# PIT DEWATERING

This lesson will explore how to estimate groundwater inflows to an open pit. You will also learn how to design a dewatering borefield using the AMWELLS module.

Problem settings

A mining company is developing a shallow resource by an open pit. The planned depth of the pit is 30 m, and it will be mined in 3 benches as illustrated by **Figure 1** (plan) and **Figure 2** (profile). The pit dimensions will be 170 by 110 m on surface (**Figure 1**).

The groundwater table in the area is 20 m below surface, that is 10 m above the planned base of the pit. The mined formation is a weathered sandstone about 70 m thick with an average conductivity of 1 m/d, a storage coefficient of 0.001 and a specific yield of 0.1. It overlays a thick clay/silt aquitard. For this lesson, the aquifer is assumed infinite, homogeneous, isotropic and with no recharge from rainfall or surface water.

Dewatering design includes selecting a dewatering method and estimating dewatering volumes.
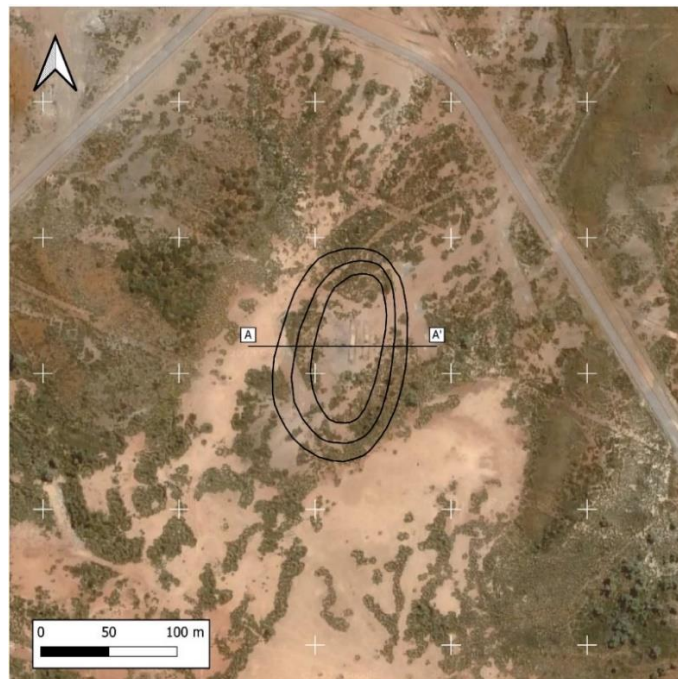
Figure 1: Map view of the pit; the AA' line indicates the location of the cross section; The contours mark the outer perimeter of a bench, the contact between the slope and the surface of the bench
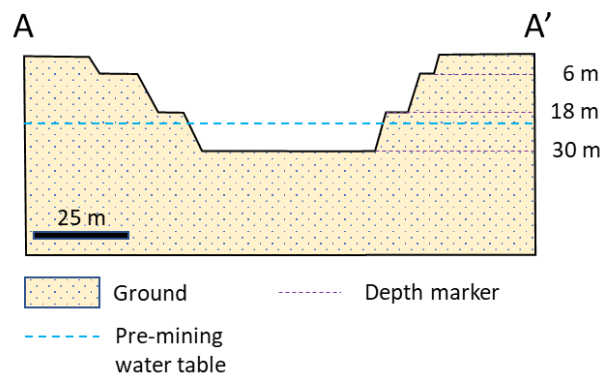
Figure 2: Cross section showing the shape of the pit and the bench to be mined at the time of the study; The location of the cross section is shown on Figure 1

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Dewatering methods

Because of high permeability of the aquifer and shallow mining depths, dewatering methods include vertical pumping wells, sumps or a combination of these two methods.

This lesson covers three dewatering options:

Option 1. Sump only. Free draining through the pit walls. Water flows to a sump on the pit floor, from where it is pumped to surface.

Option 2. Dewatering borefield. The objective of dewatering is to lower the groundwater table down to 5 m below the pit floor and to prevent seepage through the walls.

Option 3. Sump and borefield. Dewatering by a borefield with some groundwater seepage to a sump still occurring.

Create a model and input aquifer properties

The procedure to create a new AMWELLS project is detailed Lesson 6. Use the command "*Flow model/Analytical model/New model*" and use the following parameters:

- Aquifer type: unconfined, infinite;
- One pumping layer;
- Model dimensions: 500 m width and 600 m length;
- Model thickness: 70;
- Static water level: 50;
- Origin X: 206637;
- Origin Y: 7571304.

Once this is done, click on "*create*" and enter "Lesson7" as a name for the model. It is recommended to save the model in a folder with a unique name.

Once the model is created, the main dialog window opens. Use the toolbox menu on the right hand of the window to check the model dimensions (icon "Model dimensions") then use the "*Parameters*" icon to enter the aquifer parameters:

- Isotropic hydraulic conductivity of 1 m/day ($K_x=K_z$);
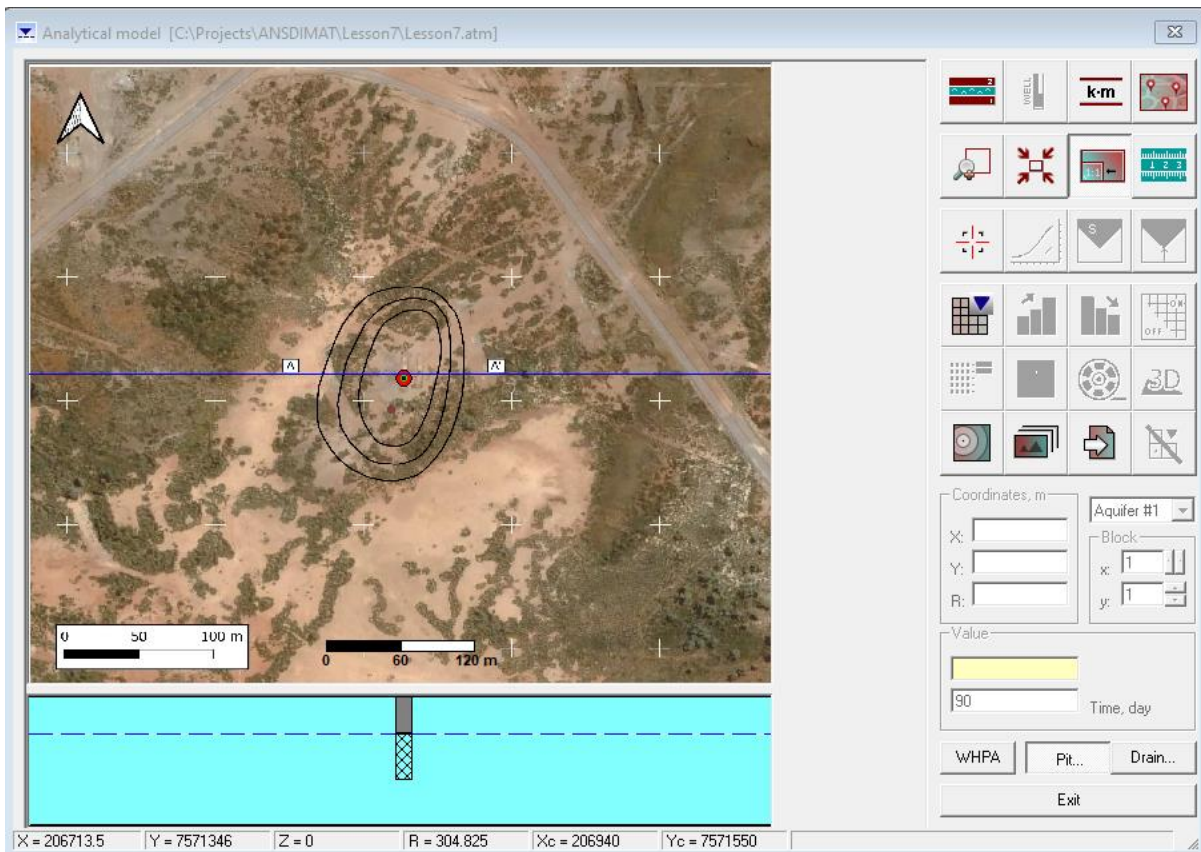- Storage coefficient of 0.001;
- Specific yield of 0.1.

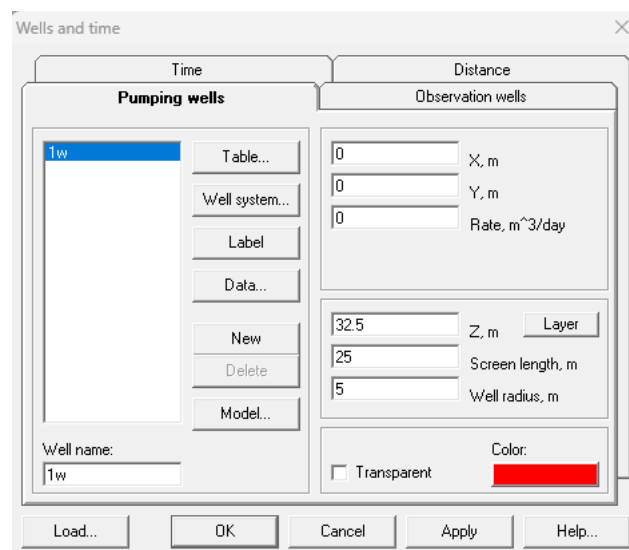Press "*Ok*" to save the parameters.

Import a map

A map is presented on **Figure 1** and is provided as jpg file with the training material for this tutorial. The procedure to import a map into AMWELLS is detailed Lesson 6.

Click on the "Load a picture" icon then browse to the Lesson7 folder and select the "map.jpg" file. In the pop-up window, check the box to make the picture visible in the main model area. Once the map is imported, the working space should look like **Figure 3**.

AMWELLS requires a minimum of 1 well located by default at the centre of the map area. This well is not necessary for the first part of this lesson but it cannot be deleted. However, it can be shifted to a position out of the map. Open the "Wells and time" dialogue window and select the well w1, then enter 0 as the value for the X, m and Y, m fields. The window should look like **Figure 4**. When the wells of the borefield are set up in the second part of this lesson, this well can be relocated to its actual position or simply removed.

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Figure 3: Main window of the analytical element model with map imported

Figure 4: "Wells and time" dialogue window with modified coordinates for the default well w1

OPTION 1. GROUNDWATER INFLOW CALCULATIONS FOR A PIT SUMP

Press the button "Pit" below the toolbox menu. This opens a new dialog window with an option to draw a simplified contour of the pit (**Figure 4**). Analytical calculations of groundwater inflow to an open pits are based on the "big well" approach, where groundwater inflows to an open pit are assumed to be the same as inflows to a large well with:

- a radius equal to the effective radius of the pit and
- a depth that is equal to the depth of the pit from the ground level.

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In order to achieve the most realistic approximation of the shape of the bench, the line marking the "*contour of the pit*" should be drawn approximately in the middle between:
- the pit base and
- the original level of the water table (**Figure 2**).

In this case, the two lines are very similar so you can use the base of the pit to draw the contour.

Note. In theory, because the sumps are dug in the pit floor, the bottom of a sump is deeper than the bottom of the pit, and this should constitute the drainage level. However, the big well approach approximates not the sump itself, but the entire pit with its effective parameters. Therefore, for the sake of simplicity, the "Depth" parameter corresponds to the depth of the pit floor, not a sump.
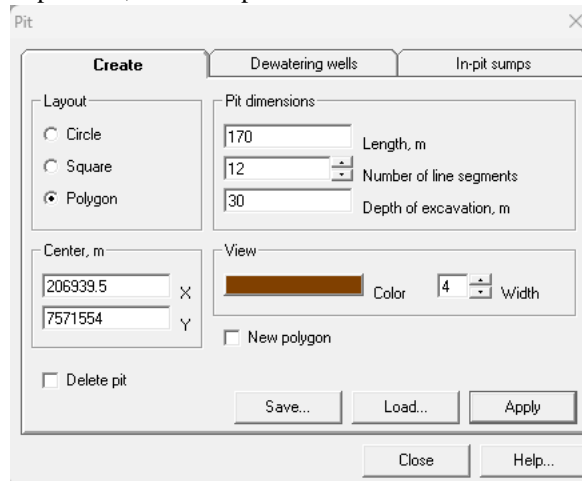
Figure 5: Pit window, "Create" tab: this tab displays options to draw the contour of a pit, including shape, length and depth

Three pit shape options are provided:
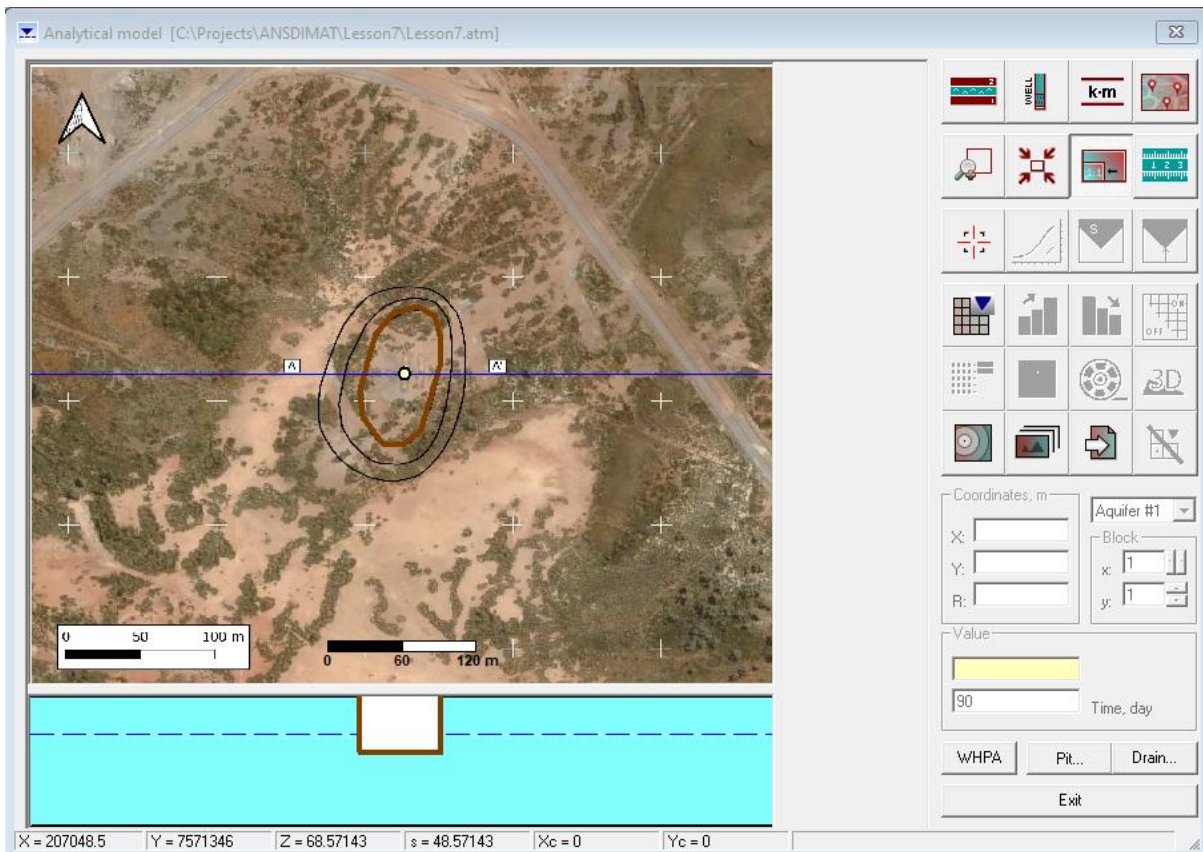- A circle
- A rectangle
- A polygon

For this lesson, use a polygon as a shape with a length of 170 m and 12 segments. Assign 30 m to the "*Depth of excavation*" field. After the shape appears on the screen, click on the inflexion points to move them in an approximation of the shape of the pit. Feel free to change the number of segments. The coordinates of the centre are automatically calculated. For more information about the other shapes and how to manipulate them, refer to the help system which is accessible by clicking the "*Help*" button.

Once the pit contour has been defined, the pit is created as a void with vertical walls and the specified depth (**Figure 6**).

Once this is done, click "*Apply*" then click on the "*In-pit sumps*" tab (the third tab on **Figure 5**) and fill in the parameter fields in white. Note that fields highlighted in yellow contain calculated values. Press the "*Help*" button in this tab for a more detailed description of each field.

Use the following parameters to calculate the inflow:
- "*Drainage elevation*" of 10 m (difference between the initial groundwater table and the pit base);
- "*Time*" of 90 days;
- In the "*Pit radius*" box, check the Width/Length ratio and select the appropriate "*area based*" parameter from the drop-down menu.

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Figure 6: Main model window with the contour of the pit (brown line)

The calculated inflow is 1320 m³/day (appears in a yellow highlighted filed as illustrated by **Figure 7**): it corresponds to the inflow into the pit 90 days after excavating Bench 3. You can notice that this inflow is strongly time-dependent, as it is impacted by the radius of influence.

You can check this by entering different values for the "*Time*" parameter and see how the value of the inflow varies. You will notice that after 50 days, the change of inflow for each additional 10 days becomes smaller.
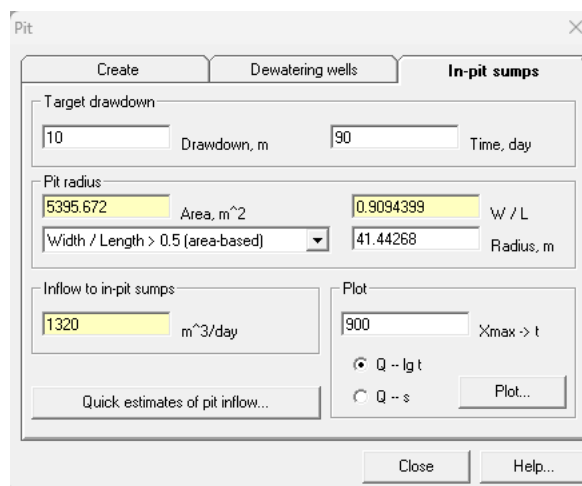
Figure 7: "In-pit sumps" tab with in-flow to sumps calculated based on a virtual well with the same area as the actual pit

Note. The "*Quick estimates*" button gives access to more detailed calculations. When clicking on this button, the "*Pit inflow*" window opens up. In this window, you have access to more parameters, including the radius of influence. You can learn about this dialog window and required parameters in the Help system, available by clicking the Help button in the "*Pit inflow*" dialog window.

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Once the inflow into the pit has been calculated, the "*pit*" window can be closed. This allows to open the "*Wells and time*" window to set-up the pumping wells prior to calculating the requirements for dewatering using a borefield. This workflow is explained in the next section.

DEWATERING BOREFIELD DESIGN (OPTION 2)

In this section, a system of dewatering wells will be designed to bring the water table at a minimum of 5 meters below the pit floor and the pit walls, once excavated. In general, design of dewatering system comprises selecting locations and pumping rates for dewatering wells, as well as dewatering well parameters such as diameter, depths, screen locations etc.
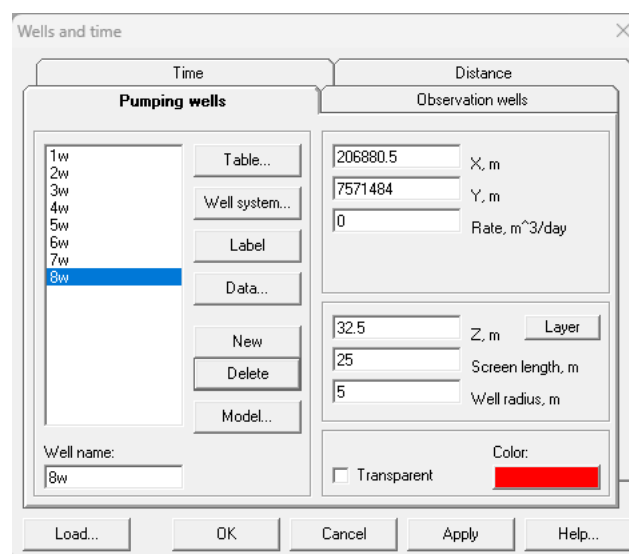
Model set up

The procedure to create a new well is detailed in Lesson 6. Click on the "Wells" icon to open the "Well and time" dialog window that has four tabs: "Pumping wells", "Observation wells", "Time" and "Distance".
In the tab "Pumping wells" either click on "New" then enter the coordinates manually, or click on "Model" and left-click at the location of the hole. You can also use "Ctrl+Left click" on the map to generate a pumping well directly without opening the "Well and time" window. The newly created well will have the same parameters as the last created well.

The pumping wells will be located on the periphery of the pit. Create 8 wells distributed around the pit, 4 on each side. Locate them close to a road for ease of access, as illustrated by Figure 10. You can move a well by left-clicking on the well marker and hold as you move it. Release at the selected location.

For the default well w1 that was moved out of the map previously, you can change its coordinates in the "Wells and time" window or, once you have located the 8 wells of the borefield, you can remove it.
You can remove a well by right-clicking on its marker in the main model window. You can also use the "Delete" button in the "Wells and time" window.

Assign well depths at 45 m (i.e. 15 m below the pit floor) to be able to achieve the required drawdown under the pit. Make all the wells screened over the water-saturated interval (i.e. screen length equals to 25 m and centre of the screen Z equals to 32.5 m). These inputs should look like **Figure 8**. The schematic profile the pit, the boreholes and the aquifer are illustrated by **Figure 9**.


Figure 8: "Well and time" window with the parameters set for the wells of the borefield

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For this exercise pumps will be located 1 m above the bottom of a well (*i.e.* a depth of 44 m) and they must remain submerged at least 4 m below the dynamic water table. This means that the water level in each dewatering well cannot go below 40 m depth or 20 m of drawdown (**Figure 9**).
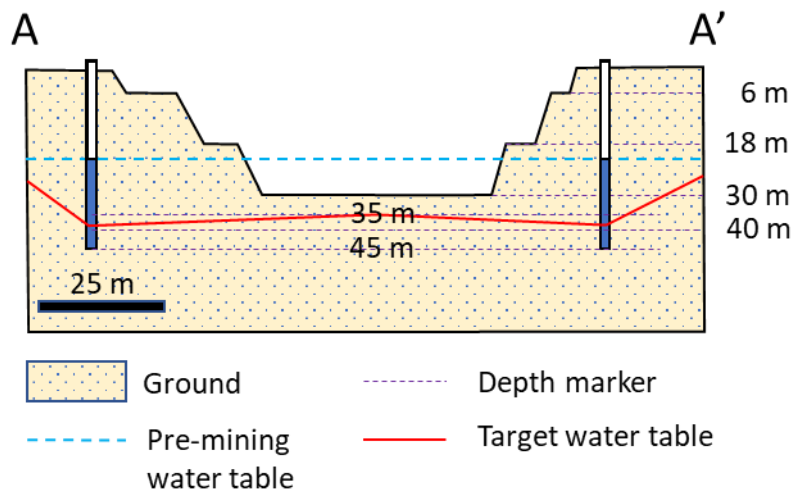

Figure 9: Schematic cross-section showing the target water table at the end of the dewatering process. As the pumps are located at 44m depth, the water table cannot sink deeper than 40 m in the pumping wells, corresponding to a maximum drawdown in the wells of 20 m
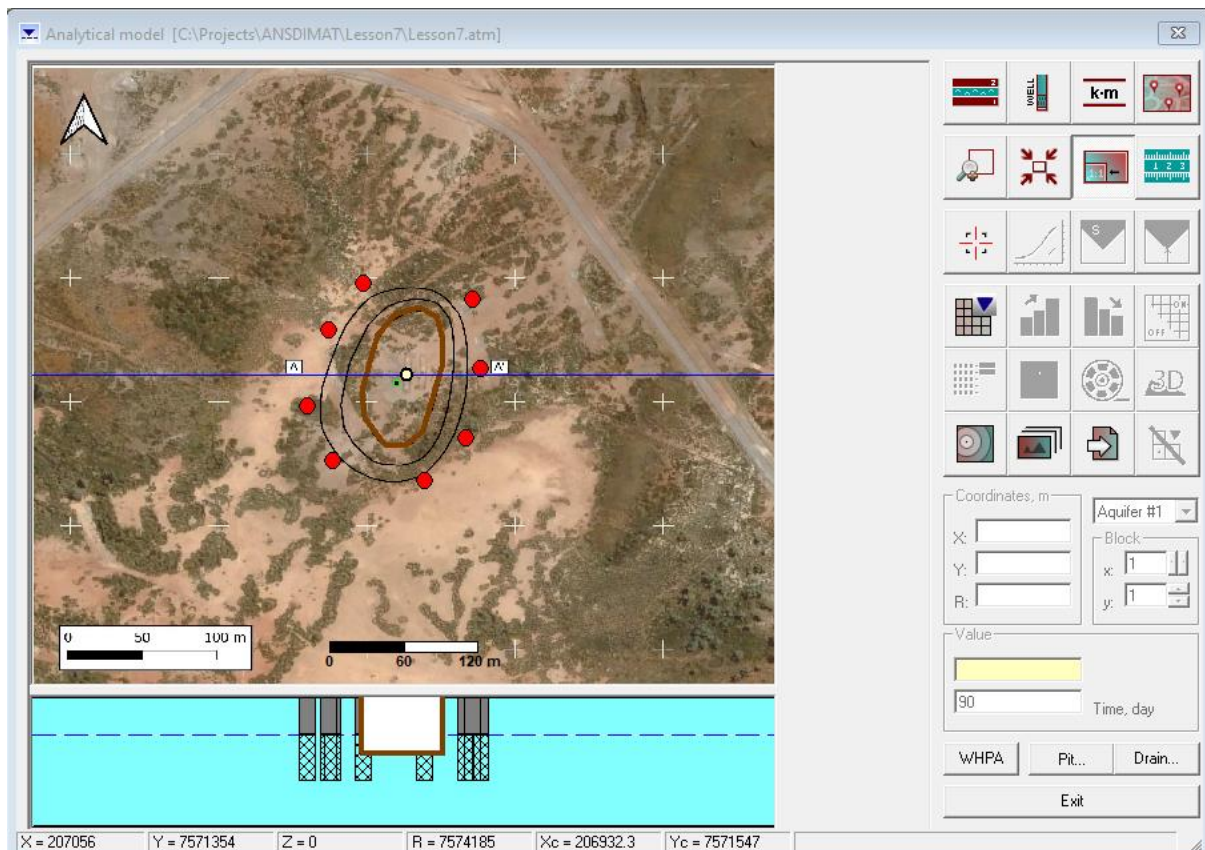
Figure 10: Model window with the pit contour (Brown line) and the pumping wells (red dots)

Input radius is 0.15 m for each well. Use any initial pumping rate. They will be automatically updated after evaluating the required pumping rate in the "Pit" window.

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Once all your wells are created, the "*Wells and time*" window should look like the **Figure 11**. Check systematically the properties for each well, specifically the length of the screen, the depth of the middle of the screen and the borehole radius.
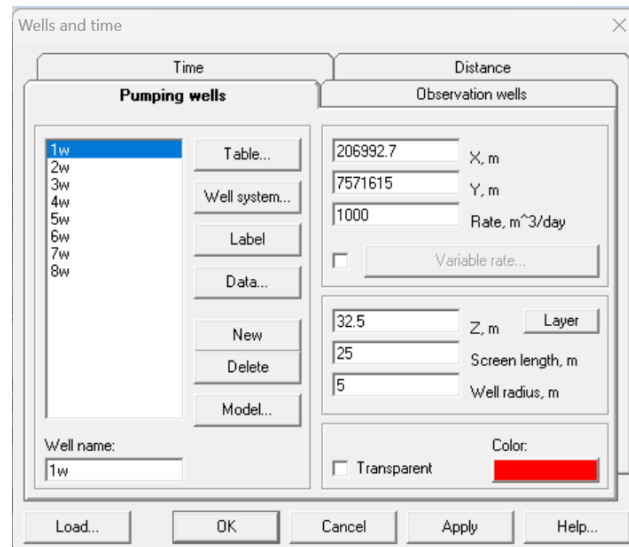
Figure 11: "Well and time" window, "Pumping wells" tab with all well parameters set

Click on the tab "*Time*", specify the duration of pumping at 90 days and use 10 time intervals, so your hydrographs would be sufficiently detailed. Click on the button "*Calculate equal time intervals*" to set an equal duration for all time intervals. The "*Time*" tab of the "*Wells and time*" window should look like **Figure 12**.
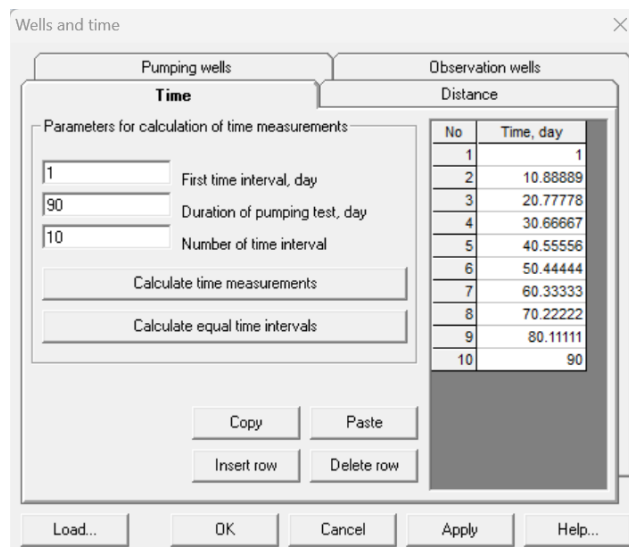
Figure 12: Pumping schedule with 10 steps entered into the "Time" tab

Open the "*Pit*" dialog window and click on the "*Dewatering wells*" tab. This tab displays a list of available pumping wells, they can be activated or deactivated by checking the box next to the well name. Enter the duration of the pumping and the target drawdown in their respective fields. By default, a target drawdown is assigned to the pit centre and its location can be modified by changing the values in the fields "*Coordinates, m*". Uncheck the box "*Assign to pit centre*" to assign the target to a different location.

You can also enter the target water level at the end of dewatering above the bottom level of the pit (Fields "*Level*").

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Two options allow you to estimate the pumping rate: AMWELLS can calculate the average rate per well by dividing the total volume of water by the number of wells. The pumping rate can also vary as a function of time/drawdown. When ticking the box "*Step-function of drawdown*" you can indicate target drawdowns at specific time steps. Adding or removing time-steps will also update the pumping schedule defined in the "*Wells and time*" dialog window.

For this lesson, enter a value of "90" (days) in the "*Time*" field and "15" (m) in the "*Drawdown target*" (i.e. 5 m below the pit base). Tick the "*Assign to pit centre*" box to assign the target to the centre of the pit. Finally, check the box to assign the same rate to all the pumping wells: this will calculate an average pumping rate for all the wells (**Figure 13**).
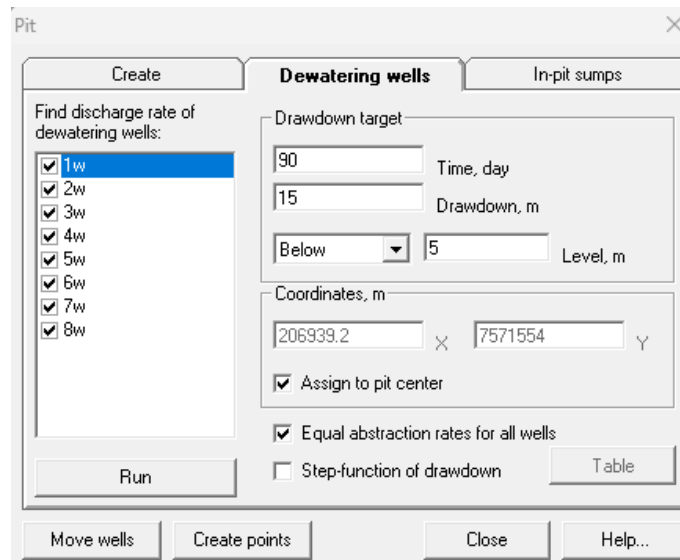

Figure 13: Parameters set in the "Dewatering wells" tab of the "Pit" window

Once you are satisfied with your parameters, click on the "*Run*" button. AMWELLS will calculate the total volume of water to be abstracted per day. Clicking on the "*Yes*" button will close the pop-up window and open the "*Wells and time*" window. Notice that now, the pumping rate in each well has been changed to 349.7 m^3/day or a similar number, depending on the exact locations of your input wells (**Figure 14**).
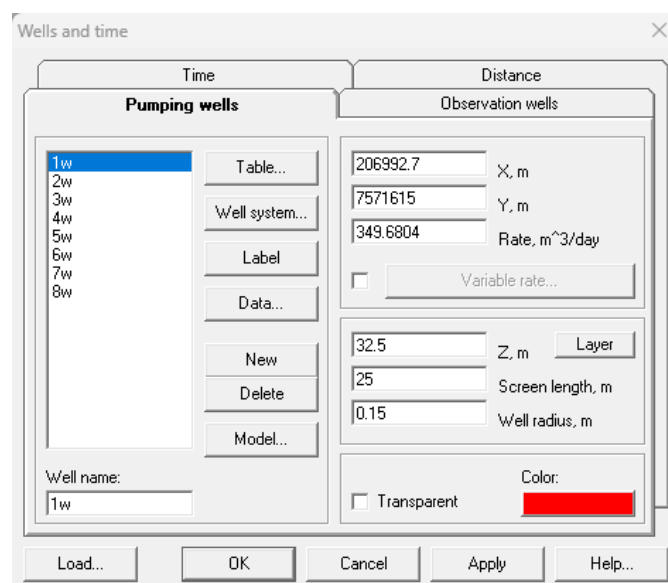

Figure 14: Pumping well parameters after calculating the dewatering requirements: the pumping rate was changed to about 349.7 m3/day instead of 1000

Model results

Drawdown hydrographs

The method to create hydrographs is detailed in the Lesson 6. In the Toolbox menu, click on the "*Value*" icon then position the cross on one of the pumping wells to check that the drawdown does not exceed the specifications (less than 20 m). Then click on the "*Plot*" icon to generate the hydrograph. By default, the time is on a logarithmic scale: this can be deselected in the "Options" tab. Check every pumping well: drawdowns vary between 17.16 and 18.94 m. Drawdown remains within specifications but is getting close to 20 m in half the wells.
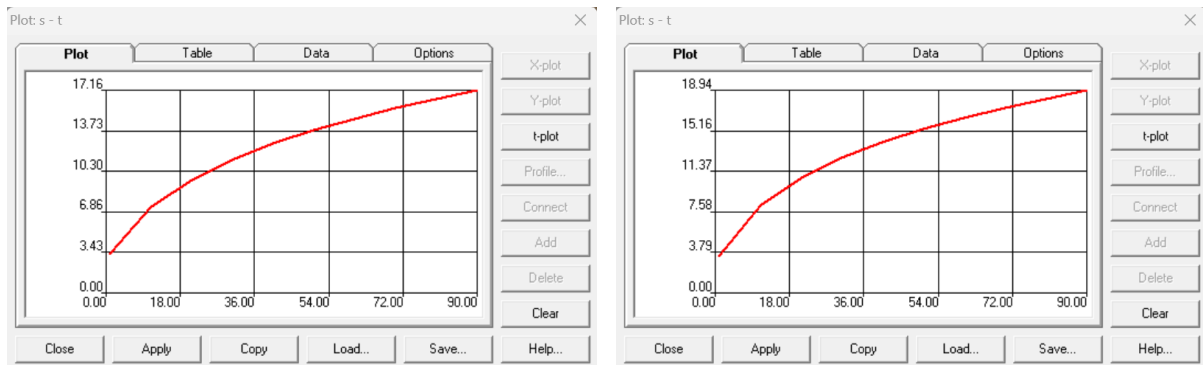
Figure 15: Minimum and maximum drawdown in pumping holes

Apply the same method and check the drawdown at the centre of the pit. A value of 15.08 m is obtained, suggesting the groundwater level at the centre of the pit will be within specifications after 90 days. A value of 15.06 m is obtained at the southern extremity of the pit, however a value of 14.20 is returned for the northern extremity of the pit, indicating the dewatering target will not be met over the whole area of the pit. This means that the borefield design needs to be changed to meet the dewatering target.

Drawdown contour map

In the Toolbox menu, click on the "*Groundwater potentiometric map*" icon to create drawdown contours. The contours are automatically calculated based on the numbers of contours, the max and min value. Since we want the water table to drop by 15 m, go to the "Values" tab and enter the following parameters:
- Minimum: 3
- Maximum: 21
- Interval: 2.

Make sure drawdown is selected. Then click on the "*Enter contours*" button (**Figure 16**) and go to the "*Contours*" tab.

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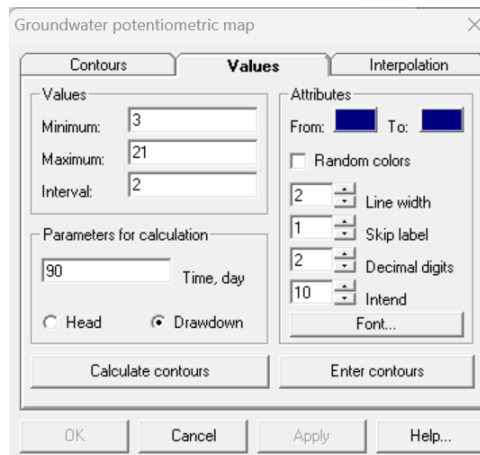
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Figure 16: "Values" tab of the "Potentiometric map" window with set parameters

In the "*Contours*" tab, select the contour for 15 m and change its colour to green (**Figure 17**) to better visualise the target. Change to red the colour for the 19 m contour then click the "*Clear*" button to remove the contours by default and click the "*Apply*" button or the "Ok" button to apply and close the window.
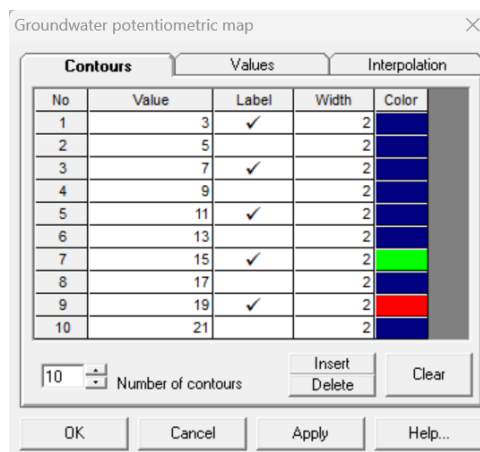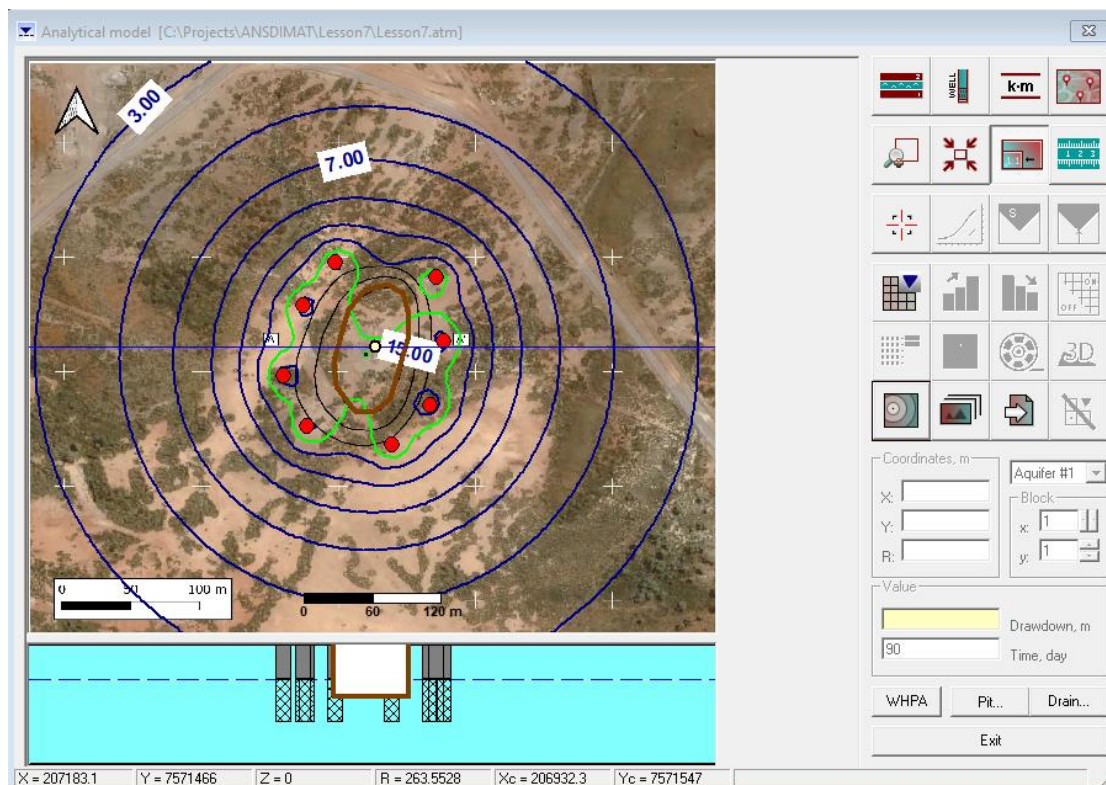

Figure 17: "Contours" tab with parameters set

The drawdown map shows that the drawdown at the centre of the pit is at or higher than 15 m (i.e. 5 m below the pit floor as required). However, over the northern end of the pit and a small area at the southern end, the drawdown is not deep enough (**Figure 18**). Hydrographs confirm that the water table remains too high by up to 0.8 m in these areas.

Overall, the model results indicate that:
- The total abstraction is insufficient to lower the water level to the target depth over the whole of the pit area;
- The pumping rate is already close to the limit for some of the wells and, as a result, it won't be possible to increase the pumping rate and keep the drawdown below 20 m in those wells.

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Figure 18: Contour map of the drawdown over the pit (Brown line); the green line indicates the 15 m target
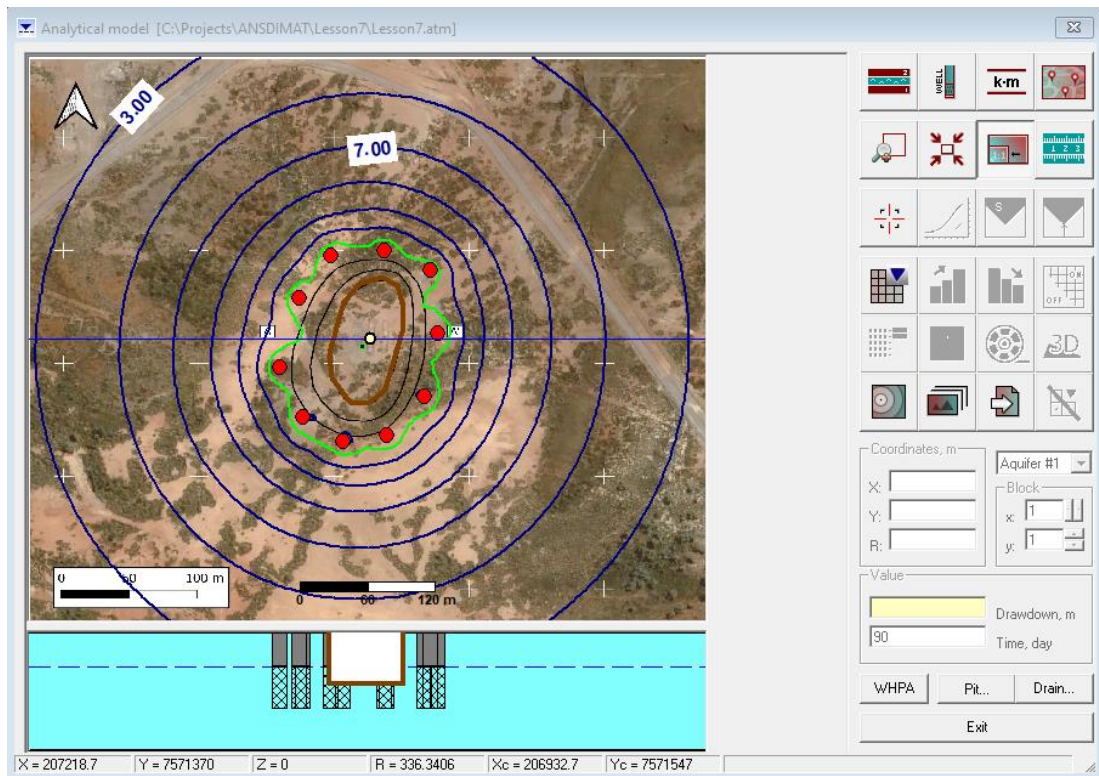
To achieve dewatering targets, let's apply the following changes to the borefield design:
- The number of boreholes needs to be increased
- Individual pumping rates need to be reduced

For this exercise add two additional wells and reduce pumping rate for each well to 285 m^3/day. The total borefield pumping rate will increase to 2850 m^3. Figure 19 illustrates that this increase will be sufficient to achieve dewatering targets. Furthermore, hydrographs at the borehole sites indicate that maximum drawdown in each of the boreholes will be between 16.96 and 18.04 m (**Figure 20**), that is well below the maximum allowed value.

The total borefield pumping rate is higher compared to the inflow to in-pit sumps estimated at 1320 m^3/day. This is a typical situation in mine dewatering, when a borefield extracts more water than a sump, because:
- the borefield option results in a deeper water table than the sump only option;
- dewatering wells pump water from the aquifer under the pit but also outside of the immediate vicinity of the pit, while sumps always have a smaller radius of influence. As seen on figures 15 and 16, after 90 days, the area influenced by the borefield extends hundreds of meters away from the pit.

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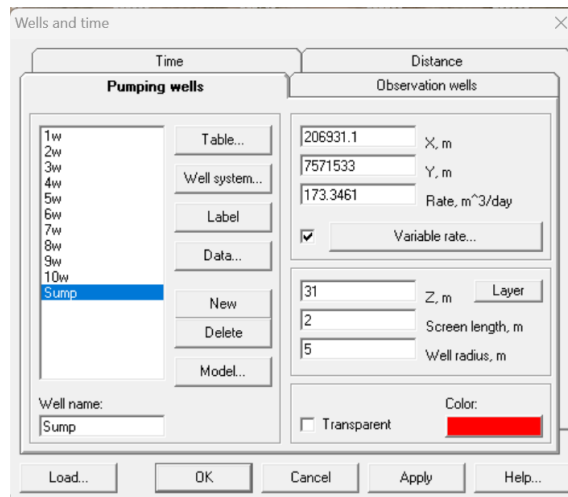**Figure 19**: Drawdown within specifications using 10 wells and a pumping rate decreased to 285 m³/day
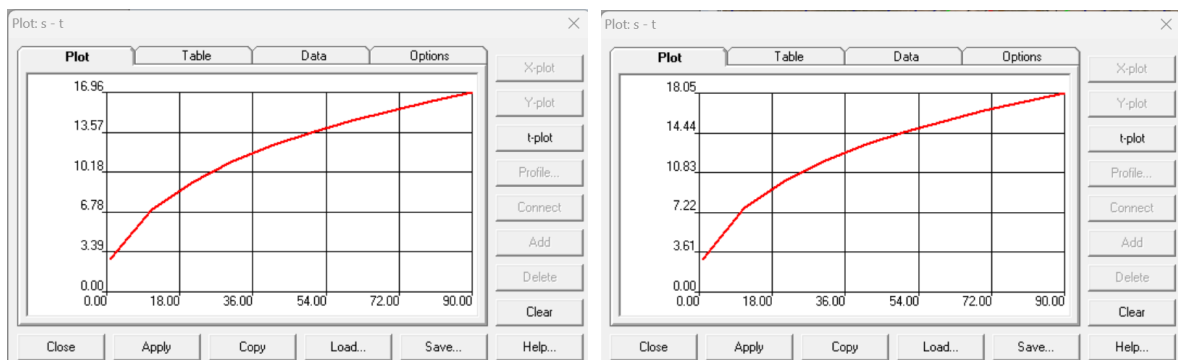
Figure 20: Minimum and maximum hydrographs at the borehole location showing the drawdown remains below 20 m

CALCULATION OF INFLOW FROM A SUMP AND A DEWATERING BOREFIELD (OPTION 3)

If we reduce the total pumping rate from the dewatering boreholes (for example, by reducing the number of holes), a part of the water will be seeping through the pit walls and discharge into the pit sump(s). This section explains how to calculate the combined dewatering requirements for a sump and a dewatering borefield.

For this method, a sump will be approximated by a vertical drain hole with a diameter equal to that of the sump. The drain elevation will be assumed equal to the sump bottom. A vertical drain is created from a pumping well. In fact, any pumping well with constant or variable pumping rate can be converted into a vertical drain with a fixed value of drainage elevation. For this lesson, create a new pumping well in the "*Wells and Time*" dialog window, call it "*Sump*" and place it in the centre of the pit floor. Input other parameters of this well as below (**Figure 21**):

- Z =31 m
- Screen length = 2 m
- Radius = 5 m.

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Figure 21: Parameters for the "big well" that will be used to simulate the sumps

The main graphical interface window should now include a new pumping well and look similar to **Figure 22**.
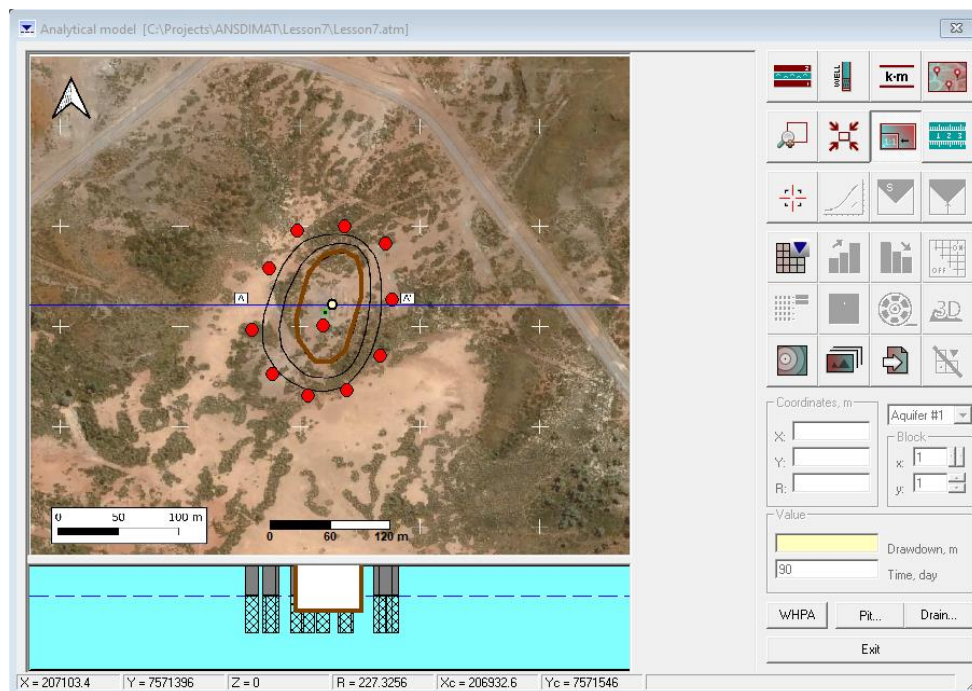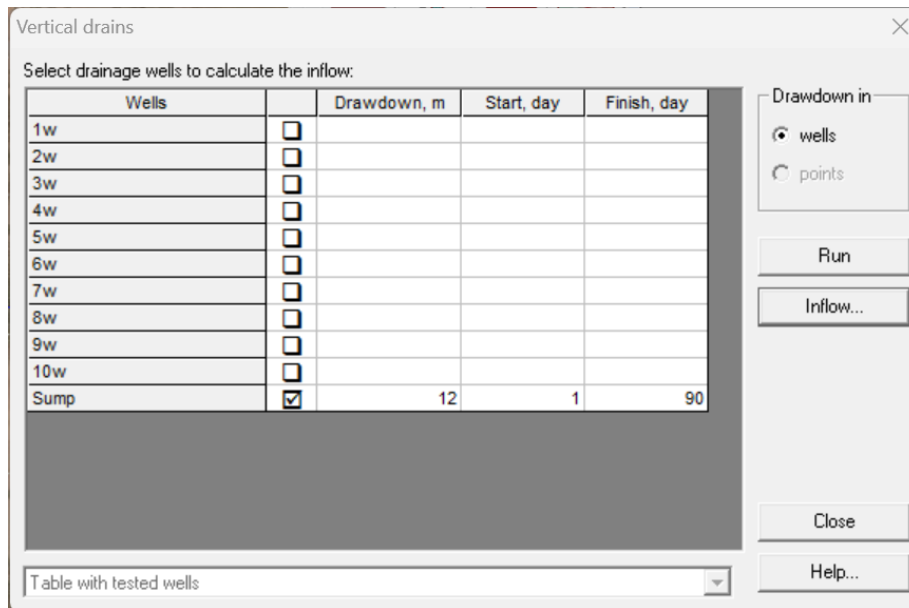

Figure 22: Main window of the analytical model showing the new pumping hole simulating the in-pit sumps

To reduce the number of wells, select all the wells with an even number and set their pumping rate to 0. You can also delete them.

To convert the "*Sump*" well into a vertical drain with a constant head boundary, click on the "*Drain*" button located under the icons of the toolbox, to the right of the main window (**Figure 22**). The "*Vertical drains*" window opens, showing a table listing all the pumping wells. Check the "*Sump*" well and make sure that all other wells are unchecked.

In the "*Drawdown*" column, set 12 m (the future base of the sump, that is 2 m below the pit floor). In the "*Finish, day*" column, enter 90 and in the "*Start, day*" column, enter 1. The window should look like **Figure 23**.

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Figure 23: Vertical drain windows with the parameters set-up for the "Sumps" well

Once this is finished, click on "*Run*". A pop-up window opens displaying the results of the calculation (**Figure 24**). It shows a table and a time-dependent inflow into the modelled sump. This is the flow rate at which water must be pumped from the sump to keep it empty.
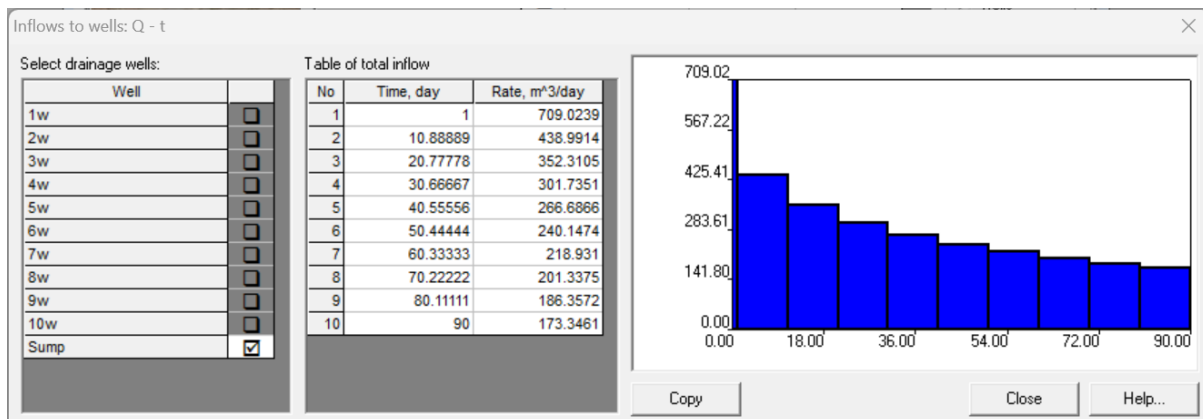
Figure 24: Results of the drain package showing the inflow to the sumps as a function of time during the dewatering phase

Thus, the total dewatering requirements at the day 90 will be 1598 m^3/day: 1425 m^3 from dewatering wells and 173 m^3 from the sump, with contribution from the sump decreasing regularly as time increases.
Note, that the dewatering requirement is higher than for the first option (sumps only) by about 300 m^3/day, and significantly lower than the requirement for option 2 (dewatering borefield, 2850 m^3/day).

This concludes the Lesson *7* of the ANSDIMAT tutorial. The datafiles supporting this lesson can be downloaded from the ANSDIMAT web site where ready-made models are also available. The pack for **Lesson 7** includes an excel file with the aquifer parameters and tables with the well parameters ready to copy in ANSDIMAT. The ANSDIMAT model provided is set-up to calculate the dewatering requirements for a borefield and sumps (option 3). The map is included in the Lesson7 folder. If you have questions or feedback, feel free to email us at: support@ansdimat.com.

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