WellHead Protection Area

This lesson will illustrate how to delineate Wellhead Protection Areas (WHPA) for a water supply borefield. The methodology requires calculating flowpaths and particle velocities using particle tracking method. This methodology is similar to that described by Blanford and Huyakorn (1991), Grubb (1993) and Pollock (2016).

1. Problem settings

A tourist camp located in the village of San Pedro (Mexico) requires water supply of 1500 m^3/day over the next 10 years. Sufficient water resources are available in a surficial aquifer composed by alluvial sands and silts. The aquifer has a thickness of 50 m, and it is underlain by low-permeable shales. Hydraulic tests resulted in a hydraulic conductivity of 0.4 m/day and a specific yield of 0.1. The aquifer static level in the borefield area is 5 m below the ground level. Based on limited monitoring data, the regional hydraulic gradient is 0.003 in the western direction.

Figure 1 shows the site aerial photo with 3 proposed water supply wells. The potential borefield is located approximately 2 km west from a mineral fertiliser factory that may adversely impact borefield water quality. A river on the west is an environmentally protected area, where impacts from borefield pumping are not permitted. This river serves as a constant head (recharge) boundary for the area.

The objective of this Lesson is to demonstrate that borefield WHPA doesn't extend over either the factory or the river.

Figure 1: Planned location of the borefield: blue dots show locations of the proposed boreholes

ANSDIMAT – software for analytical modelling of groundwater wells
E-mail: support@ansdimat.com
Tel: +61 478 633 429

ANSDIMAT
www.ansdimat.com

2. Model setup

Creating a new AMWELLS model

The procedure to create an AMWELLS model has been described in details in the Lesson 6. Select the command *Flow models/Analytical models/New model*. The pop-up window offers a choice of options for the conceptual model: select an unconfined aquifer, semi-infinite with one recharge boundary.

Assign wells as fully penetrating. The model dimensions are:

- 4000 m long
- 2000 m wide
- 50 m thick
- Water table is at 45 m (corresponding to 5 m below ground level)
- Leave the origin coordinates as 0.0.

Click on the "*Create*" button. More details about functions in this window can be found in the help menu, directly accessible by clicking on the "*Help*" button.

Model parameters

The main AMWELLS window opens. It consists of a map area, a profile and a toolbox panel on the right hand side. The icons in the toolbox allow setting up the model parameters. Click on the top left icon ![icon] to check the model dimensions (length, width, depth, etc). The window should look like Figure 2. Click "*OK*" to save the parameters and close the window.
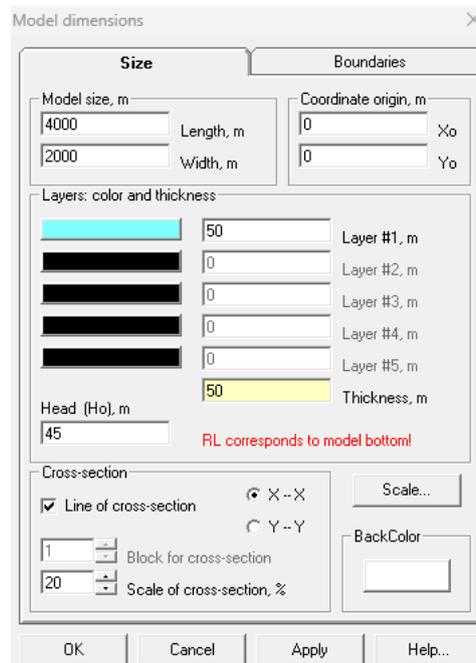
Figure 2: Window showing the dimensions of the model

ANSDIMAT – software for analytical modelling of groundwater wells
E-mail: support@ansdimat.com
Tel: +61 478 633 429

ANSDIMAT
www.ansdimat.com

Click on the "*Model parameters*" icon ![k·m]. In the new window, set the horizontal conductivity to 5 m/d and the vertical conductivity to 0.5 m/d. Assign 10^{-5} to storage coefficient and 0.1 to specific yield. The window should look like Figure 3. Click "*OK*" when you are satisfied with parameter values.
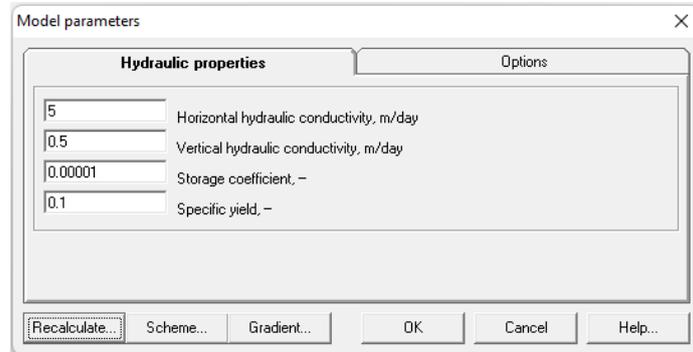
Figure 3: Window showing the aquifer parameters

Uploading a map

A detailed explanation on the workflow to import maps is provided in the Lesson 6. To import a map, click on the "*Picture*" icon ![icon]. In the pop-up window, select your map file, tick the box next to "*Picture visible*" then click "*OK*". Your screen should look like the Figure 4.
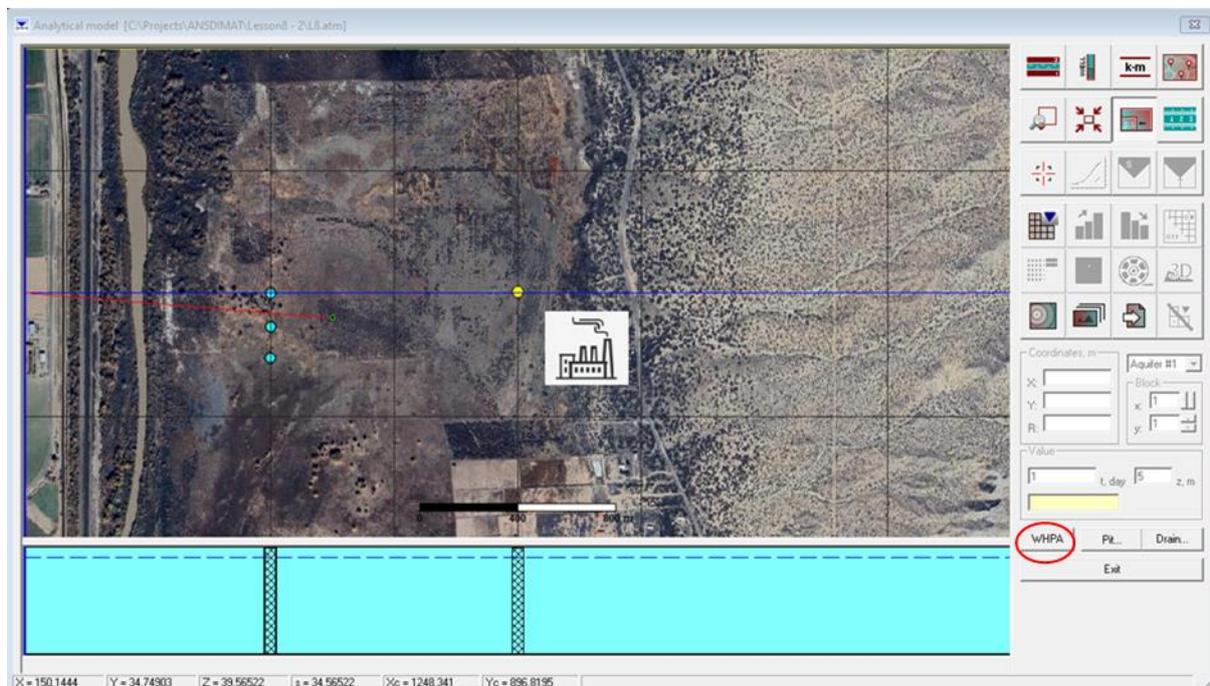
Figure 4: AMWELLS main window after importing the map

ANSDIMAT – software for analytical modelling of groundwater wells
E-mail: support@ansdimat.com
Tel: +61 478 633 429

ANSDIMAT
www.ansdimat.com

Recharge boundary (River)

Boundary conditions can be defined if the conceptual scheme contains a boundary. For this Lesson, one recharge boundary was included (see "*Creating a new AMWELLS model*" earlier in this Lesson). To define boundary conditions, click on the "*Model dimensions*" icon and select the "*Boundaries*" tab. A boundary is defined as a straight line. It can be set-up in two ways:

- Enter the coordinates of the start and end points in the coordinates fields (in meters) or;
- Draw the boundary in the model.

It is often easier to draw the boundary in the map area. Click on the "*Model*" button: the pop-up window disappears and you can now draw the boundary directly on the map. Use the left mouse button to position one extremity of the line and the right mouse button to position the other. Once you are satisfied with the boundary line, use the "*Esc*" key to return in the Boundary tab. Since this is a recharge boundary, it appears in dark blue, but the colour can be changed. Your Boundary tab should look like Figure 5 and the map should be similar to Figure 6.
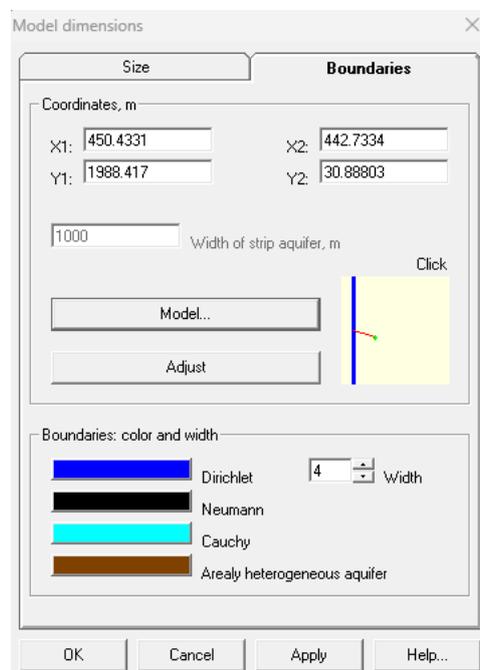
Figure 5: "Model dimensions" window showing the "Boundaries" tab; the X and Y fields indicate the coordinates of the ends of the straight line marking the recharge boundary

ANSDIMAT – software for analytical modelling of groundwater wells
E-mail: support@ansdimat.com
Tel: +61 478 633 429

ANSDIMAT
www.ansdimat.com
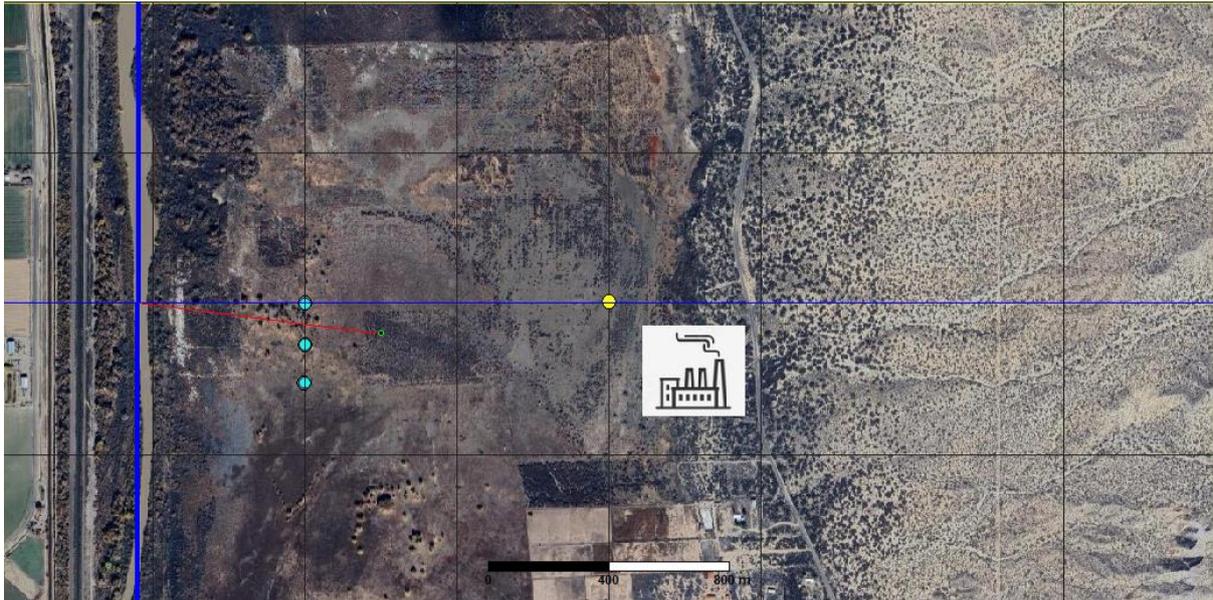
Figure 6: Model map after setting up the recharge (river) boundary; the boundary is marked by a dark blue line

Once you are satisfied with the boundary, click "*OK*" to save the parameters and close the window.

Setting up pumping wells

Positioning wells has been explained in Lessons 6 and 7, refer to these lessons for more details. You can also refer to the "*Help*" menu for a detailed description of the functions in the "*Well*" window.

The uploaded map shows locations of the proposed wells as blue circles. Left-click on the well at the centre of the map and move it to the northernmost location. Then open the "*Well and time*" window by clicking on the "*Well*" icon . Set the ate to 500 m^3/day, then check that Z is set at 25 m, the screen length at 50 m and the bore diameter at 0.1 m. Click "*OK*" to save the parameters and close the window. Then, on the map, use **ctl + left click** to create the last two wells. Re-open the "*Well and time*" window to check that all the wells have the same parameters then rename them PW1, PW2 and PW. In the "Time" tab, enter 3650 (10 years) for the duration of pumping, then 365 for the first interval. Set the number of intervals to 10 and click on "Calculate equal time intervals". Click "*OK*" to save and close the window. Differently from Lessons 6 and 7, only the well location and construction parameters are required in this window: time steps are not required. Once you are finished, the "*Well and time*" window should look like Figure 7. The model is now ready for Well Head Protection Area (WHPA) calculation.

ANSDIMAT – software for analytical modelling of groundwater wells
E-mail: support@ansdimat.com
Tel: +61 478 633 429

ANSDIMAT
www.ansdimat.com
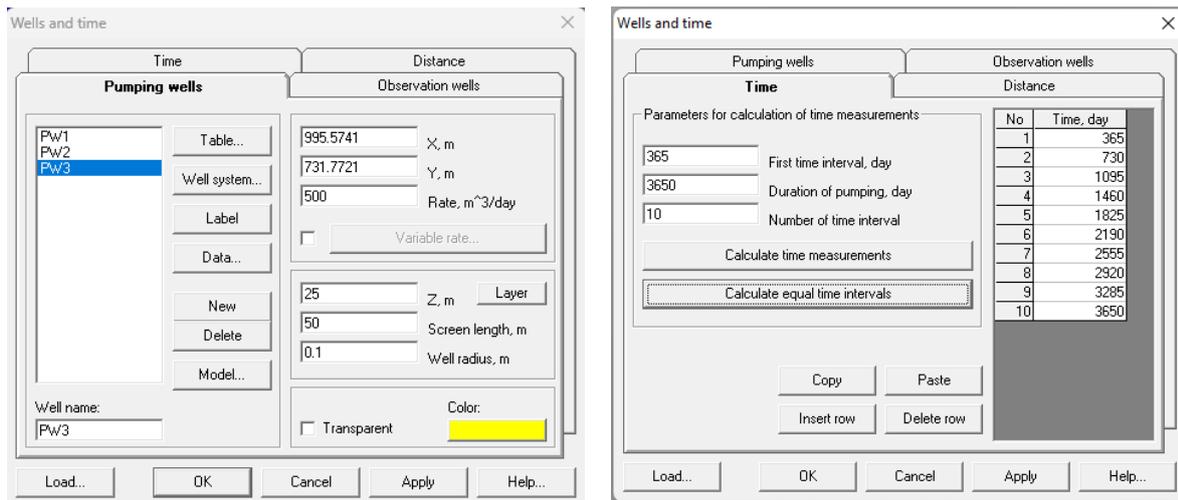
Figure 7: "Well and time" window with the 3 wells set-up

3. WellHead Protection Area (WHPA) package

<u>Creating WPHA zones</u>

The WHPA package is accessed by clicking on the WHPA button, to the bottom left of the toolbox panel (circled in red on Figure 4). This activates a new dialog window, where extension of Zones II (biological contamination) and III (chemical contamination) can be calculated and visualized. Zone II corresponds to the area drained by the borefield over the average lifetime period of bacteria in the subsurface: it generally varies between 100 and 400 days. Zone III corresponds to the area drained by the borefield over the duration of the project: the water from this area must remain chemically fit for human consumption. After clicking on the WPHA button, the main AMWELLS window should look like Figure 8. This window requires inputs of hydraulic gradient, porosity and time.

Gradient

The parameters of the hydraulic gradient can be entered in the Flow and porosity area. Set the Gradient parameter to 0.003 and the Angle to 270 degrees. The arrow positioned in the top left corner of the map should now point toward the left (westward).

Porosity

Set the porosity at 0.1.

Time

Use the two fields in the "*Time value for capture zones*" area to select the extension of the capture zones. The default values are 400 days for zone II and 25 years for zone III. The duration of the time period for the calculation of the zones depends on national regulations and the duration of the project so they can be modified as required. Note that the time period for zone II is in days while it is in years for zone III. For this exercise, keep the default value for zone II and enter 10 years for zone III (the duration of the project).

You can also change the accuracy of the analysis (see drop-down list with the same name): "Accurate" provides a higher confidence in the result at the cost of a higher calculation time. On the contrary, "*Rough*" is very quick but less accurate. "*Rough*" generally results in a larger area and "*Accurate*" - in a smaller area. Use the "*Escape*" key to abort the calculation at any time.

ANSDIMAT – software for analytical modelling of groundwater wells
E-mail: support@ansdimat.com
Tel: +61 478 633 429

ANSDIMAT
www.ansdimat.com

After setting up all the parameters above, the main window should look like Figure 8.
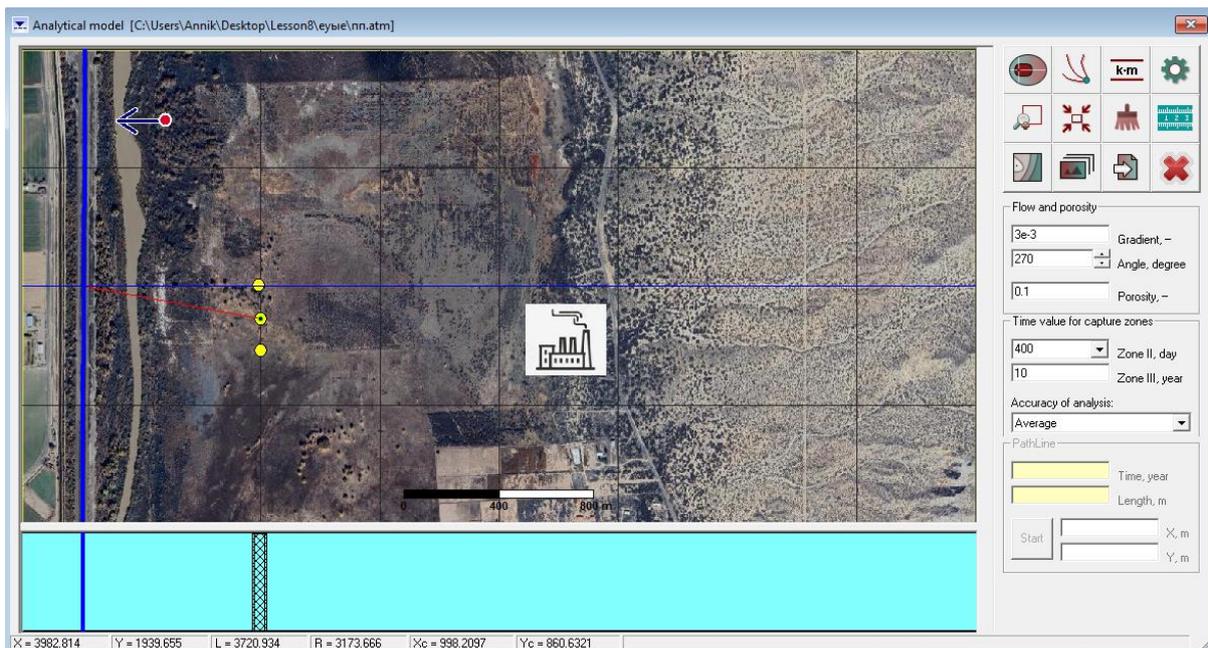
Figure 8: Main AMWELL window after the activation of the WHPA package

Particles set-up

Click on the top right icon [⚙] to access the options. This window, displayed in Figure 9, allows modifying the colours of the particle paths and the markers for the zones and the accuracy parameter, offering the option to set-up a specific step and angle combination.
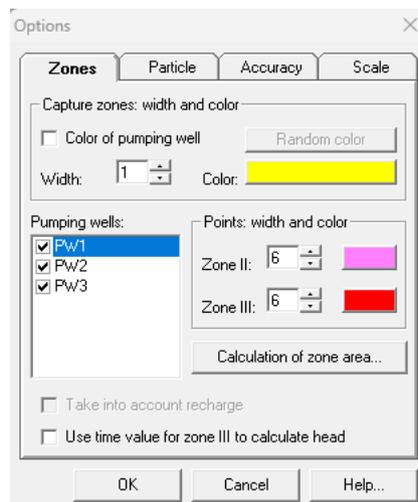
Figure 9: "Options" window for the WHPA package

ANSDIMAT – software for analytical modelling of groundwater wells
E-mail: support@ansdimat.com
Tel: +61 478 633 429

ANSDIMAT
www.ansdimat.com

Running the model and plotting results

Once you have set and checked all your parameters, the model should be run by clicking on the "*Calculate zones*" icon in the top left corner of the toolbox. The Figure 10 shows an example of result: the paths of the particles are marked by coloured lines and the boundaries of the Zones II and III are marked by dots of different colours. If the trajectory of the particles does not seem realistic, you can modify the accuracy parameter or use an alternative algorithm to draw the streamlines. To change the algorithm, click on the "*Calculate zones*" icon while holding the Shift key.

The map on Figure 10 shows that the WHPA zones do not extend either to the river or to the factory, so the borefield wouldn't create adverse impacts and its water quality wouldn't deteriorate either because of the presence of the factory.

Results can be copied as images with the "copy and clipboard" icon or they can be exported in a .dat ASCII xyz file with the icon for reporting.

To get dimensions of calculated WHPA zones, select icon "Options" () and then the button "Calculation of zone area" in the Options dialog window (Figure 9).
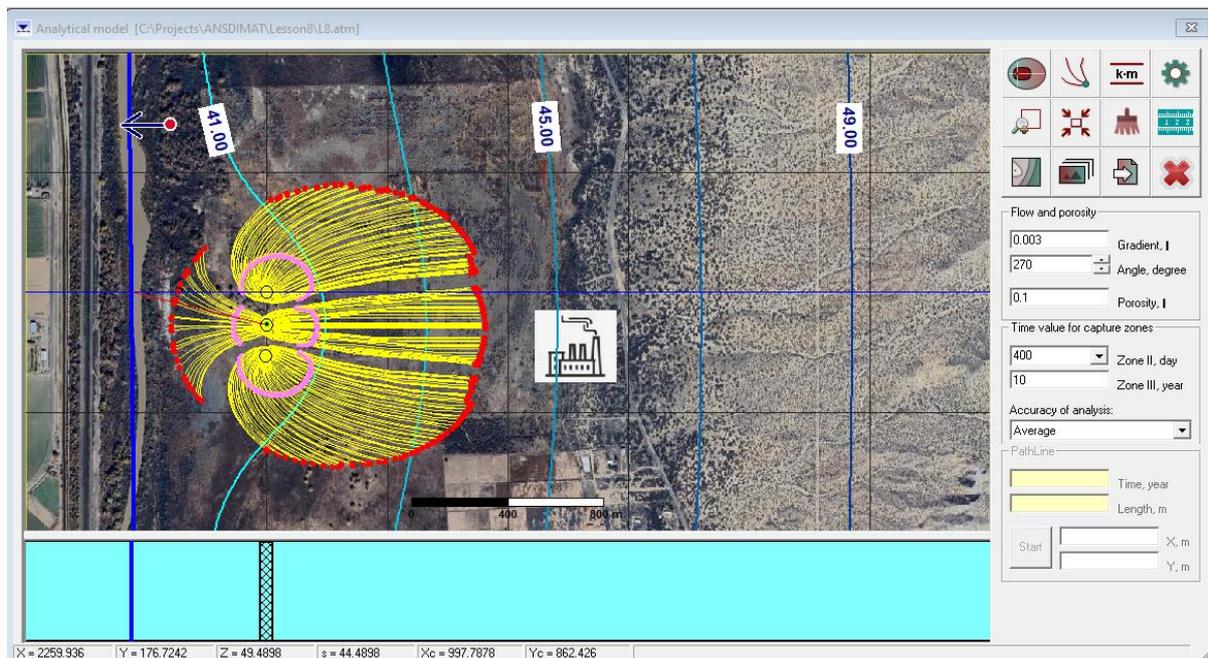
Figure 10: Map showing the extension of the calculated zones based on default parameters; Zone II: pink dots; Zone III: Red dots: Paths: Orange line

Contours

Contours can be drawn to show hydraulic heads prior to and/or after the WHPA calculation, as illustrated in Figure 10. Use the "*Contour*" icon to open the "Isoline of head" window. This dialog window is identical to "Groundwater potentiomenric map" window of AMWELLS that is explained in

ANSDIMAT – software for analytical modelling of groundwater wells
E-mail: support@ansdimat.com
Tel: +61 478 633 429

ANSDIMAT
www.ansdimat.com

the Lessons 6 and 7. Click on the "*Values*" tab, set the minimum at 30, the maximum at 60 and the interval at 2, then change the colour in the "From" box to cyan and click "*Enter contours*". Click on the "*Contours*" tab, click "*Clear*", then "*Apply*" then "*OK*" to close the window.

4. Conclusion

You have learned how to use the WHPA package to delineate capture zones around a borefield. This concludes the tutorial. Further information can be found in the help menu and on the ANSDIMAT website. A complete model for this lesson as well as original parameters can be downloaded from the tutorial section of the ANSDIMAT website. You can contact the technical support if you have specific questions.

References

Blanford, N.T. and Huyakorn, P.S. 1991. WHPA: A Modular Semi-Analytical Model for the Delineation of Wellhead Protection Areas. U.S. EPA Office of Ground-Water Protection, Washington, D.C.

Grubb, S. 1993. "Analytical Model for Estimation of Steady-Sate Capture Zones of Pumping Wells in Confined and Unconfined Aquifers". Ground Water. Volume 31, Number 1. January-February 1993. National Ground Water Association. Dublin, Ohio.

Pollock, D.W., 2016, User guide for MODPATH Version 7—A particle-tracking model for MODFLOW: U.S. Geological Survey Open-File Report 2016–1086, 35 p., http://dx.doi.org/10.3133/ofr20161086.

ANSDIMAT – software for analytical modelling of groundwater wells
E-mail: support@ansdimat.com
Tel: +61 478 633 429

ANSDIMAT
www.ansdimat.com