3D Example for **SUTRA**

POND

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This is a simple transient flow and transient solute transport simulation example representing an alluvial aquifer. Drawdown evolves from a single production well, eventually causing a solute plume to emanate from a pond and migrate to the well. The geometry of the aquifer is not vertically-aligned, demonstrating the flexibility of the non-vertical fishnet mesh.

The fluid density is constant and the fluid compressibility is set to a value of one, providing storativity throughout the volume equivalent to a specific yield value equal to the porosity value. This unnaturally high value is used to give interesting dynamics to the hydraulic head distribution in a brief transient simulation. By the end of the simulation, both the head and concentration solutions are nearly at a steady state.

The rough maximum dimensions of the irregular bowl-shaped domain containing the alluvial aquifer (z vertically upward) are:
in x: 1000. m
in y: 1000. m
in z: 60. m

Setting up the 3D dispersion model requires careful consideration. While a 60. m longitudinal dispersivity may be reasonable for the horizontal transport reach of 1000. m between pond and well, this value is not possible for longitudinal dispersion in flow occurring vertically across the aquifer (which at its thickest is only 60. m). Thus, longitudinal dispersivities in this example are adjusted to be representative of the length scale of transport in each possible flow direction. Specifically, the flow-direction-dependent dispersivities in **SUTRA** are set to give longitudinal dispersivity of 60. m for any horizontal flow and 8.0 m for vertical flow. Due to layering, when flow is parallel to layers, transverse dispersion in alluvial aquifers is usually much greater in the direction parallel to layers than in the direction across layers. To represent this situation, the flow-direction-dependent dispersivities are set to give horizontal transverse dispersivity for any horizontal flow of 6.0 m, horizontal transverse dispersivity for any vertical flow of 6.0 m, and vertical transverse dispersivity for any horizontal flow of 0.01 m.

These dispersive properties are obtained through careful specification of the 6 dispersivity values, as listed below.

The main parameter values are:

Hydraulic conductivity	1.0×10^{-3} m/s (max & mid directions are horizontal, min value is vertical)
Fluid compressibility	1.0 (approximates specific yield of about 0.10)
Porosity	0.10
Solute diffusivity	1.0×10^{-9} m^2/s
Longitudinal dispersivity for	
flow in max direction	60.0 m
flow in mid direction	60.0 m
flow in min direction	8.0 m
Transverse dispersivity	
in max direction for flow in mid-min plane	6.0 m
in mid direction for flow in max-min plane	6.0 m
in min direction for flow in max-mid plane	0.01 m
Recharge	0.50 m/yr = 15.844×10^{-9} $(m^3/s)/(m^2$ of top surface)
Well	-0.015 m^3/s (about equal to the total recharge)
Pond water level	0.10 m
Initial head	0.0 m

Boundary Conditions:

Natural recharge occurs over the entire aquifer surface. The well is vertical and is screened in mid-aquifer. The pond is modeled as a region of specified head on the upper surface of the aquifer.

Initial Conditions:

The initial conditions for head and concentration are zero values. This allows a simple start for the simulation, although it causes some undesired adjustments of the head field and solute plume at early time.

> *Note:* A better (more realistic) initial condition would be the natural steady state flow field in which all of the applied recharge discharges from the model through the pond. This would require a separate simulation to calculate the natural head distribution prior to running the transient model with pumping, but it is not done here in order to keep the procedure simple. The user may try this.

Mesh:

The mesh consists of 4000 unevenly spaced elements (20 in x, 20 in y, and 10 in z). The transient simulation consists of 16 time steps beginning with a step of ½ month. Each succeeding time step increases in duration by a factor of 1.4. Total elapsed time at the end of the simulation is about 20 yr. The CG solver is used for flow (2 - 36 iterations per time step) and GMRES is used for transport (2 - 16 iterations per time step).

Simulation:

The run takes about 6 seconds on a PC running Windows XP with a 3.4 GHz Pentium 4 processor; it uses about 7 Mbytes of RAM.

***SUTRA** files:*

> input:
> *Pond3D.inp*, *Pond3D.ics*, and SUTRA.FIL
>
> output:
> *Pond3D.smy*, *Pond3D.lst*, *Pond3D.rst*, *Pond3D.nod*, *Pond3D.ele*, and *Pond3D_Timed_Obs.obs*

Preprocessing:

The ArgusONE setup file, *Pond3D.mmb*, is included for use with **SutraGUI**. In **SutraGUI**, this problem requires a non-vertical mesh with two units. The top of the model and bottom of each unit are assigned elevations at the locations of the corners of the Fishnet blocks. The '624 interpolation' given in ArgusONE is used for these elevations. Recharge is specified as a constant background value for the specific_source parameter of the <u>Sources of Fluid Top</u> information layer with zero concentration of inflow. The well is specified as a vertical line object in the <u>Sources of Fluid Lines1</u> information layer, and the pond is specified as an area of specified head with non-zero concentration of inflow in the <u>Specified Hydraulic Head Top</u> information layer. Vertical observation wells are specified (within the <u>SUTRA Observation Solids 1</u> information layer) in two locations, one near the pond and the other in the pumping well.

Results:

Results are reported for each of 16 expanding time steps (total of about 22 years after beginning of recharge and pumping, and the pond begins to leak).

Postprocessing:

The match of specified and calculated pressures may be checked using **CheckMatchBC**.

> Start **CheckMatchBC**, click **Select Files**, then navigate to and open the files *Pond3D.inp* and *Pond3D.nod*.

Hydrographs of pressure and concentration at the observation nodes may be viewed using **GW_Chart**.

Start **GW_Chart** and select **Chart type | Hydrographs**.
Under "Data," click the **SUTRA** radio button.
Under "SUTRA Data," click the radio button for the type of observation data you wish to plot (**Pressure** or **Concentration**).
Click the **Read** button, then navigate to and open the SUTRA observations file *Pond3D_Timed_Obs.obs*.
In the list of observation nodes in the upper left, set the entry in the "Plot" column to **Yes** for any nodes for which you wish to plot results.

Spatial distributions of results may be viewed with **ModelViewer**; a setup file, *Pond3D.mv*, is provided. By selecting Toolbox:Animation:Run, the growth of the plume may be seen.

NOTE: A version of **SutraPlot** that is compatible with **SUTRA** Version 2.2 is currently under development. Once it is completed, a setup file for plotting results from this simulation in **SutraPlot** will be provided. Please check the web site http://water.usgs.gov/nrp/gwsoftware/sutraplot/sutraplot.html for updates.

Suggestions:

The user is encouraged to improve the simulation by creating a natural steady-state head distribution as the initial condition for the transient simulation; this is described in the note, above. Also, time step expansion may be slowed (reduce time step multiplier, TMULT; increase the number of time steps, ITMAX) (while saving all results in the .nod and .ele files) to create a smoother animation. To reduce instability in the solution (that causes negative values and values higher than the maximum pond concentration) the mesh may be refined by specifying more elements in each Fishnet block and more elements vertically in each unit. Spatial variations of hydrologic properties such as permeability may also be implemented, for example using **SutraGUI** to place low and high permeability lenses within the aquifer and the results examined.