from Tank (2):** To allow the system to reach a steady state condition, we will add another fixed-head boundary condition and will connect it to Tank (2) so we allow water to flow out of Tank (2). Add another fixed-head block to your model. You can change the name of the fixed-head block to "User". Set the head of the newly added fixed-head boundary to 5m. Use a two way pipe to connect Tank (2) to the newly added fixed head boundary. Assign the following parameters to the pipe connecting Tank (2) to "User".

   - Pipe length: *150* [m]
   - Hazen-Williams coefficient: *90*
   - Diameter: *0.025* [m]

   Your GUI should look like figure 8.

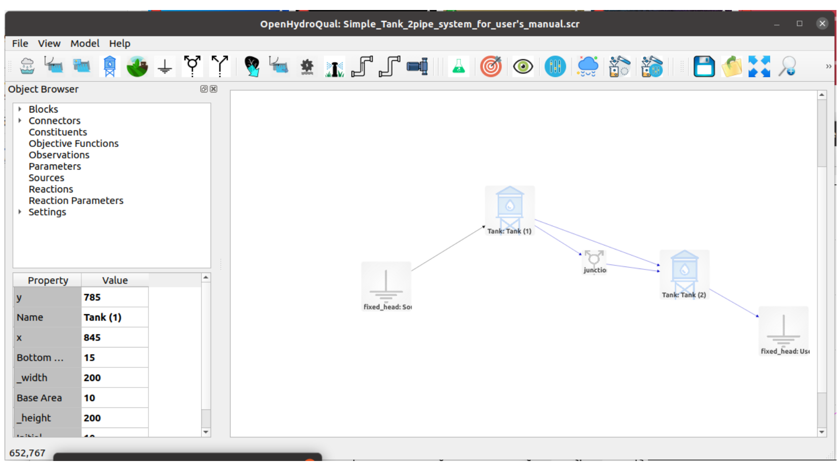

Figure 8: GUI screenshot for the pipe network, pump model, and outlet

8. **Save and then run the model**

9. **Inspect the results:** Now again look at flow through the pump, the storage of tanks (1) and (2) and flow through the pipes. You may run the model for a longer period of time so it reaches a complete steady-state condition.

10. **Evaluate other scenarios:** Make changes to the pump characteristic curve parameters, pipe sizes and elevations to see how they will affect your results.