PONDS 3.2 TECHNICAL MEMO

Date: December 13, 2007

Re: **GROUNDWATER BASEFLOW ANALYSIS USING PONDS REFINED METHOD MODULE**

Groundwater baseflow occurs when the control level in a wet pond or underdrained pond is lower than the surrounding seasonal high ground water table elevation, resulting in a hydraulic gradient which slopes towards the pond and produces groundwater seepage into the pond, as illustrated in Exhibit 1 below. These conditions may occur, for example, when the orifice elevation of a wet pond or the underdrain pipe inverts of a dry underdrained pond or roadway underdrain is set below the seasonal high groundwater table elevation.

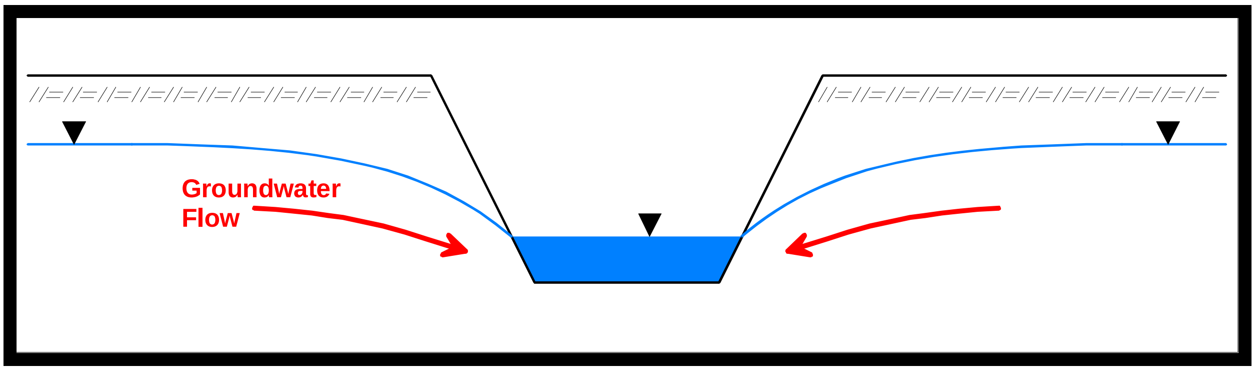


Exhibit 1. Illustration of Groundwater Baseflow Seepage

It is often necessary to quantify the rate of baseflow seepage into the pond (& the water table drawdown profile) in order to satisfy permitting requirements and to ensure that pipes (etc.) are adequately sized. PONDS Refined Method Module has a predefined Baseflow Hydrograph type to assist in performing baseflow seepage analysis.

THE BASEFLOW HYDROGRAPH

The baseflow hydrograph applies an outside recharge to the ground surface (outside the pond) sufficient to raise the groundwater table from an initial level (such as the seasonal low water table elevation) to a final level (such as the seasonal high groundwater table elevation) over a specified duration of time, as illustrated in Exhibit 2 below.

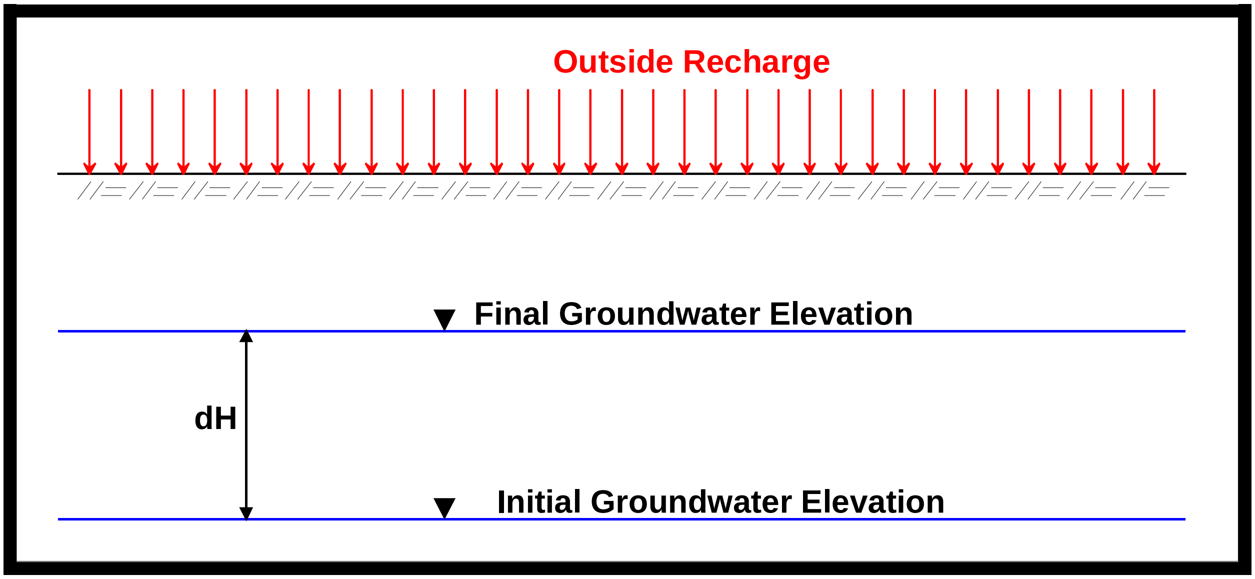


Exhibit 2. Example of Outside Recharge in Baseflow Hydrograph

In Exhibit 2, the outside recharge, as calculated internally by PONDS, is as follows:

Recharge Rate = dH x n / dT

where:

dH is the desired change in groundwater elevation

n is the fillable porosity of the soil

dT is the desired length of time over which the change in groundwater elevation occurs

In the baseflow hydrograph there is no direct inflow (from runoff) into the pond. However, the rise in groundwater table may induce baseflow infiltration from the soil into the pond, depending on the relative elevations of the pond and any control structures, etc.

Also note that the boundary condition (used by Modflow for PONDS) is set to No-Flow for the baseflow hydrograph. This means that at the farthest edges of the model, the water table is free to rise and fall, but no water can flow in or out of the model at the boundary.

Exhibit 3 below shows the data input dialog box for the baseflow hydrograph.

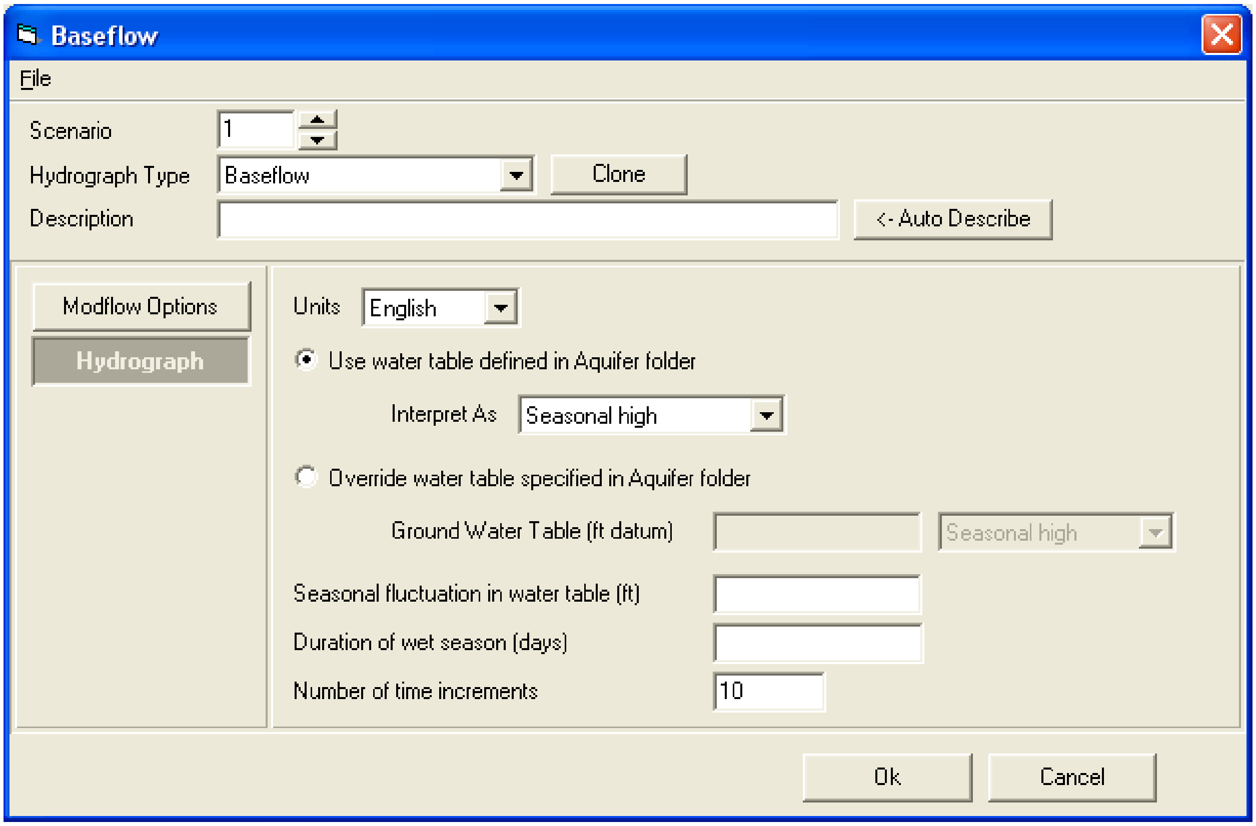


Exhibit 3. Baseflow Hydrograph Data Input

For the baseflow hydrograph, it is necessary to define:

① Either the starting or finishing groundwater table elevation, i.e., either the seasonal low groundwater table or the seasonal high groundwater table elevation

② The difference in elevation between the initial and final groundwater levels, i.e., the seasonal water table fluctuation

③ The time it takes for the water table to go from its initial to final level, i.e., the duration of the wet season.

④ The number of time increments to model. The wet season duration divided by the number of time increments defines the length of each time increment. It is better to define a large number of small increments than to define a small number of large increments. In general, the resulting time increment should not be greater than 1 day, and preferably less.

When performing a baseflow analysis, it is usually of interest to evaluate the resulting groundwater drawdown profile. PONDS can save the groundwater profile, but this feature is not activated by default, in order to reduce the data file size. To activate the option for saving the groundwater mound profile, select the following menu sequence:

Options ➜ Advanced Modflow Options...

This will open the Modflow Options dialog box, as shown in Exhibit 4. The groundwater mound output flag must be activated in order for PONDS to save the groundwater mound profile.

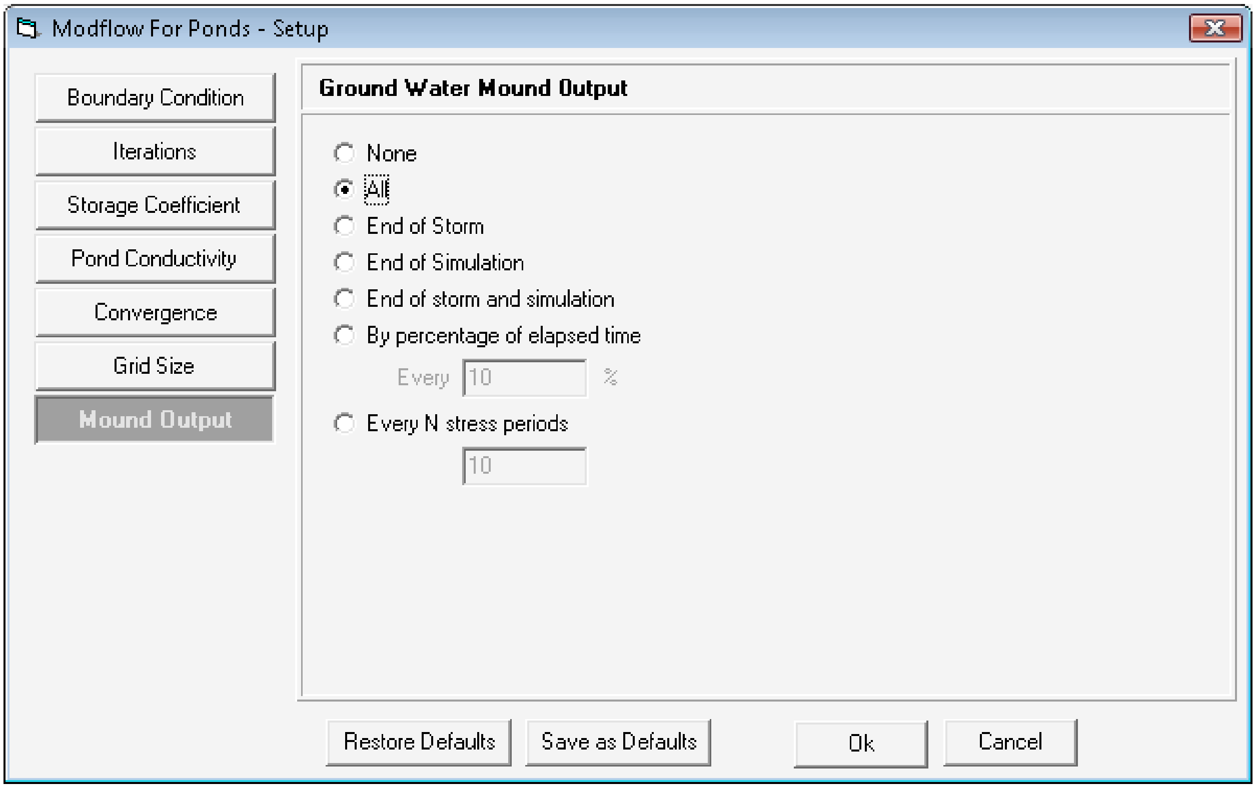


Exhibit 4. Advanced Modflow Options, Groundwater Mound Output Flag

EXAMPLE 1 - BASEFLOW INTO POND FOR GRADUAL RISE IN WATER TABLE

The objective of this example is to estimate the peak groundwater seepage rate into a pond for a normal wet season.

The groundwater fluctuates between seasonal low groundwater table to seasonal high groundwater table as follows:

Seasonal low water table elevation = +99 ft
Seasonal high water table elevation = +103 ft
Rise (or fluctuation) of water table during wet season = 4 ft
Duration of wet season = 120 days

The pond itself has the following properties:

Length of pond = 500 ft
Width of pond = 200 ft
Control elevation of pond = +100 ft

And the aquifer parameters are as follow:

Bottom of aquifer elevation = + 93 ft
Hydraulic conductivity of aquifer = 10 ft/day
Specific yield of aquifer = 25%

The duration of wet season used in this example is typical of conditions in Central Florida (Orlando) but can be adapted to local conditions. The wet season in the Orlando (Florida) area generally starts in June and extends to the end of September, a period of approximately 120 days.

The following screen shots illustrate the required data entry in PONDS.

Exhibit 5 below shows the aquifer data input parameters for Example 1.

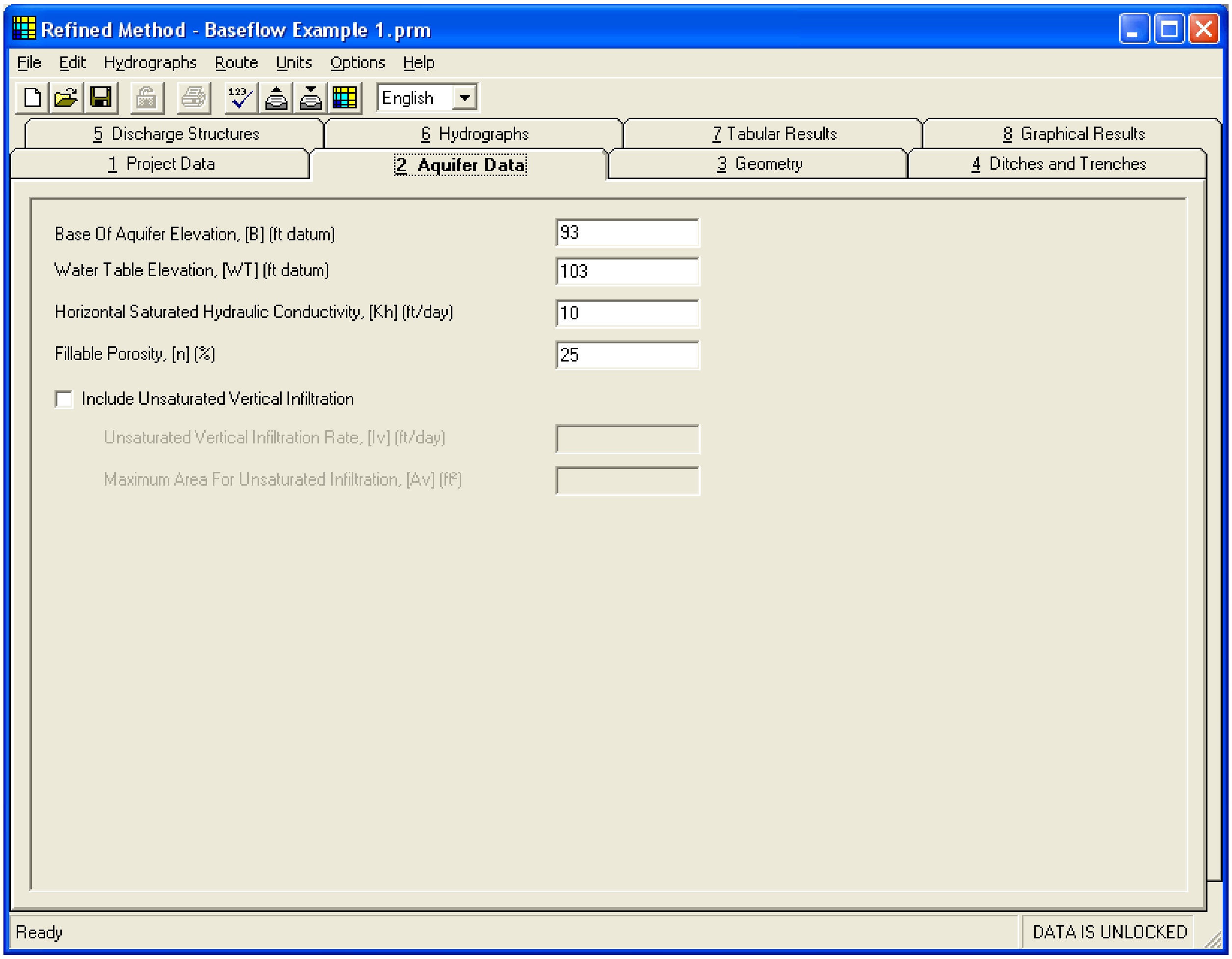


Exhibit 5. Example 1 Aquifer Data

Note that for the water table elevation in this example, we have chosen to enter the seasonal high groundwater elevation. You could also specify the seasonal low groundwater elevation, or specify a dummy groundwater elevation which will not be used (the groundwater elevation can not be blank) as long as the parameters in the baseflow hydrograph input dialog box are set accordingly.

Exhibit 6 below shows the Geometry Data input parameters for Example 1.

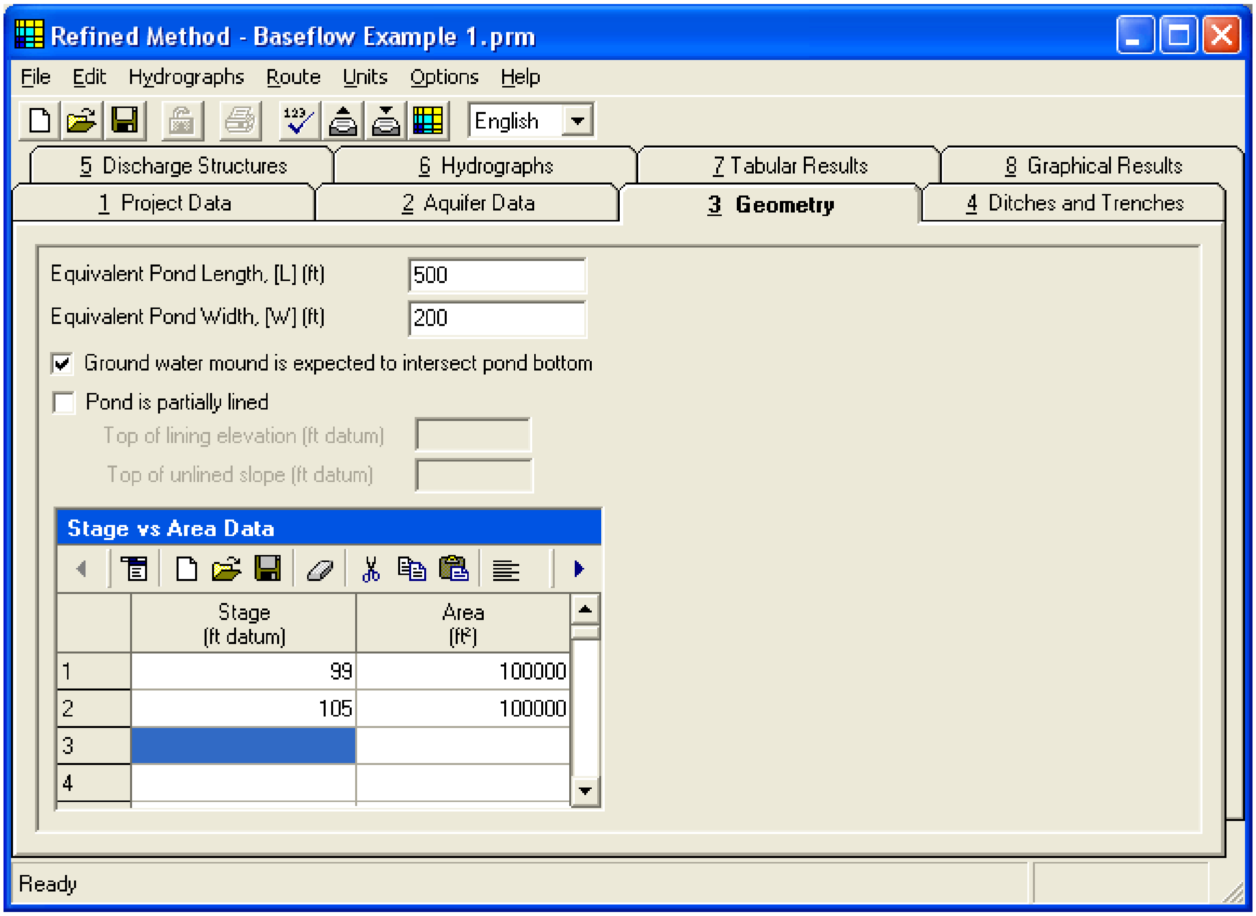


Exhibit 6. Example 1 Geometry Data

The pond length and width were specified in the problem statement for Example 1. However, no stage vs area data are specified, and the following simplifying assumptions are made:

- The pond bottom must be set to some nominal depth below the control elevation. Since the control elevation is specified to be +100 ft, the pond bottom is set to +99 ft. The actual elevation of the pond bottom is not critical as long as it is below the control elevation.

- The top-of-bank elevation is not specified. The top-of-bank elevation is assumed top be at some nominal height above the seasonal high groundwater table elevation. The top-of-bank elevation is assumed to be +105 ft in this example.

- The stage vs area relationship for this pond is not specified. We have assumed a vertical walled prism, equal to the width times the length (i.e., 100,000 ft^2).

The discharge structure data shown in Exhibit 7 below assumes a 6-inch diameter orifice is used to control the water level in the pond, at an elevation of +100 ft.

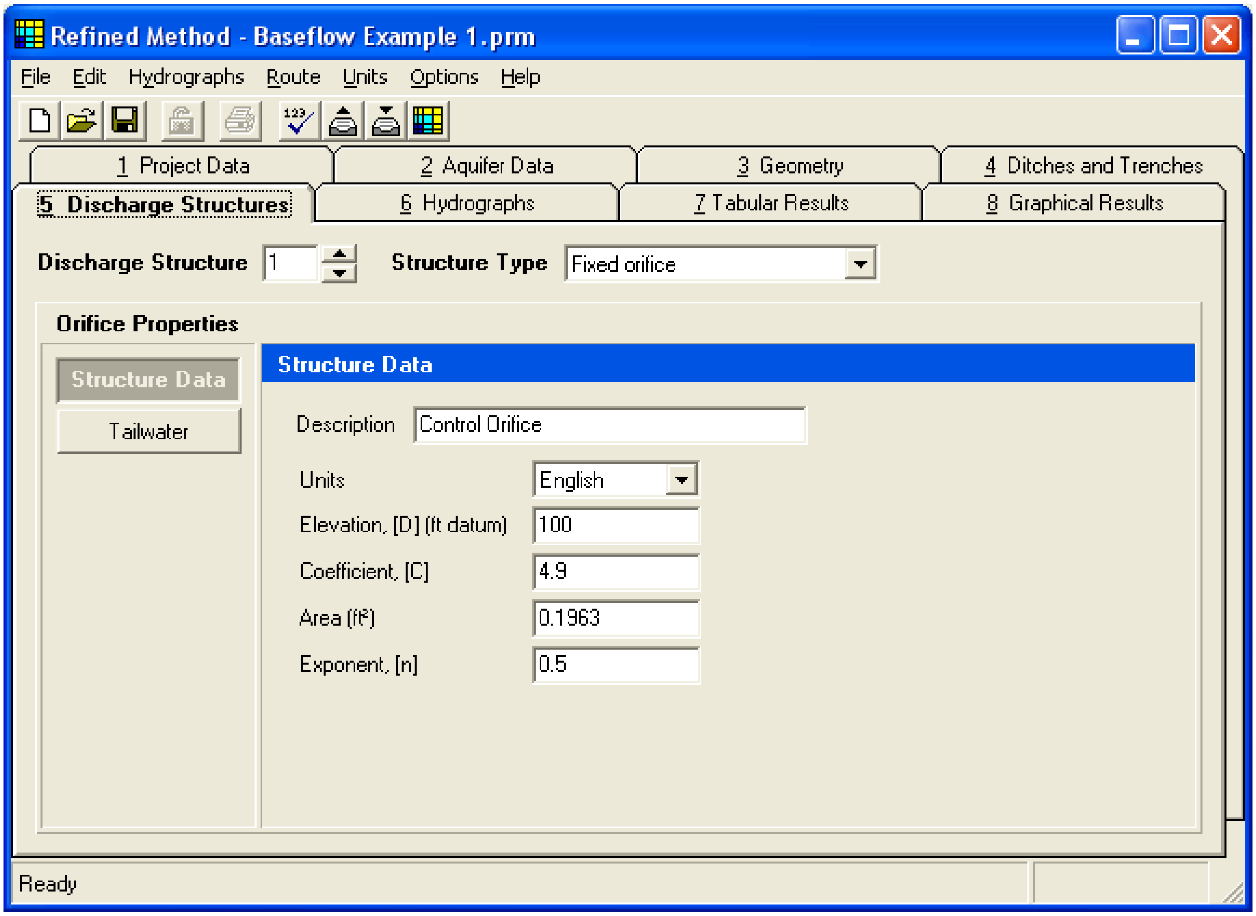
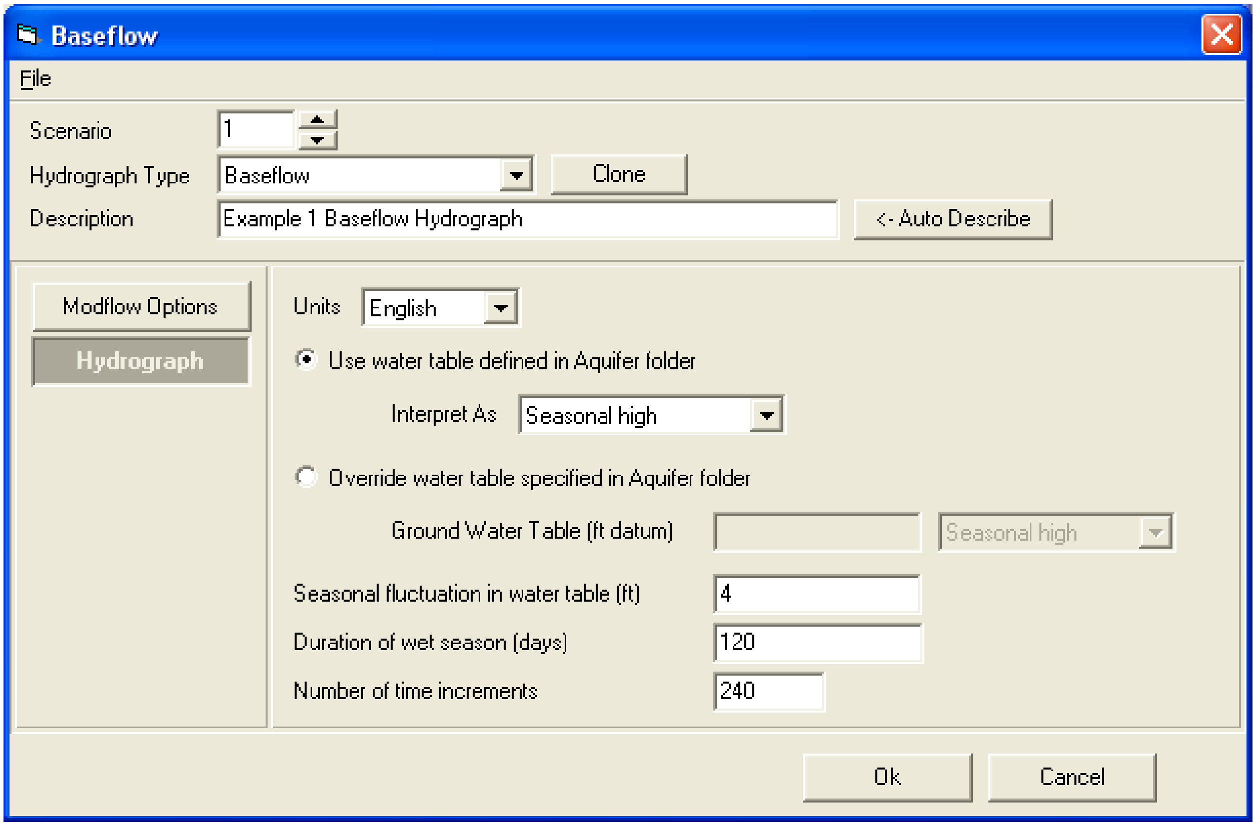


Exhibit 7. Example 1 Discharge Structure Data

Exhibit 8 below shows the hydrograph input data for Example 1.



Example 8. Example 1 Hydrograph Input Data

Note that the groundwater options specified in Exhibit 8 identify the groundwater elevation previously defined in the Aquifer Data to be the seasonal high groundwater elevation (+103 ft) and the seasonal fluctuation in water table is 4 feet.

The wet season of 120 days has been divided into 240 intervals, i.e., each interval represents half a day.

The resulting pond stage and baseflow infiltration rate are shown in Exhibit 9 below. As seen in Exhibit 9, the peak baseflow infiltration rate occurs after 120 days (when the groundwater table is highest). Note that at 120 days, the water level in the pond is fairly static (at the control elevation) and the discharge is approximately equal to the infiltration rate, but with opposite sign.

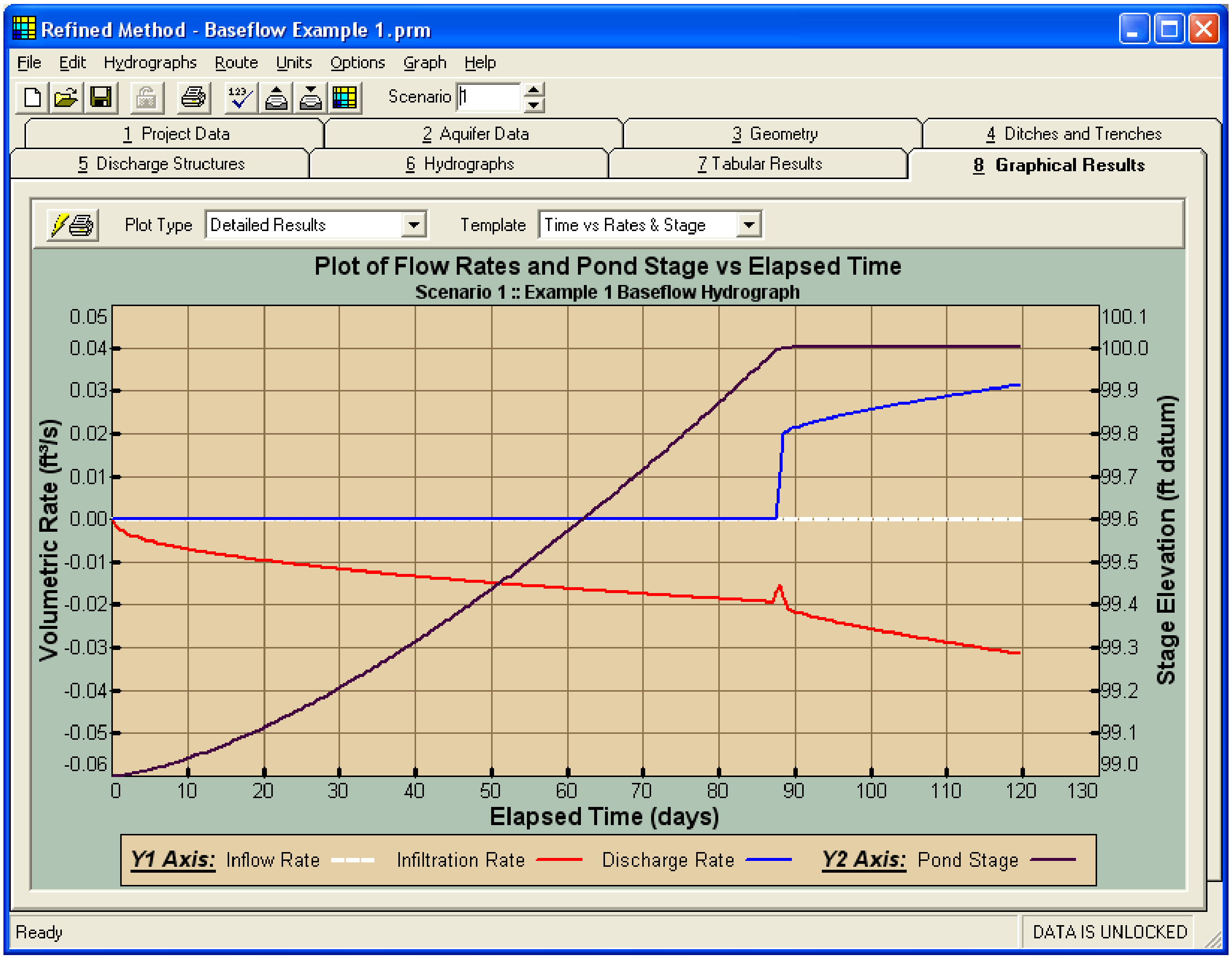


Exhibit 9. Example 1 Plot of Baseflow Infiltration Rate.

As seen in Exhibit 9 above, the baseflow infiltration rate at the end of 120 days is approximately 0.031 cfs.

Example 10 below shows the groundwater mound profile at the end of 120 days. (Assumes that the Modflow Option for saving the groundwater mound profile has been activated.)

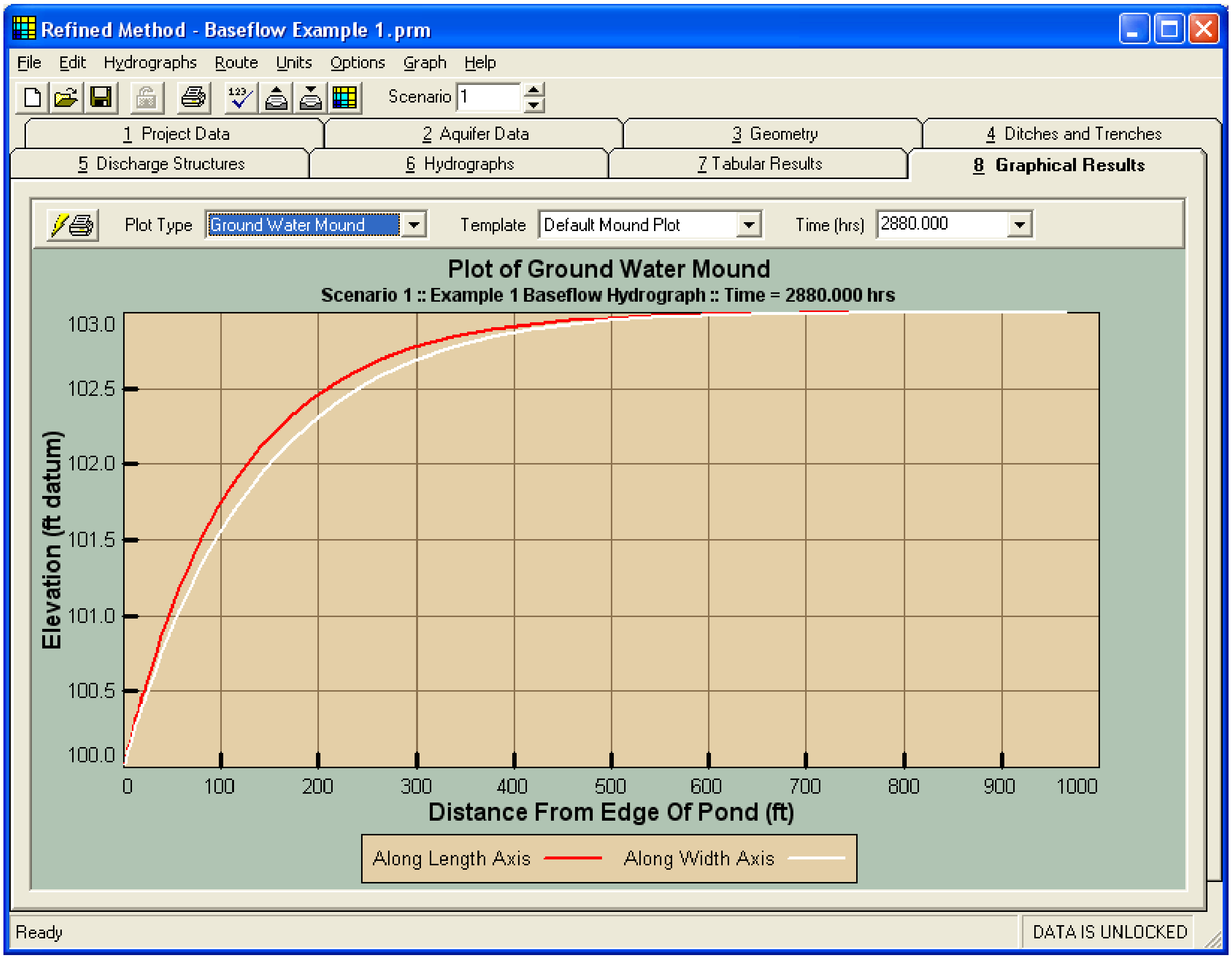


Exhibit 10. Example 1 Groundwater Mound Plot

EXAMPLE 2 - BASEFLOW INTO POND FROM ROAD UNDERDRAINS

Baseflow from a roadway underdrain can be modeled in the same way as baseflow from a pond. Conceptually, the only difference between a roadway underdrain and a pond is that the pond represents an open space with a porosity of 1.0, whereas a roadway underdrain is typically has a porosity less than 1.0 (such as a gravel filled French drain). Consider a roadway underdrain installed in the following conditions:

The groundwater fluctuation during the wet season is as follows:

Rise (or fluctuation) of water table during wet season = 4 ft
Seasonal high water table elevation = +104 ft
Duration of wet season = 120 days

The underdrain itself has the following characteristics:

Length of underdrain (L) = 600 ft
Width of underdrain (W) = 2.5 ft
Invert elevation of underdrain pipe = +102 ft

And the aquifer has the following properties:

Bottom of aquifer elevation = + 96 ft
Hydraulic conductivity of aquifer = 7 ft/day
Specific yield of aquifer = 25%

Exhibit 11 below shows the aquifer data input parameters for Example 2. Note that in this example we have specified the seasonal high groundwater table elevation.

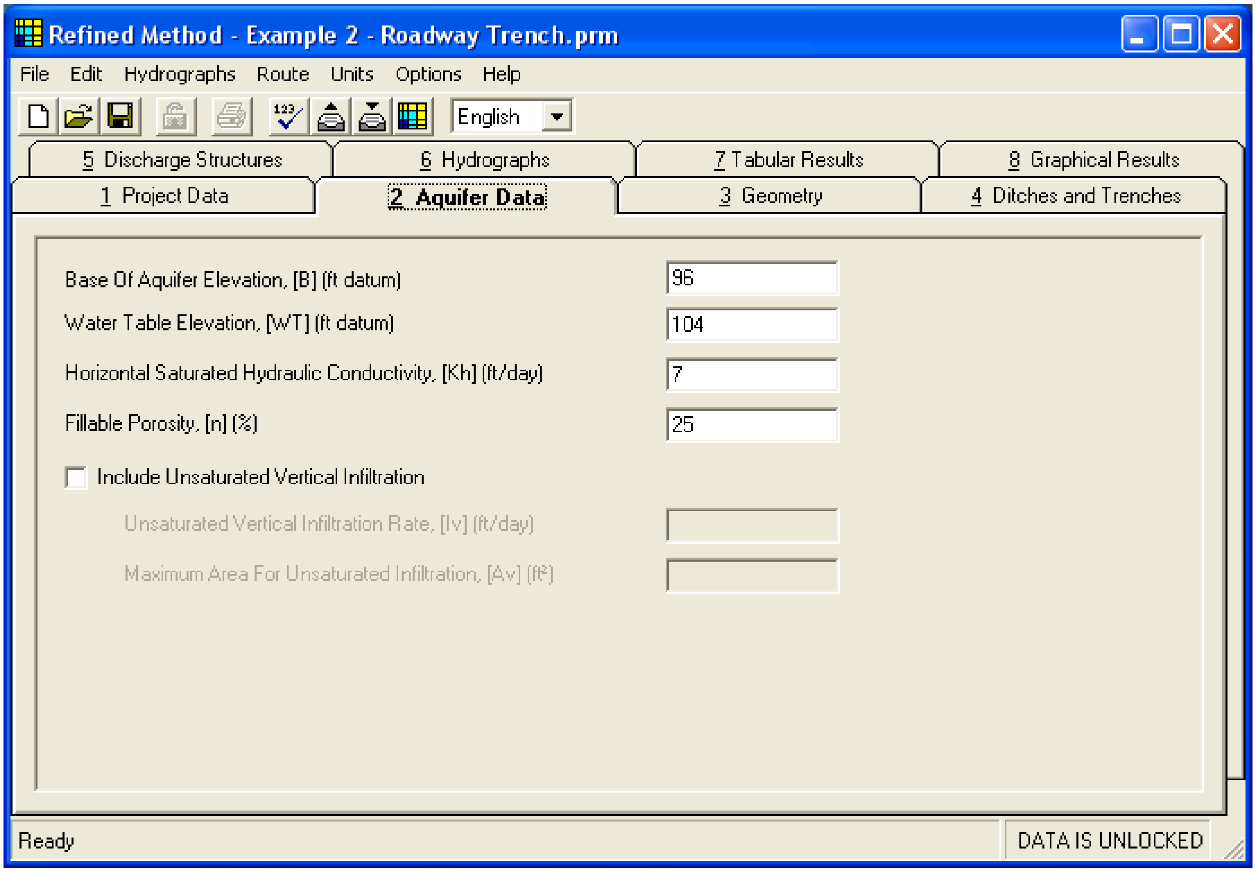


Exhibit 11. Example 2 Aquifer Data

Exhibit 12 below shows the Geometry Data parameters for Example 2.

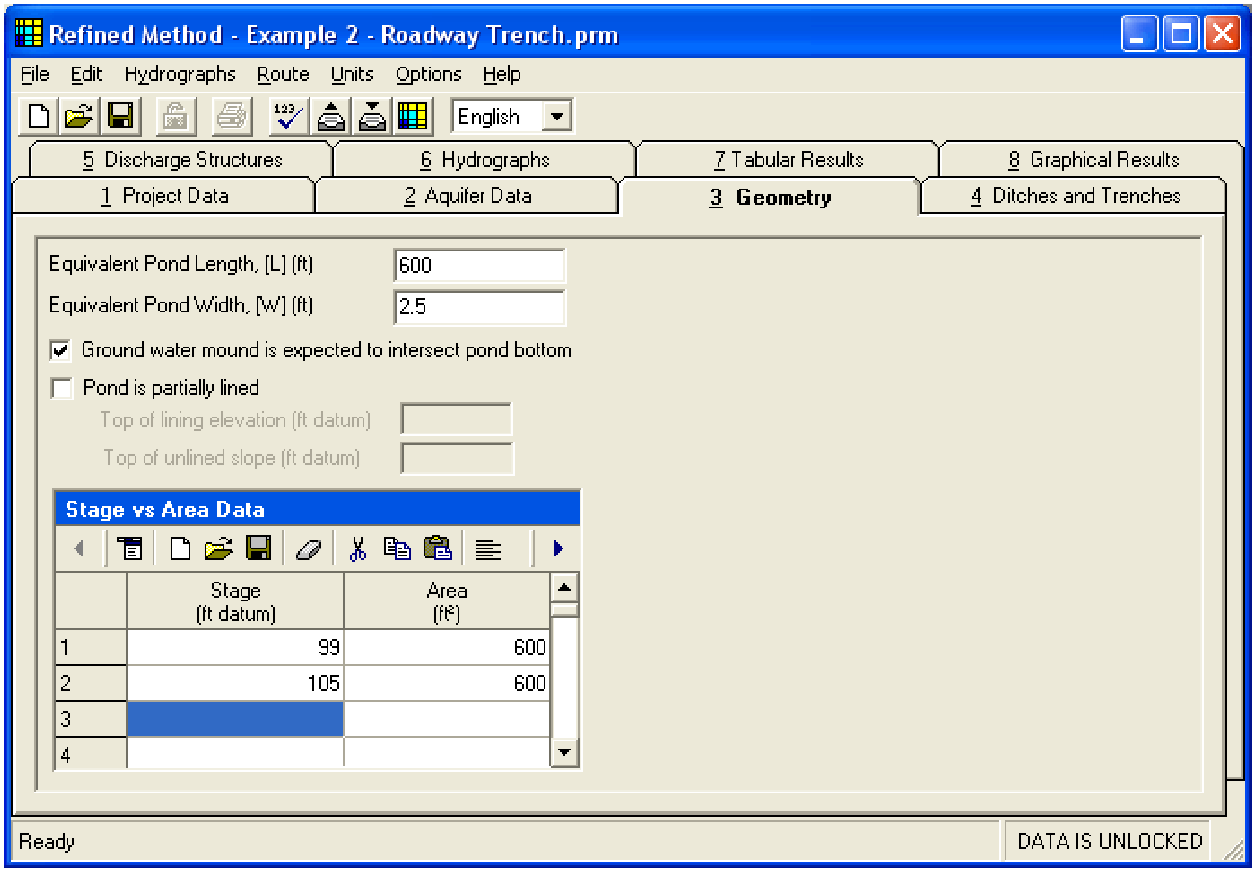


Exhibit 12. Example 2 Geometry Data

In Exhibit 12 above, we have assumed that the underdrain is gravel-filled with a net porosity of 40%. Therefore, the stage vs area data (which are used to define the stage-storage relationship of the drain) have been adjusted by multiplying the open trench area times the porosity of the gravel fill, as follows:

$$Area_{net} = Area_{open} \text{ x porosity} = 600 \text{ ft x } 2.5 \text{ ft x } 0.4 = 600 \text{ ft}^2$$

This correction primarily effects how the water level in the drain responds to changes in the inflow volume (from direct inflow, infiltration, discharge, etc.). However, as conditions approach steady state, and the baseflow infiltration and stage approaches a constant value, the porosity corrections become less important. I.e., the porosity correction influences the transient results more so than the steady state results.

Exhibit 13 shows the discharge structure data for the underdrain. We have assumed a 6-inch orifice.

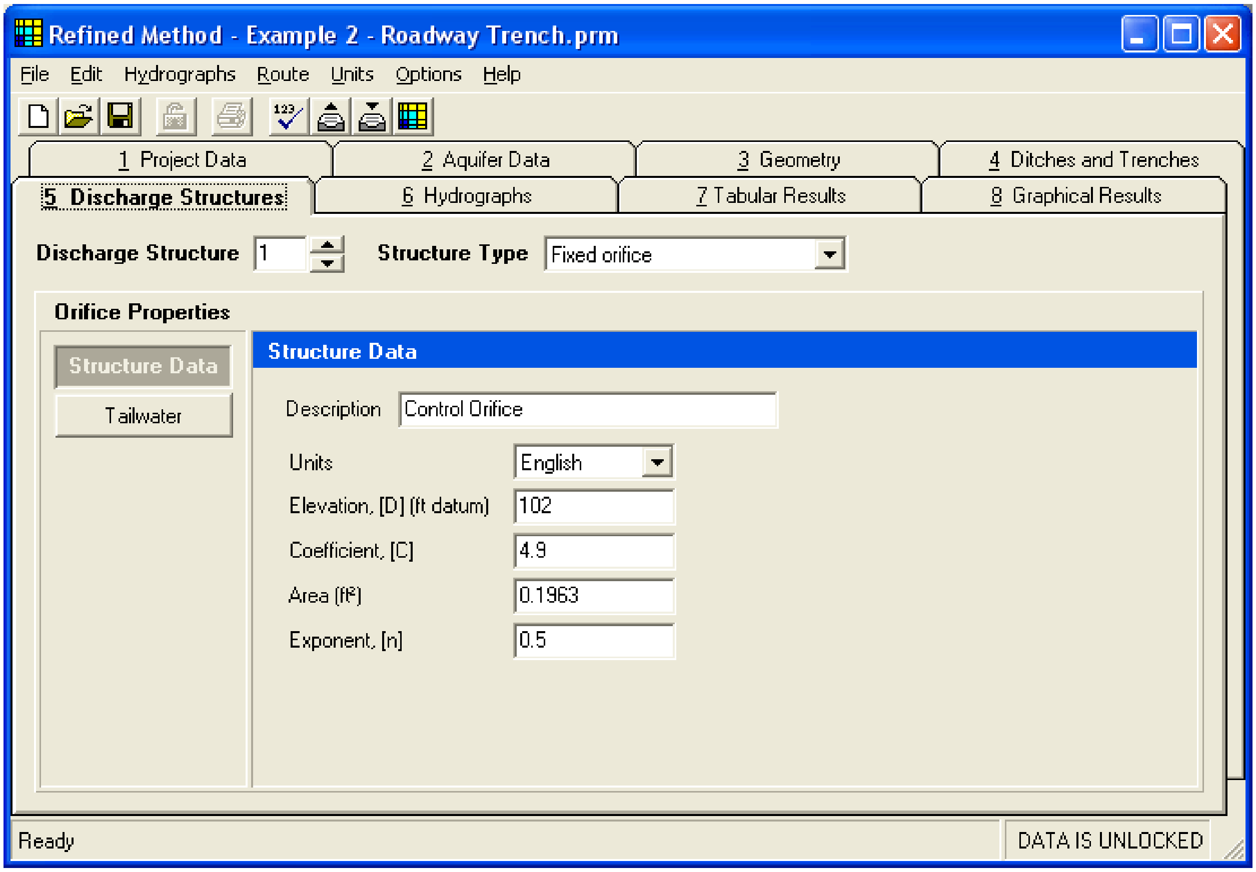


Exhibit 13.   Example 2 Discharge Structure Data

Exhibit 14 shows the Baseflow Hydrograph input data for Example 2. In this case, the water table elevation in the Aquifer Data input parameters (+104 ft) will be interpreted as the seasonal high groundwater table.

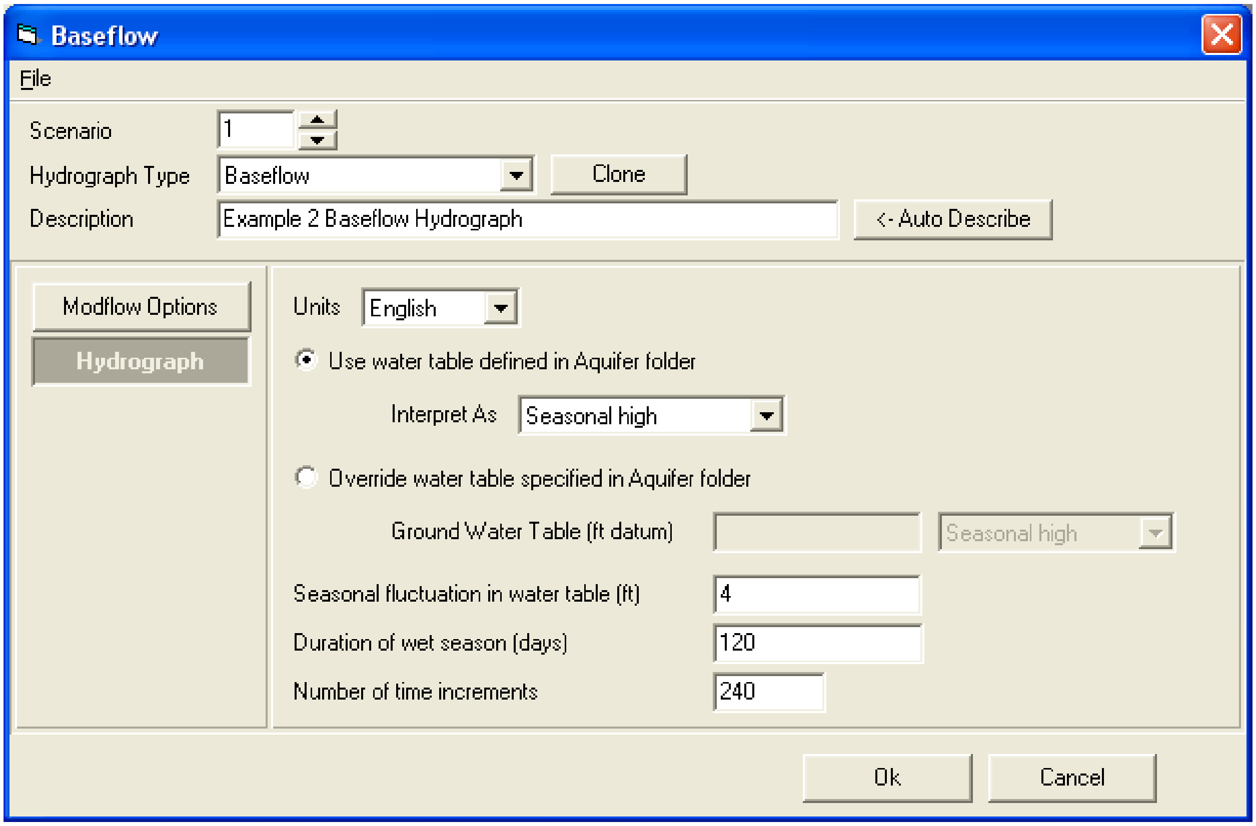


Exhibit 14 shows the baseflow infiltration over time.

Exhibit 15 shows a plot of the baseflow infiltration and discharge rates for the underdrain as well as the water level within the underdrain.

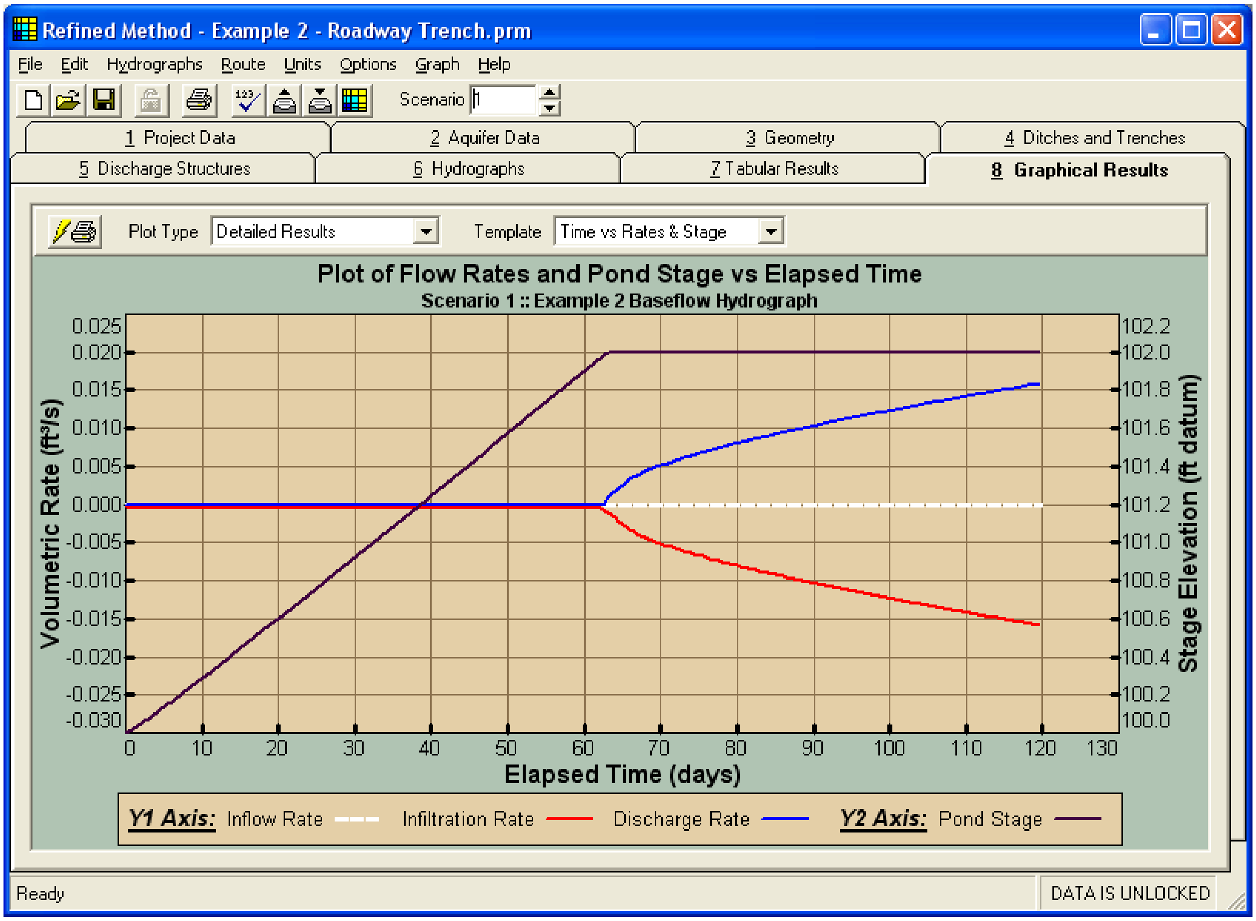


Exhibit 15. Example 2 Baseflow Infiltration Rate

As seen in Exhibit 15 above, the baseflow infiltration rate reaches a maximum value of about 0.016 cfs at an elapsed time of 120 days, corresponding to the maximum (seasonal high) groundwater table elevation.

Exhibit 16 shows the groundwater drawdown profile produced by roadway underdrain in Example 2.

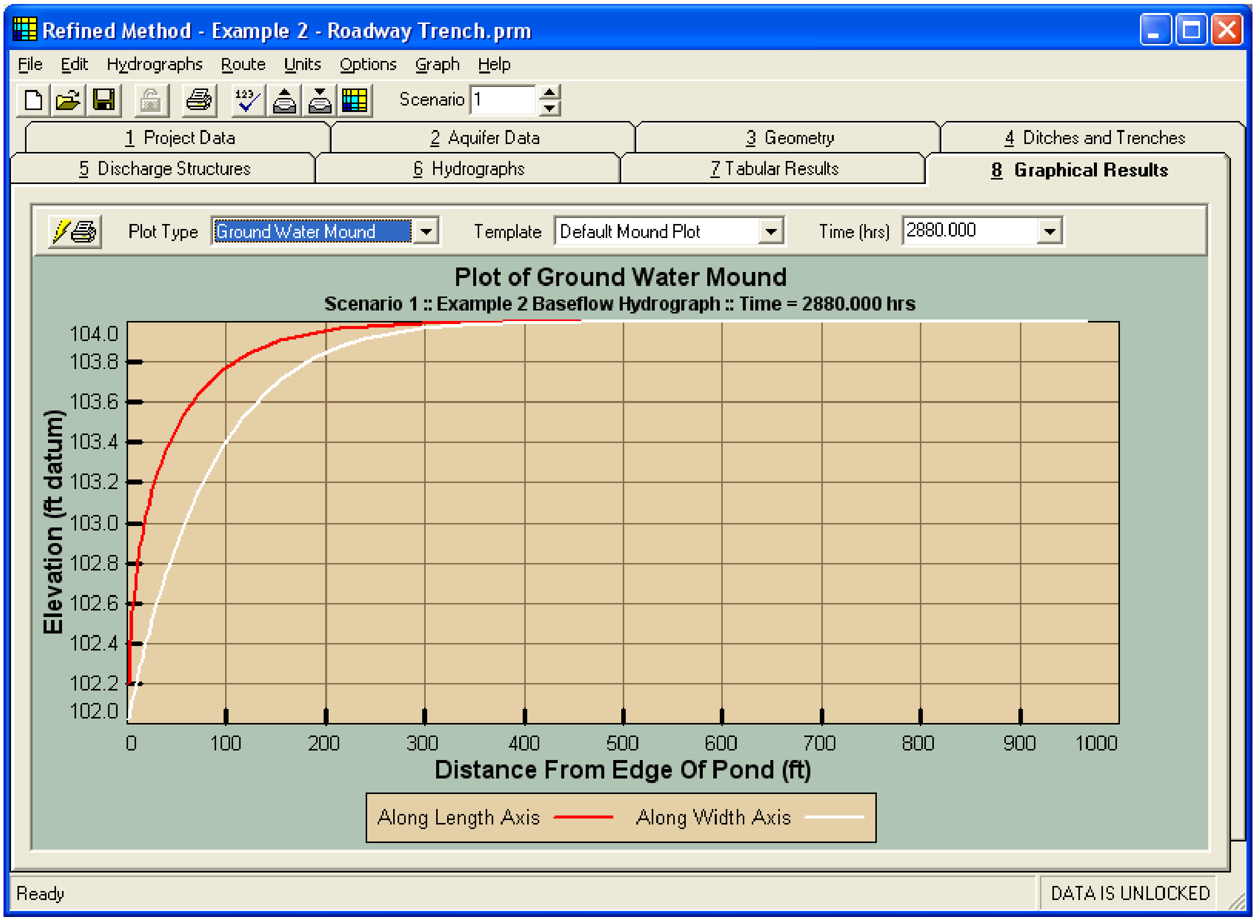


Exhibit 16. Example 2 Groundwater Drawdown Profile

EXAMPLE 3 - TOTAL BASEFLOW FOR ONE-YEAR GROUNDWATER CYCLE

This example demonstrates how to set up a baseflow calculation manually. In this example, a year-long groundwater cycle is simulated, from seasonal low to seasonal high groundwater table, and then back to seasonal low in order to estimate the total baseflow discharge volume from the pond in the course of a typical year.

In this example, the groundwater is assumed to fluctuate as follows:

- The end of the dry season occurs roughly at the end of May, and the wet season begins at about the beginning of June.
- From June through August, the water table is rising, reaching the seasonal high groundwater table elevation at about the end of August.
- The groundwater table then stays relatively flat from September through October.
- From November to the end of May, the groundwater table is in decline, completing the cycle.

In addition:

- The seasonal low groundwater table is +33.5 feet
- The seasonal fluctuation in the groundwater table is 3.5 feet.
- The porosity of the soil, n = 25%

The outside recharge during each phase of the analysis is calculated as follows:

<u>Phase 1</u>
Rise of 3.5 ft in 3 months, June 1 through August 31,
Duration = 92 days
Recharge = dH x n / dT = 3.5 ft x 0.25 / 92 days = 0.008832 ft/day

<u>Phase 2</u>
Water table is flat, September 1 through October 31
Duration = 61 days
Recharge = 0 ft/day

<u>Phase 3</u>
Water table is declining, November 1 through May 31
Duration = 212 days
Recharge = dH x n / dT = -3.5 ft x 0.25 / 212 days = -0.003833 ft/day

Note the sign convention. When the water table is rising, the recharge is positive, and when the water table is declining, the recharge is negative.

Using the above recharge calculations, the hydrograph can most easily be set up in a spreadsheet, as shown in the partial example in Exhibit 17 below.

Date	Day Index	Elapsed Time (hrs)	Inflow Rate (cfs)	Outside Recharge (ft/day)
	0	**0**	**0**	**0.008832**
6/1/2006	1	**24**	**0**	**0.008832**
6/2/2006	2	**48**	**0**	**0.008832**
6/3/2006	3	**72**	**0**	**0.008832**
6/4/2006	4	**96**	**0**	**0.008832**
6/5/2006	5	**120**	**0**	**0.008832**
6/6/2006	6	**144**	**0**	**0.008832**
6/7/2006	7	**168**	**0**	**0.008832**
6/8/2006	8	**192**	**0**	**0.008832**
6/9/2006	9	**216**	**0**	**0.008832**
...Continue downward to complete one-year cycle…				

Exhibit 17. Excerpt from Spreadsheet Tabulation for One-Year Baseflow Hydrograph

Note that the Inflow Rate (direct inflow to pond from runoff, etc.) is zero since all water entering the pond is assumed to come from groundwater.

Copy the hydrograph data series (time-inflow-recharge) from the spreadsheet, and paste directly into a PONDS Local Hydrograph, as shown in Exhibit 18 below. Also, in the same dialog box, change the Modflow boundary condition to No-Flow, as shown in Exhibit 19 below. (Or change the default boundary condition specified in the Advanced Modflow Options.)

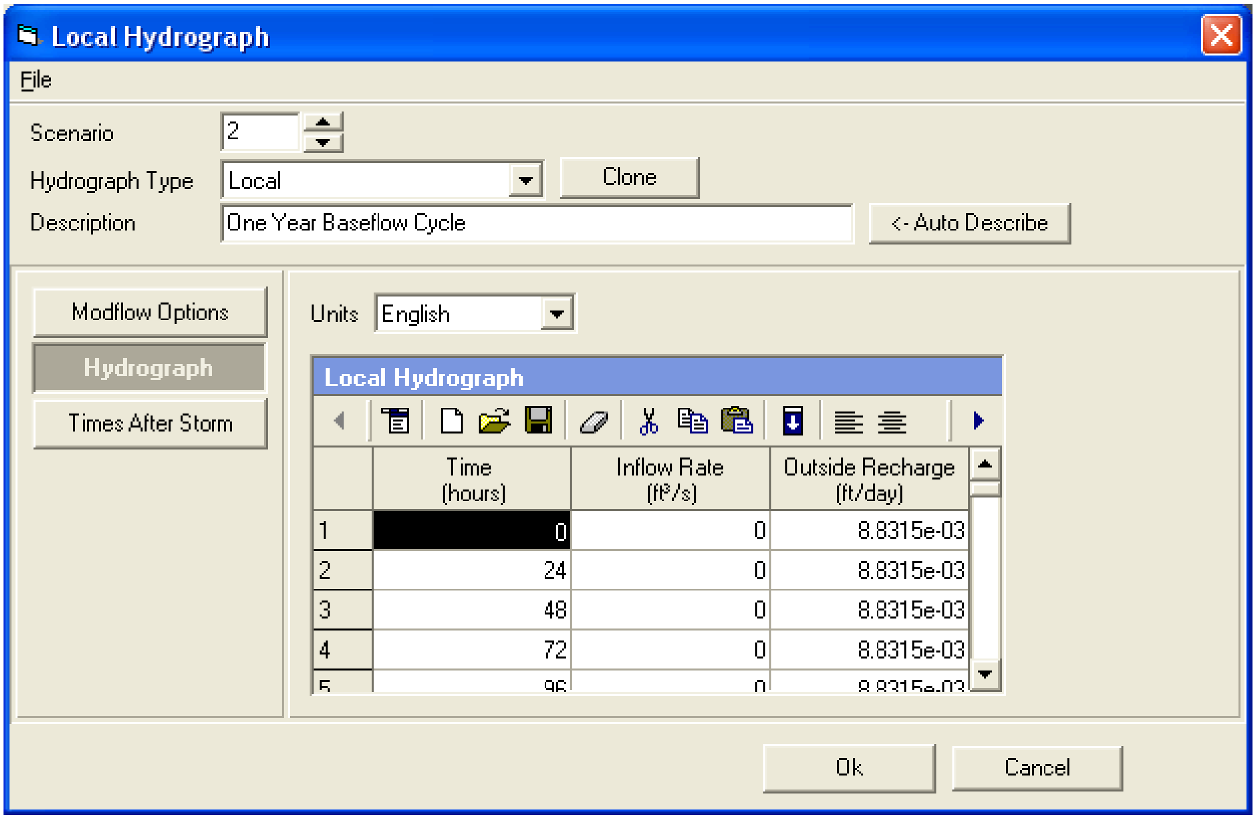


Exhibit 18. Example 3 Hydrograph Data

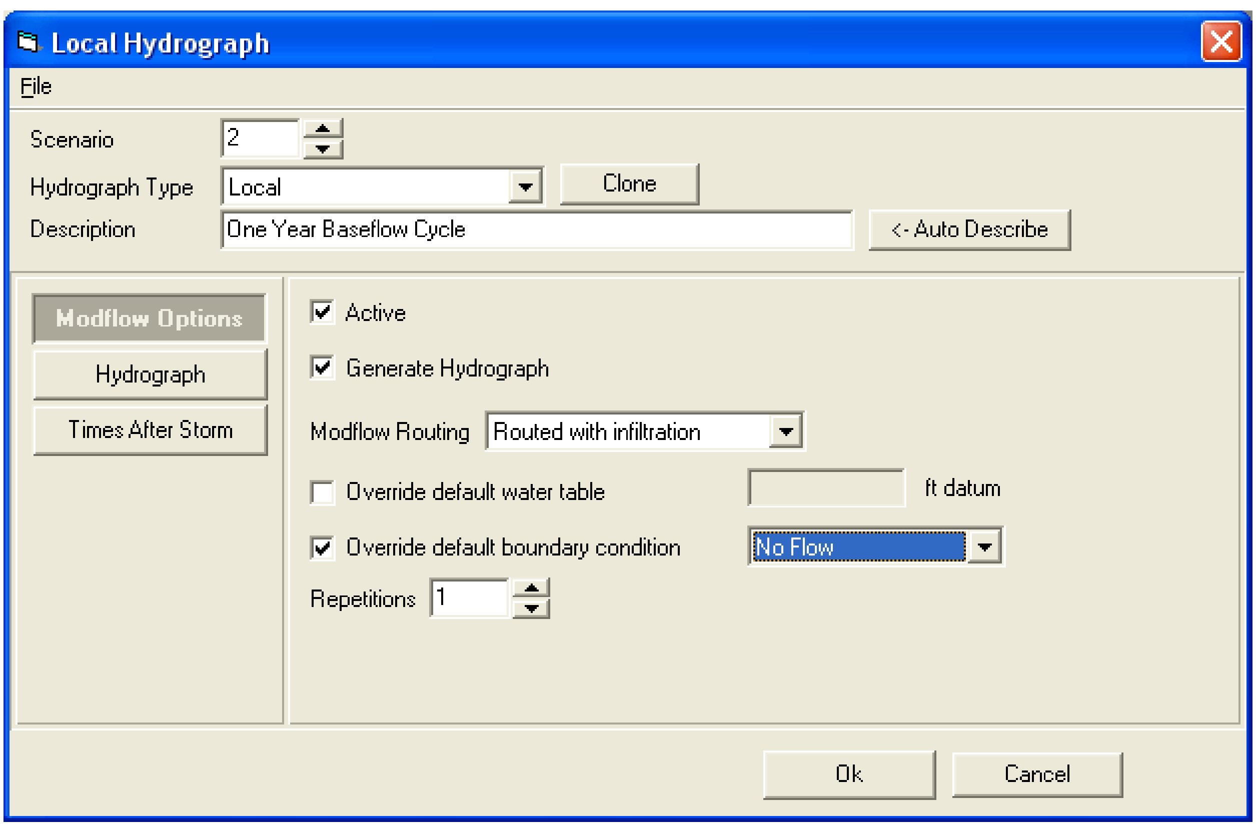


Exhibit 19. Example 3 Modflow Options

Aquifer Data for Example 3 are given in Exhibit 20 below. Note that the groundwater elevation defined in the aquifer data represents the starting groundwater table at the beginning of the simulation, which in this example is the seasonal low groundwater table.

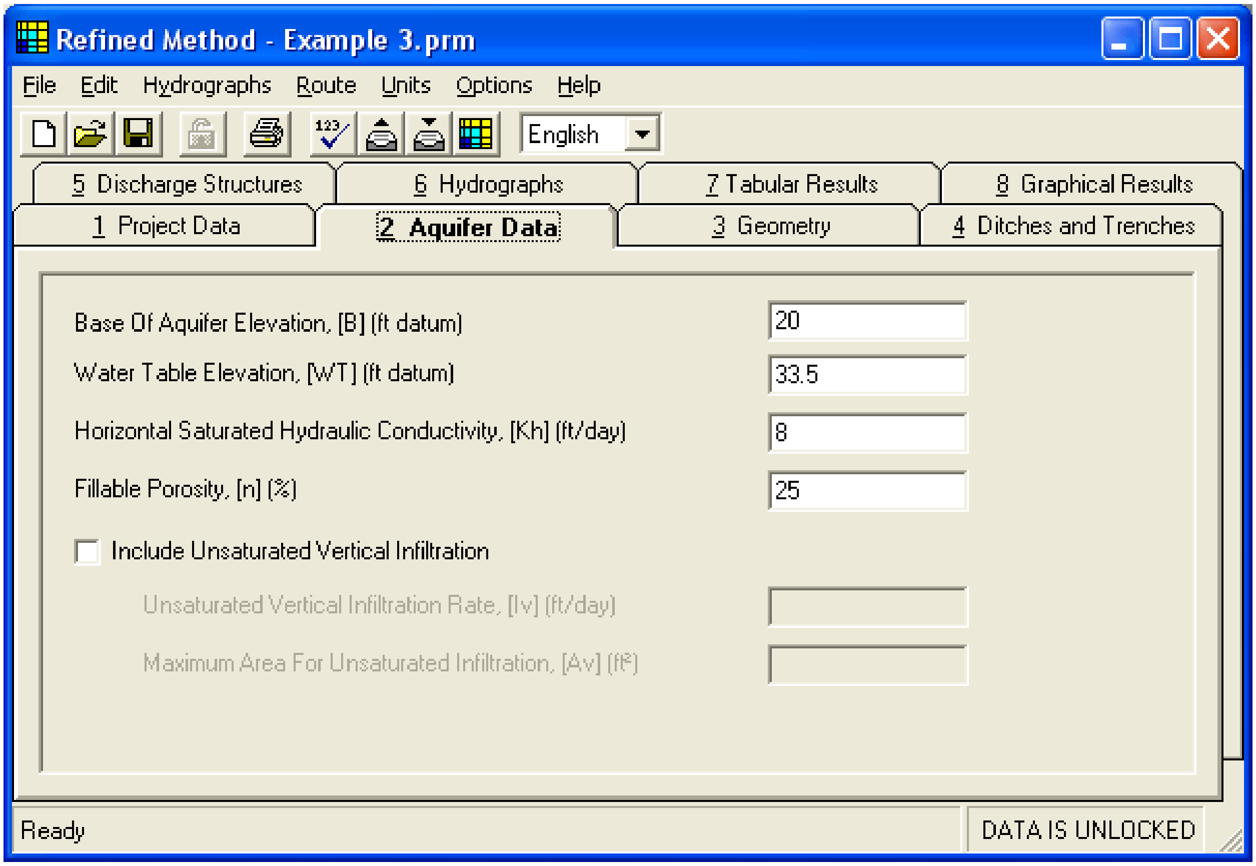


Exhibit 20. Example 3 Aquifer Data

Geometry Data for Example 3 are given in Exhibit 21 below.

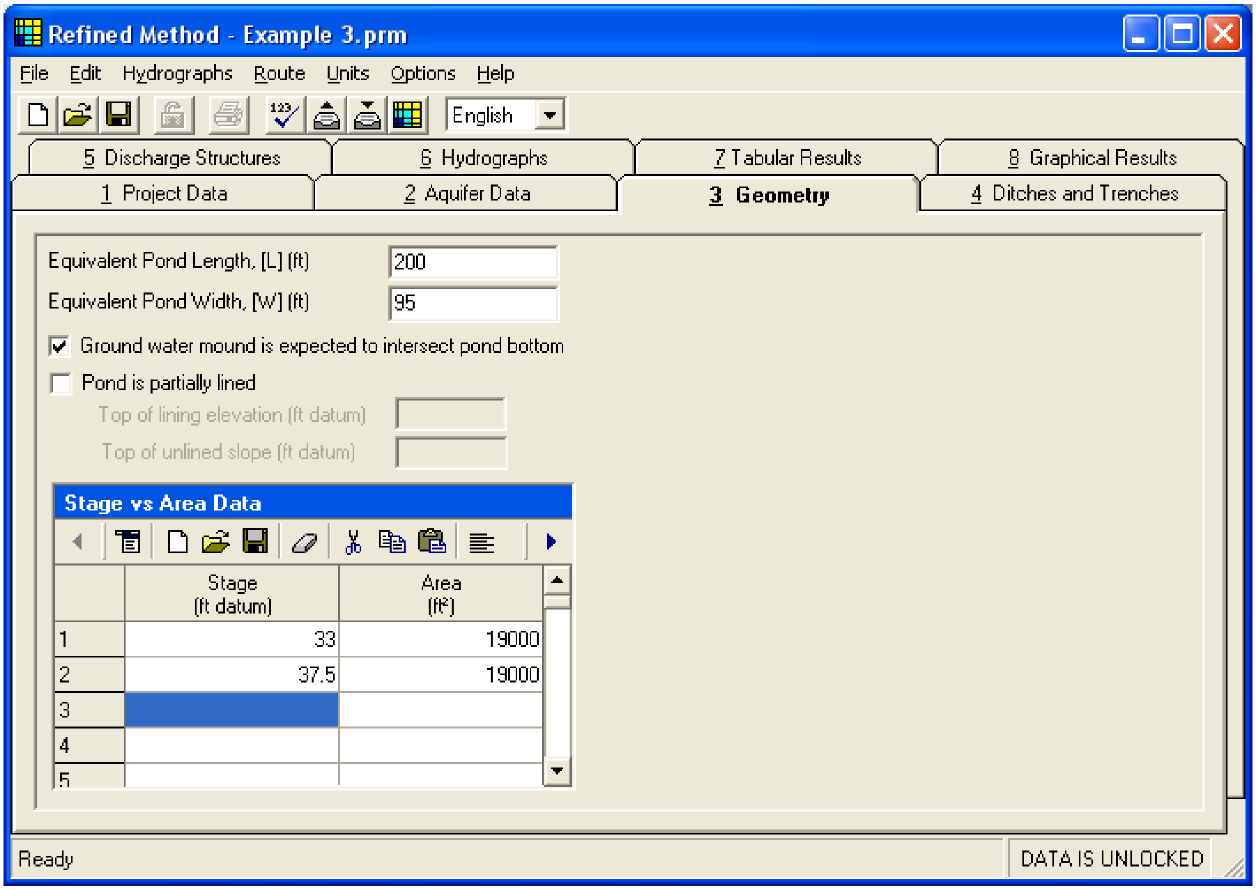


Exhibit 21. Example 3 Geometry Data

Discharge Structure Data for Example 3 are given in Exhibit 22 below.

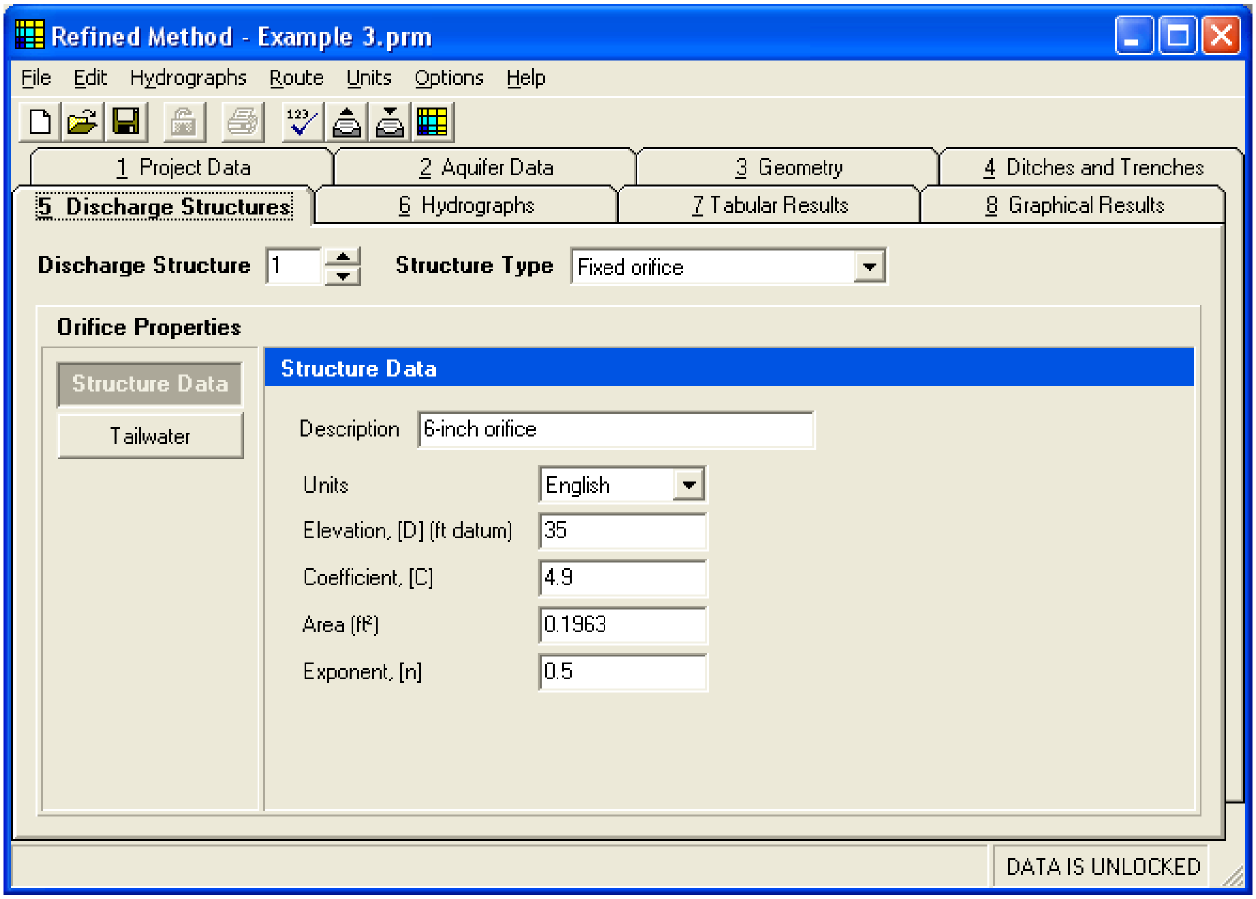


Exhibit 22. Example 3 Discharge Structure Data

Exhibit 23 shows a plot of the resulting pond stage and cumulative discharge from the pond. As seen in Exhibit 23, over the course of a year, this pond is expected to discharge approximately 105,000 ft^3 of groundwater baseflow.

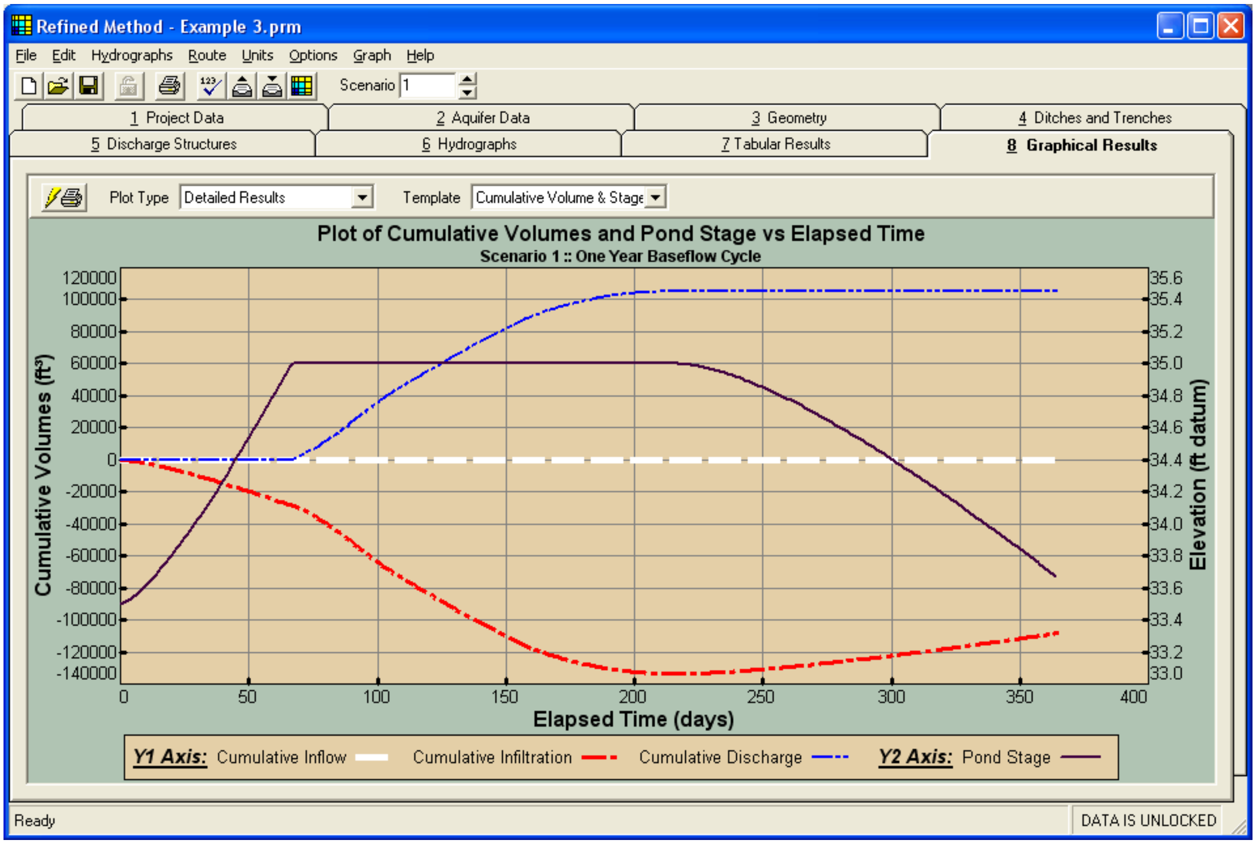


Exhibit 23. Example 3 Cumulative Discharge