HypoFrame–A workbook for simulating hypothetical aquifer tests in UGTA-like systems

HypoFrame is a workbook for simulating hypothetical aquifer tests to test the water-level modeling (WLM) approach for estimating drawdowns. The hypothetical aquifer system is comprised of flat-lying geologic units of uniform thickness and laterally isotropic, homogeneous hydraulic conductivity (Figure 1). Two intersecting faults divide the aquifer system into four quadrants: Lower Left (LL), Upper Left (UL), Upper Right (UR), and Lower Right (LR). Rock sequences in each quadrant can be displaced vertically within each quadrant.

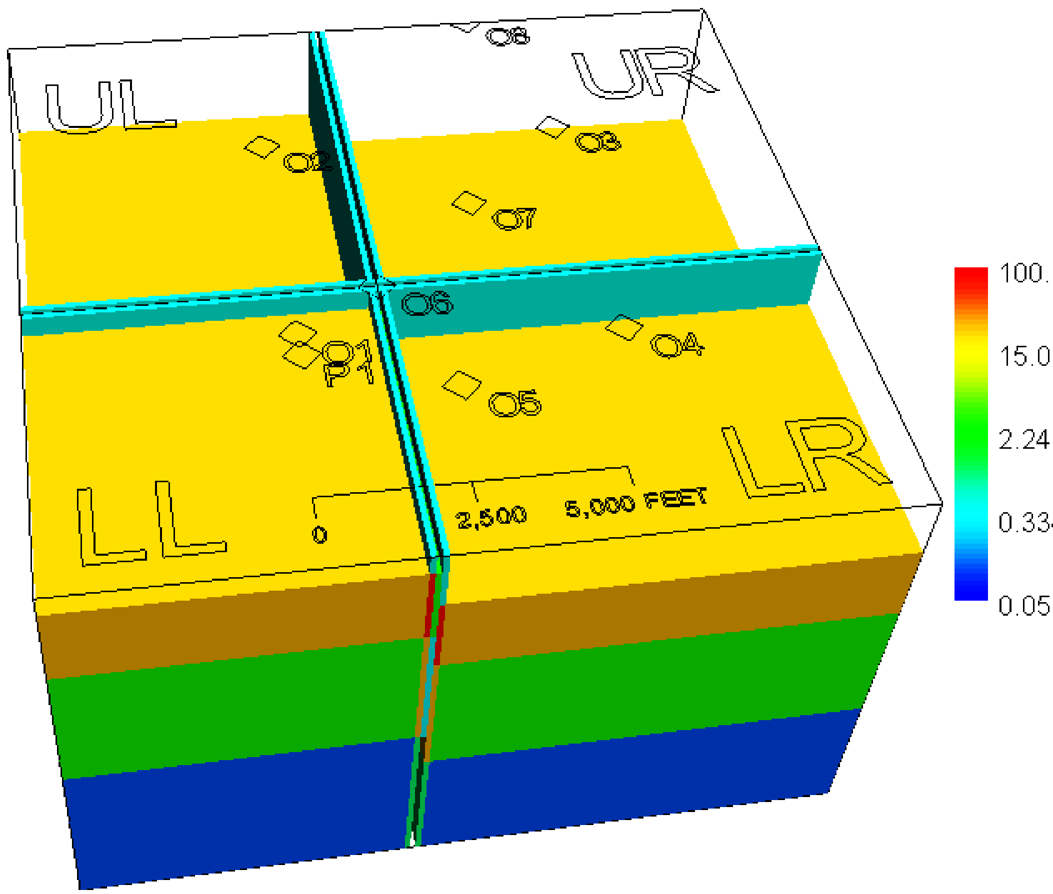


Figure 1.—Hydraulic conductivity distribution of a hypothetical aquifer system that has been divided into four quadrants by two intersecting faults.

The aquifer system is simulated with a three-dimensional MODFLOW model. The model domain is discretized laterally with a variably spaced grid that is finer near the pumping well and faults. Vertical discretization is uniform with depth except for a 1-unit length layer at the water table, so that the storage coefficient and specific storage are equivalent. This allows specific yield to be assigned directly in a layer where transmissivity is not a function of head.

The unconfined aquifer system is simulated vertically from the water table to a user-specified base. The uppermost layer has a storage coefficient that equals specific yield. Drying and wetting of cells are prohibited. The base of the aquifer system is assumed to be an impermeable boundary.

Drawdowns are simulated directly, so initial heads are zero throughout the model. Water can be injected or extracted to control the sign of the simulated drawdowns. Simulated head changes will be positive and equivalent to drawdowns if water is injected. Complex pumping schedules can be simulated and are user specified.

Flow and drawdown in pumping and observation wells are simulated and sampled with the MNW package. Flow to the pumping well is distributed proportionally to cell transmissivities by the MNW package. Flow is induced in all observation wells because all cross multiple layers.

Water levels with a known pumping signal and environmental noise are created by adding MODFLOW results to measured water levels without pumping effects. Simulated drawdowns in each observation well are interpolated in time to match measured water levels. Simulated drawdowns with and without noise are written to a new workbook that can be read by SeriesSEE.

–●– Next –●–

SEE page

The hypothetical aquifer system and wells are defined on the SEE page (Figure 2). The two intersecting faults that divide the aquifer system into four quadrants lie along the X and Y axes. Log hydraulic-conductivity profiles are depicted by depth with well screen depths for each quadrant.

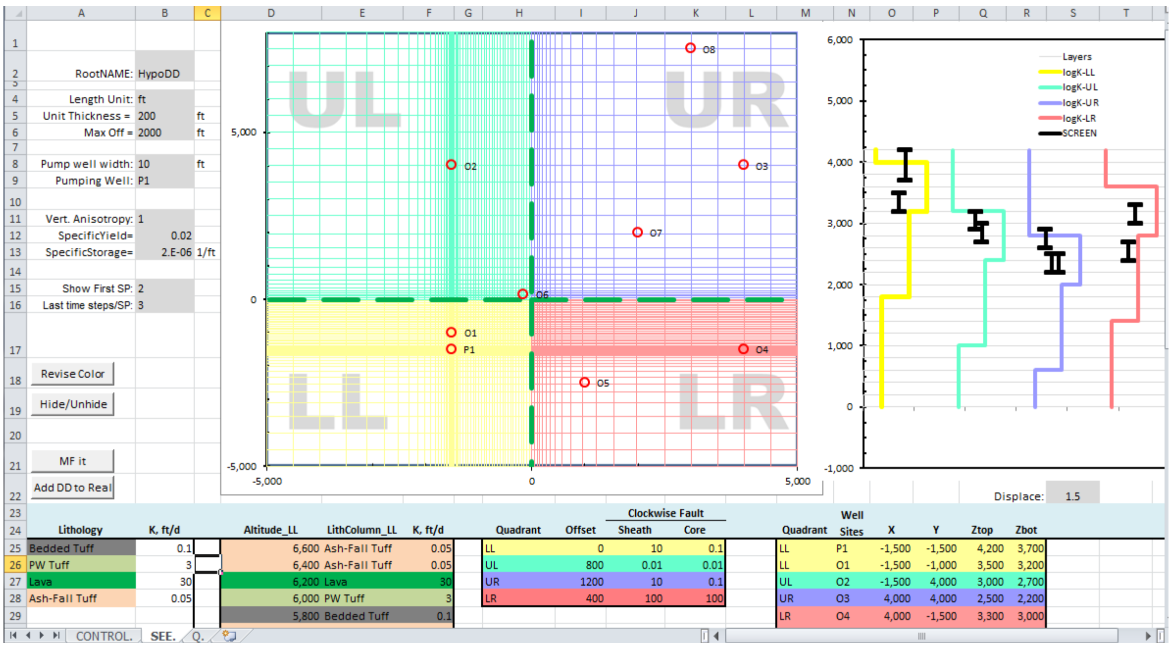


Figure 2.—SEE page in the HypoFrame workbook where lithology, hydraulic conductivity, faults, and wells are defined.

Previous –●– Next

Lithology and Hydraulic Conductivity

Hydraulic conductivities are assigned to lithologic units and distributed vertically with a single geologic column (Figure 3). The geologic column extends above and below the simulated aquifer system. This is so a defined lithology exits lithologic units have been displaced across fault structures. Hydraulic conductivities are distributed realistically because hydraulic conductivity is correlated perfectly with lithology.

	A	B	C	D	E	F
23						
24	Lithology	K, ft/d		Altitude_LL	LithColumn_LL	K, ft/d
25	Bedded Tuff	0.1		6,600	Ash-Fall Tuff	0.05
26	PW Tuff	3		6,400	Ash-Fall Tuff	0.05
27	Lava	30		6,200	Ash-Fall Tuff	0.05
28	Ash-Fall Tuff	0.05		6,000	Ash-Fall Tuff	0.05
29				5,800	Ash-Fall Tuff	0.05
30				5,600	Ash-Fall Tuff	0.05
31				5,400	Ash-Fall Tuff	0.05
32				5,200	Ash-Fall Tuff	0.05
33				5,000	Ash-Fall Tuff	0.05

Figure 3.—Lithology-hydraulic conductivity table and geologic column that vertically distributes hydraulic conductivity on the SEE page.

Lithology and Hydraulic Conductivity

Names of lithologic units and associated colors are assigned in column A.

Hydraulic conductivities are assigned in column B.

The number of lithologic units is limited to less than 100.

	A	B
23		
24	Lithology	K, ft/d
25	Bedded Tuff	0.1
26	PW Tuff	3
27	Lava	30
28	Ash-Fall Tuff	0.05

The geologic column extends above and below the simulated aquifer system.

The altitude defines the top of a lithologic unit.

D	E	F
Altitude_LL	_LL	K, ft/d
6,600	Ash-Fall Tuff	0.05
4,000	Lava	30
3,800	Lava	30
3,600	Lava	30
3,400	Lava	30
3,200	PW Tuff	3
-4,400	Ash-Fall Tuff	0.05
-4,600	Ash-Fall Tuff	0.05

A lithology is selected with a pull-down menu in column E where choices are user-defined in column A.

	D	E	F
23			
24	Altitude_LL	LithColumn_LL	K, ft/d
25	6,600	Ash-Fall Tuff	0.05
26	6,400	Ash-Fall Tuff	0.05
27	6,200	Lava	30
28	6,000	Bedded Tuff	3
29	5,800	PW Tuff	0.1
30	5,600	Lava	0.05
		Ash-Fall Tuff	

The row color and assigned hydraulic conductivity are revised automatically after a lithologic unit is selected.

	D	E	F
23			
24	Altitude_LL	LithColumn_LL	K, ft/d
25	6,600	Ash-Fall Tuff	0.05
26	6,400	Ash-Fall Tuff	0.05
27	6,200	Bedded Tuff	0.1
28	6,000	PW Tuff	3
29	5,800	Bedded Tuff	0.1
30	5,600	Ash-Fall Tuff	0.05

Previous –●– Next

Fault Structures

Four fault structures, one per quadrant, can be defined independently (Figure 4). Fault offset of the rock mass in each quadrant is relative to the stationary rock mass in the LL quadrant. Hydraulic-conductivity alterations in the faults are defined as multipliers of the country-rock hydraulic conductivity. Hydraulic-conductivity multipliers of fault sheath and fault core are specified independently so the hydraulic effect of the faults can be simulated realistically.

	H	I	J	K
23			Clockwise Fault	
24	Quadrant	Offset	Sheath	Core
25	LL	0	1000	1000
26	UL	800	1	1
27	UR	1200	1	1
28	LR	400	1	1
29				
30				
31				

Figure 4.—Table for specifying fault offset, hydraulic conductivity multiplier of fault sheath, and hydraulic conductivity multiplier of fault core on the SEE page.

Fault Structures

Rock masses within the UL, UR, and LR quadrants are offset relative to the LL quadrant.

Offsets are selected from a pull-down menu in column I.

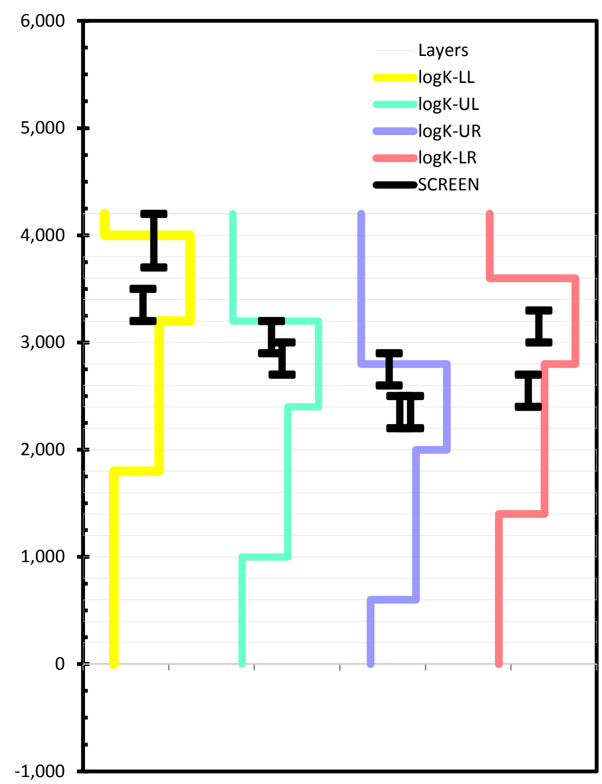
	H	I	J	K
23			Clockwise Fault	
24	Quadrant	Offset	Sheath	Core
25	LL	0	1000	1000
26	UL	800	1	1
27	UR		1	1
28	LR		1	1
29				
30				
31				

1,200
1,000
800
600
400
200
0
-200

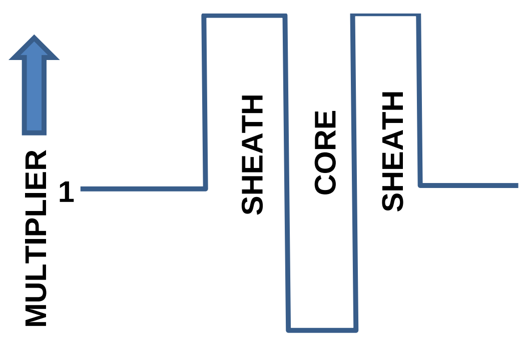
The relative distribution of log-hydraulic conductivity with depth is reported by quadrant in the range N1:U21.

Displacement of rock masses in each quadrant is charted also.

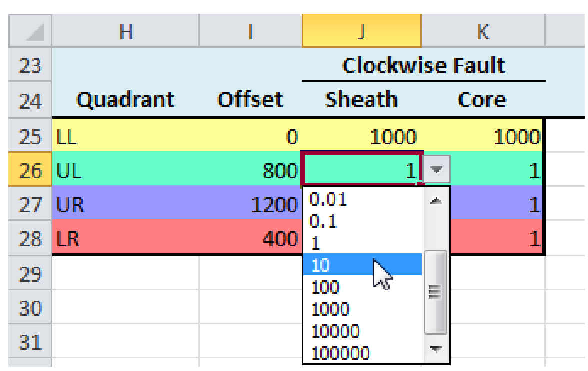
Hydraulic conductivity are limited to the range of depths that are simulated with the MODFLOW model.



Alteration by fault structures is specified as multipliers of the hydraulic conductivity of the country rock in the sheath and core areas of each fault.



Multipliers for the sheath on each side of the fault core are specified with a pull-down menu in column J.



	H	I	J	K
23			Clockwise Fault	
24	Quadrant	Offset	Sheath	Core
25	LL	0	1000	1000
26	UL	800	1	1
27	UR	1200		1
28	LR	400		1
29				
30				
31				

Multipliers for the core of each fault are specified with a pull-down menu in column K.

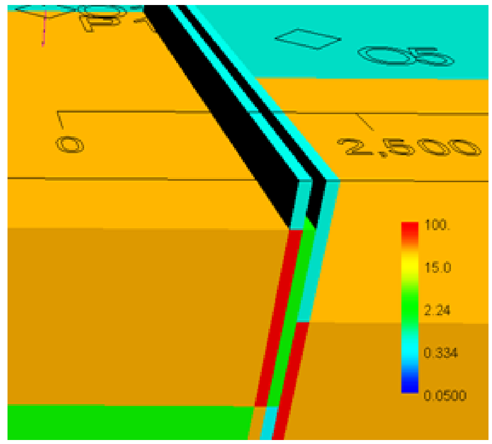
	H	I	J	K
23			Clockwise Fault	
24	Quadrant	Offset	Sheath	Core
25	LL	0	1000	1000
26	UL	800	1	0.01
27	UR	1200	1	
28	LR	400	1	
29				
30				
31				

0.001
0.01
0.1
1
10
100
1000
10000

Visualize the three-dimensional hydraulic conductivity distribution with ModelViewer. Effects of displacement and all multipliers are depicted.

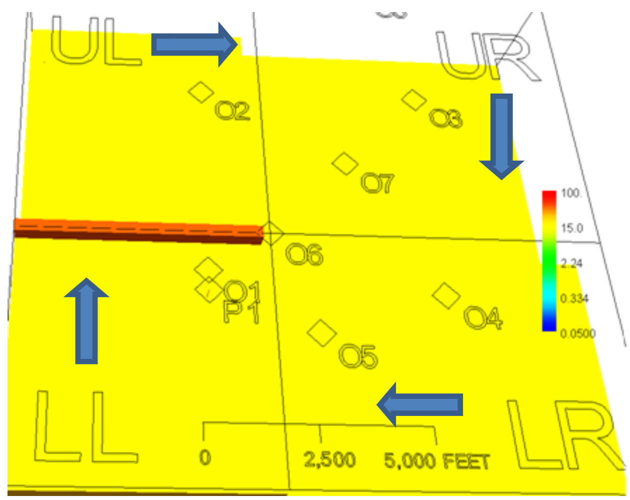
The generic file name is 04_*ROOTNAME*-K.mv, where the *ROOTNAME* is defined in cell B2 on the SEE page.

The example file is 04_HypoDD-K.mv



Sheath and core fault multipliers affect segments clockwise from the specified quadrant.

For example, all sheath and core multipliers equal 1 except for the LL quadrant, which equals 1,000. A hydraulic conductivity contrast exists in the fault segment above the LL quadrant and in no other fault segments.



Quadrant	Offset	Clockwise Fault Sheath	Clockwise Fault Core
LL	0	1000	1000
UL	800	1	1
UR	1200	1	1
LR	400	1	1

[Previous](#) –●– [Next](#)

Wells

As many as two dozen wells can be specified in the HypoFrame workbook (Figure 5). The name, mapped location, and screened interval of each well are specified on a row between columns N and R, inclusive. The row of each well is color coded by quadrant, which corresponds with the colored quadrants in map view and the profiles of log-hydraulic conductivity with depth.

	N	O	P	Q	R
23	Well				
24	Sites	X	Y	Ztop	Zbot
25	P1	-1,500	-1,500	4,200	3,700
26	O1	-1,500	-1,000	3,500	3,200
27	O2	-1,500	4,000	3,000	2,700
28	O3	4,000	4,000	2,500	2,200
29	O4	4,000	-1,500	3,300	3,000
30	O5	1,000	-2,500	2,700	2,400
31	O6	-150	150	3,200	2,900
32	O7	2,000	2,000	2,500	2,200
33	O8	3,000	7,500	2,900	2,600
34					

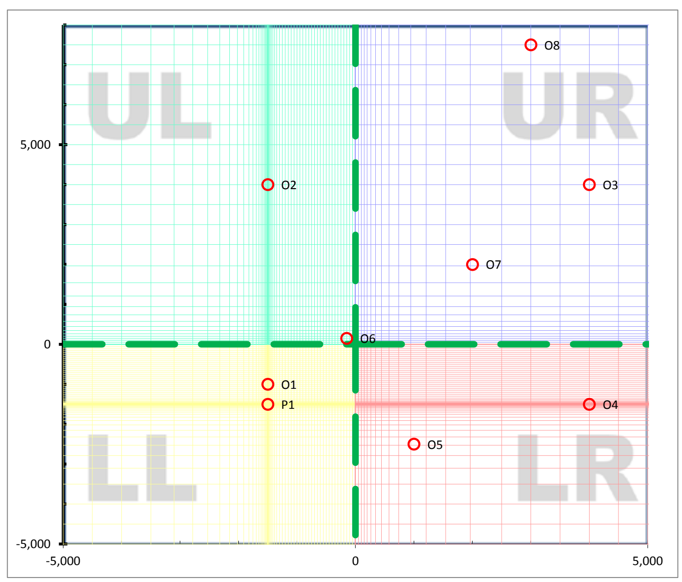
Figure 5.—Table for defining well locations and screened intervals on the SEE page.

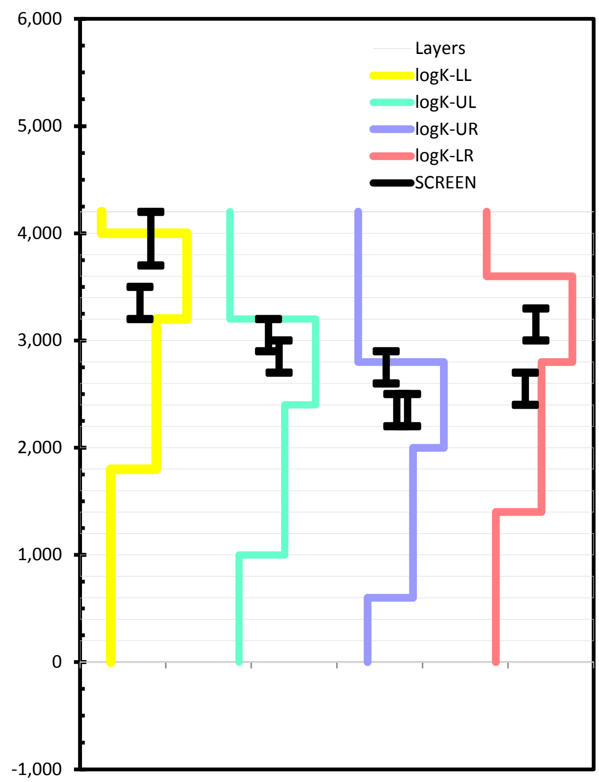
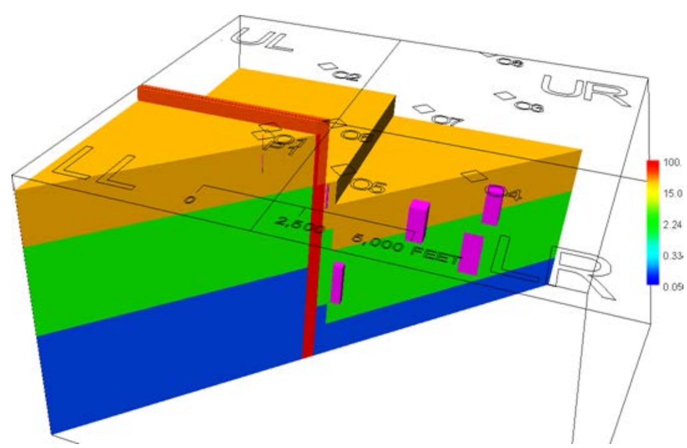
Wells

Labeled well locations are plotted in map view in the range D1:M22.

Colored quadrants in the map correspond with colored rows in the well definition table.

Lateral extent of the map can be redefined by the user.

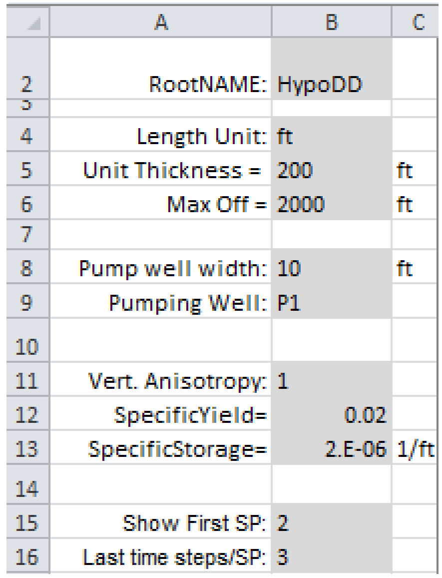


Unlabeled screened intervals are plotted in vertical profile by quadrant in the range N1:U21. Vertical positions are to scale while the horizontal positions mean nothing. Colored log-hydraulic conductivity profiles correspond with colored rows in the well definition table. Vertical extent of the profiles can be redefined by the user.	
Visualize the three-dimensional distribution of wells with ModelViewer. Generic file names are 04_*ROOTNAME*.mv and 04_*ROOTNAME*-K.mv, where the *ROOTNAME* is defined in cell B2 on the SEE page. The example files are 04_HypoDD.mv and 04_HypoDD-K.mv which show well placement with simulated drawdowns and hydraulic conductivity, respectively.	

[Previous](#) –●– [Next](#)

Global Properties

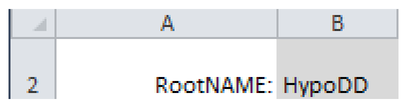
Global properties and MODFLOW output preferences are defined on the SEE page (Figure 6). Root file name, units of length, vertical discretization, pumping well, vertical anisotropy, specific yield, specific storage, and MODFLOW output frequency are specified in the range B2:B16.



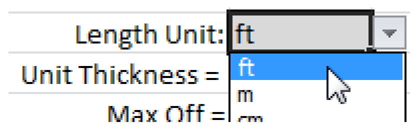
	A	B	C
2	RootNAME:	HypoDD	
3			
4	Length Unit:	ft	
5	Unit Thickness =	200	ft
6	Max Off =	2000	ft
7			
8	Pump well width:	10	ft
9	Pumping Well:	P1	
10			
11	Vert. Anisotropy:	1	
12	SpecificYield=	0.02	
13	SpecificStorage=	2.E-06	1/ft
14			
15	Show First SP:	2	
16	Last time steps/SP:	3	

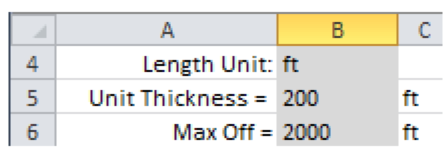
Figure 6.—Global properties and MODFLOW output preferences are defined on the SEE page.

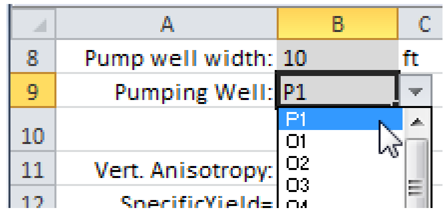
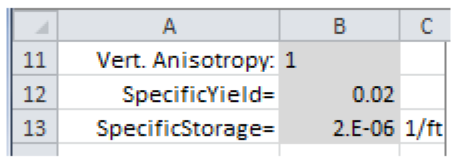
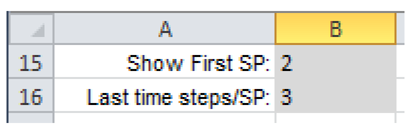
Global Properties and MODFLOW OC

<table>
<tr><td>Well specific identifier embedded in MODFLOW and batch files that are created by HypoFrame.</td><td>
| | A | B |
| 2 | RootNAME: | HypoDD |</td></tr>
<tr><td>Select a length unit from the pull-down menu in cell B4.

Unit thickness is the thickness of each lithologic unit in the geologic column and the thickness of each MODFLOW layer, except layer one.

“Max Off” is the maximum vertical displacement that can be specified along a fault structure.</td><td>


| | A | B | C |
| 4 | Length Unit: | ft | |
| 5 | Unit Thickness = | 200 | ft |
| 6 | Max Off = | 2000 | ft |</td></tr>
</table>

The width, DX, of the MODFLOW cell with the pumping well is specified in cell B8. This should not be too small a number because pumpage is simulated with the MNW package. Head loss between cell and well is a function of ln(ro/rw) where ro = 0.2DX and rw has been fixed at 0.2. DX of less than 5 is numerically ugly. Select a pumping well from the list of wells that are user-defined in the range N25:N48.	
Vert. Anisotropy, the ratio of horizontal to vertical hydraulic conductivity Specific yield, dimensionless Specific storage, in 1/L, which typically ranges between 1E-6 and 3E-6 1/ft or 3E-6 and 10E-6 1/m.	
Show first SP is the first stress period where binary heads will be written and can be viewed with ModelViewer. Last time steps/SP defines when binary heads are written for a time step. For example, binary heads are written for a time steps 23, 24, and 25 with cell B16 equaling 3 and 25 time steps per stress period.	

Previous –●– Next

HypoFrame Controls

Workbook functionality and file manipulation are controlled with buttons in range A18:A22 on the SEE page (Figure 7). MODFLOW file creation, and creating a SeriesSEE source file.

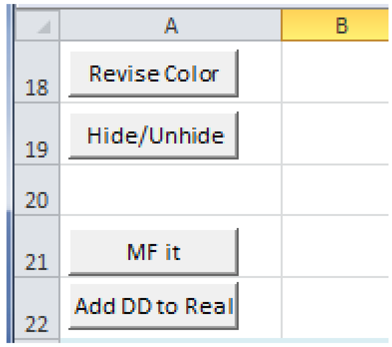


Figure 7.—Controls on the SEE page for workbook functionality, MODFLOW file creation, and creating a SeriesSEE source file.

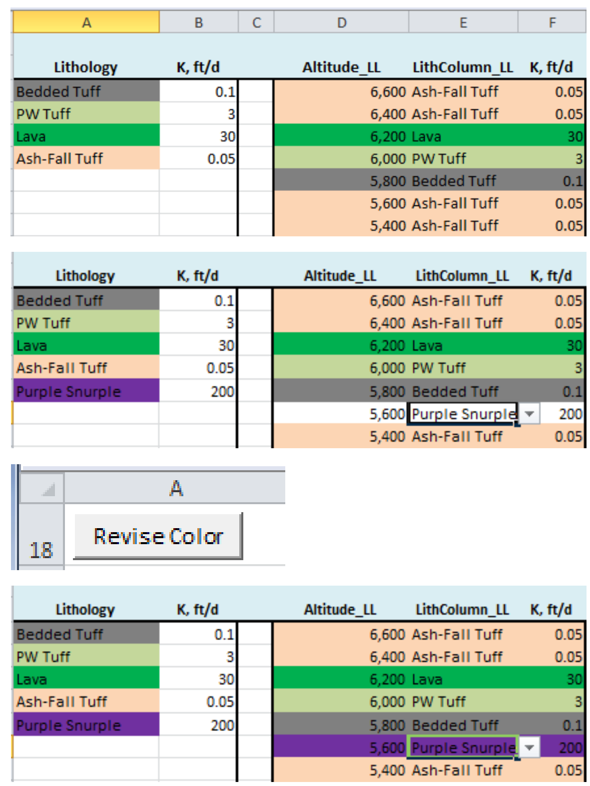
HypoFrame Controls

Names of lithologic units and associated colors are assigned in column A.

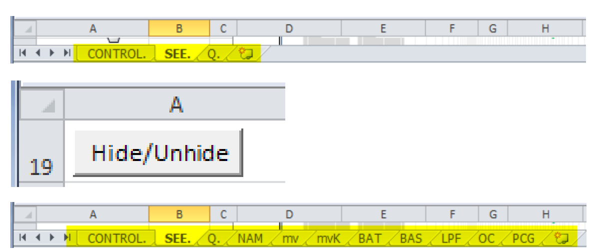
Assigned colors in column A are reflected in columns D:F with conditional formatting.

The relation between assigned colors in column A and displayed colors in columns D:F is established with a macro that is executed by clicking the "Revise Color" control.

The "Revise Color" control is used after revising the list of lithologic units in column A or the cell colors have been changed.



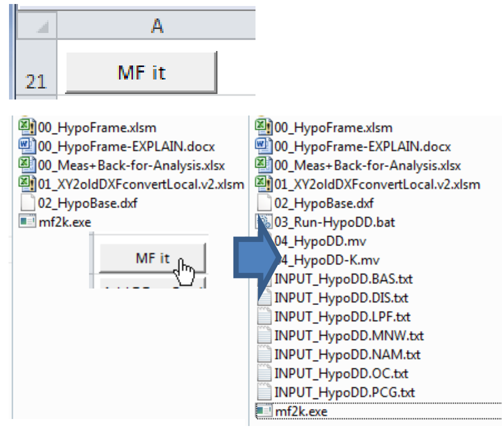
The Hide/Unhide control hides and unhides pages in HypoFrame. Regularly used pages such as SEE and Q are needed by the user and always remain visible. The remaining worksheets support workbook functions and are hidden or revealed with the Hide/Unhide control.

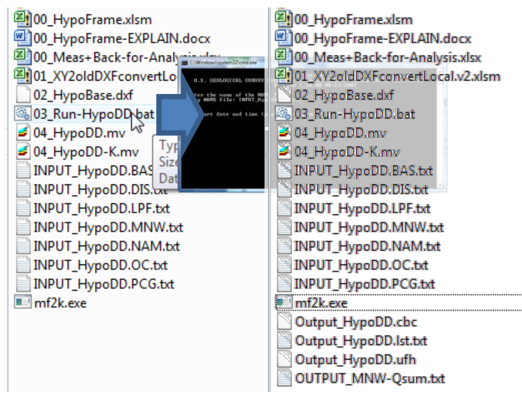


The “MF it” control writes all MF2K, ModelViewer, and batch files. The batch file is 03_Run-***RootNAME***.bat that simulates flow.

Double click 03_Run-***RootNAME***.bat in the working directory to execute MODFLOW and simulate an aquifer test in the hypothetical system.

The example file is 03_Run-HypoDD.bat.



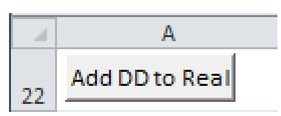


The “Add DD to Real” control creates a SeriesSEE source file from the MODFLOW results and an existing SeriesSEE source file that contains measured barometric and water-level fluctuations.

The created SeriesSEE source file contains,

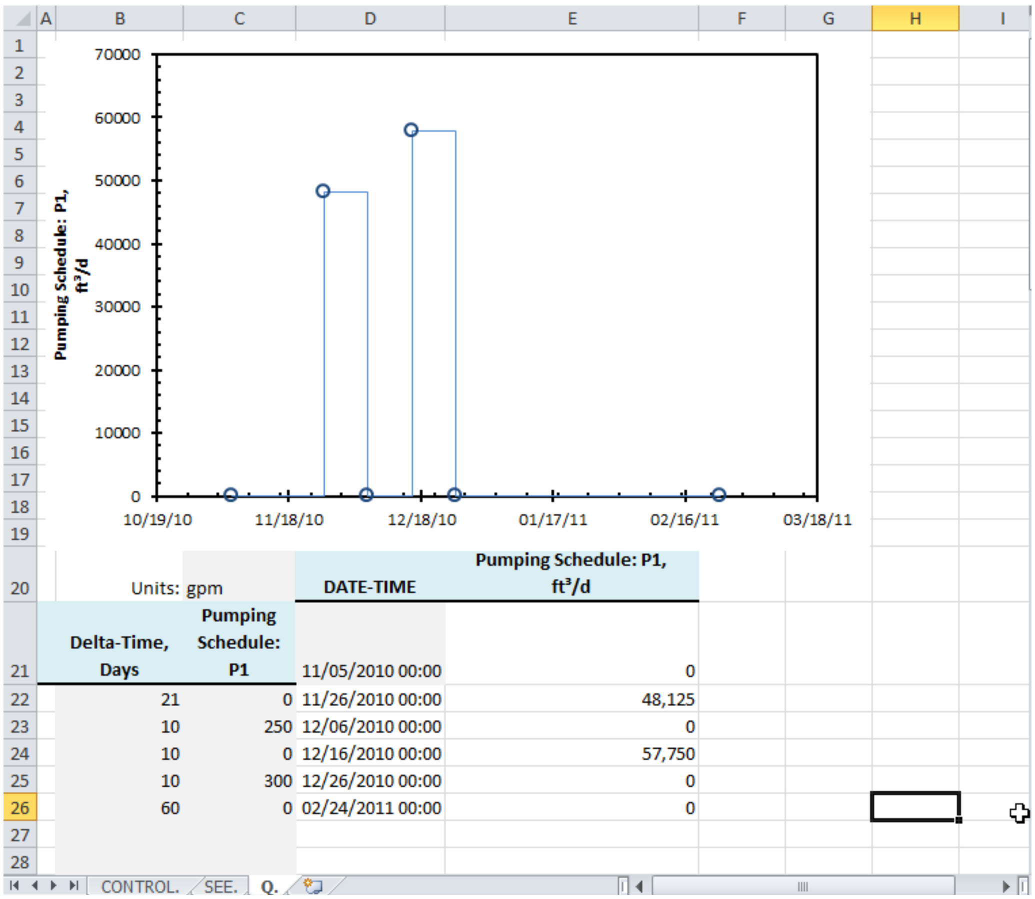
- Simulated drawdowns from all hypothetical wells,
- Simulated drawdowns from all hypothetical wells with environmental fluctuations from a user-defined well added,
- Simulated pumping schedule, and
- Measured barometric and water-level fluctuations minus the series that was added to the simulated drawdowns.

View results with SeriesSEE.



Q page

The pumping schedule from the production well is defined on the Q page (Figure 8). Step tests and many variations in discharge can be defined and simulated, but simulation time increases noticeably as many rate changes are simulated explicitly. Explicitly simulating the first 10-d period with multiple step tests and variable production rates during development takes 5 to 10 times longer than the example in figure 8.



Units: gpm

Delta-Time, Days	Pumping Schedule: P1	DATE-TIME	Pumping Schedule: P1, ft^3/d
		11/05/2010 00:00	0
21	0	11/26/2010 00:00	48,125
10	250	12/06/2010 00:00	0
10	0	12/16/2010 00:00	57,750
10	300	12/26/2010 00:00	0
60	0	02/24/2011 00:00	0

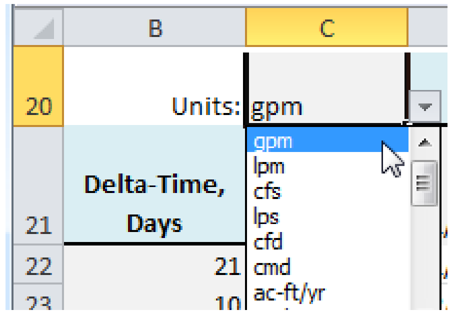
Figure 8.—Q page in the HypoFrame workbook where the pumping schedule is defined.

Previous –●– Next

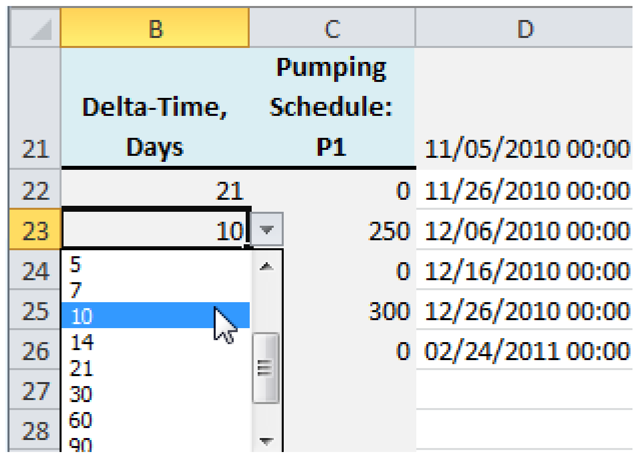
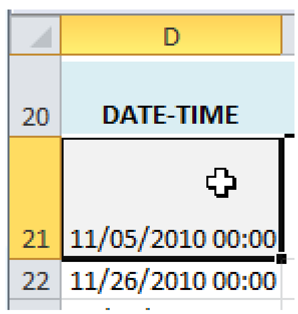
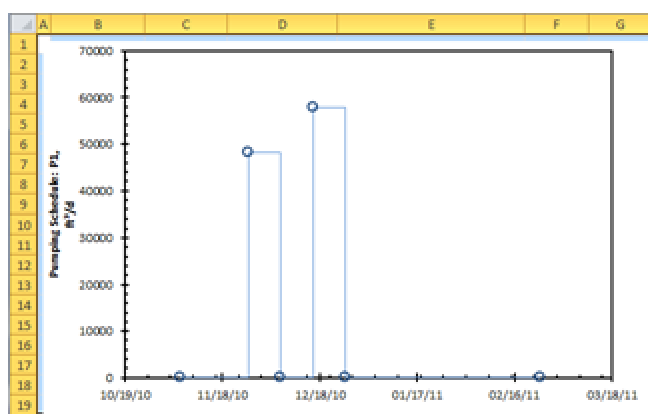
Pumping Schedules

Flexible pumping schedules can be simulated with HypoFrame. Pumping periods are specified by duration and added cumulatively to a user-specified initial date-time. Ten-day development and constant rate pumping periods should be selected even if pumping schedules are very flexible.

Pumping Schedule

<table>
<tr>
<td>Discharge units are specified in cell C20 with a pull down menu. This is used to convert discharge from user-specified units to consistent units of L^3/T.</td>
<td>
</td>
</tr>
<tr>
<td>Select the duration of pumping for each stress period from pull-down menus in column B.

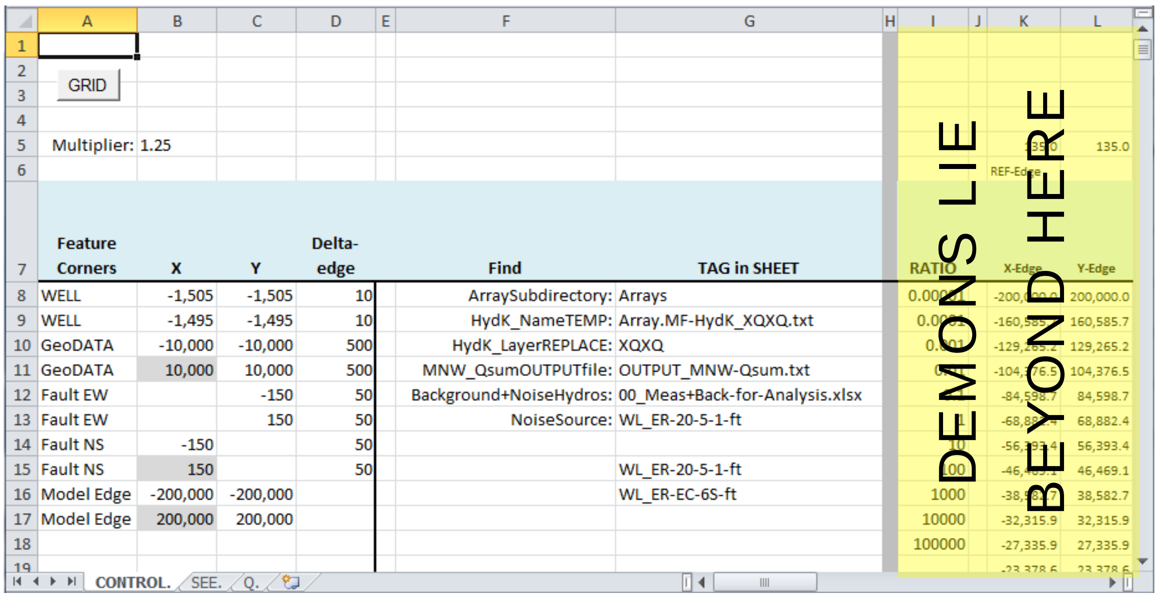
Specify the pumping rate in user-specified units in column C.

HINT: 10 days is the correct answer for non-zero pumping rates.</td>
<td>
</td>
</tr>
<tr>
<td>The initial date-time assigned in cell D20 is used to register model results with measured environmental fluctuations in the Background+NoiseHydros workbook which is specified in cell G13 on the CONTROL page.</td>
<td>
</td>
</tr>
<tr>
<td>Check results in time-Q plot in range A1:G19.</td>
<td>
</td>
</tr>
</table>

[Previous](#) –●– [Next](#)

CONTROL page

Model gridding, the measured water-level workbook, and a noise source that is added to simulated drawdowns are defined on the CONTROL page (Figure 9). Redefining the extent of a relatively uniform grid and fault widths is the primary purpose to re-grid the model domain. Specifying a new measured water-level workbook or noise source is a more reasonable reason to be fiddling with the CONTROL page.



	A	B	C	D	E	F	G
1							
2							
3	GRID						
4							
5	Multiplier:	1.25					
6							
7	Feature Corners	X	Y	Delta-edge		Find	TAG in SHEET
8	WELL	-1,505	-1,505	10		ArraySubdirectory:	Arrays
9	WELL	-1,495	-1,495	10		HydK_NameTEMP:	Array.MF-HydK_XQXQ.txt
10	GeoDATA	-10,000	-10,000	500		HydK_LayerREPLACE:	XQXQ
11	GeoDATA	10,000	10,000	500		MNW_QsumOUTPUTfile:	OUTPUT_MNW-Qsum.txt
12	Fault EW		-150	50		Background+NoiseHydros:	00_Meas+Back-for-Analysis.xlsx
13	Fault EW		150	50		NoiseSource:	WL_ER-20-5-1-ft
14	Fault NS	-150		50			
15	Fault NS	150		50			WL_ER-20-5-1-ft
16	Model Edge	-200,000	-200,000				WL_ER-EC-6S-ft
17	Model Edge	200,000	200,000				
18							

Figure 9.—CONTROL page in the HypoFrame workbook where grid features, measured series, and a noise source can be redefined.

The CONTROL page usually is a hidden page where information is stored away from the user, but I didn't have time to write clever forms that interact with a hidden page. HypoFrame easily can be blown to shreds by the user. Very few safeguards were coded to protect users from themselves.

Previous –●– Next

Model Grid

Limit fiddling to the ***grey*** cells.

GeoDATA defines area of reasonably uniform cell spacing except where refined around pumping well and faults. Extent is defined in cell B11 and uniform MODFLOW-cell size is defined in cell D10.

Faults are 6 cells wide with 2 cells each for the sheath-core-sheath pattern. Change MODFLOW-cell width in cell D12 to alter fault widths.

Model extent is defined in cell B17. Changing this value is pointless.

Limit fiddling to the ***grey*** cells.

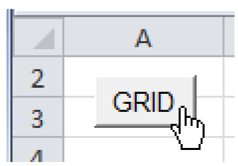
	A	B	C	D
7	**Feature Corners**	**X**	**Y**	**Delta-edge**
8	WELL	-1,505	-1,505	10
9	WELL	-1,495	-1,495	10
10	GeoDATA	-10,000	-10,000	500
11	GeoDATA	10,000	10,000	500
12	Fault EW		-150	50
13	Fault EW		150	50
14	Fault NS	-150		50
15	Fault NS	150		50
16	Model Edge	-200,000	-200,000	
17	Model Edge	200,000	200,000	

CONTROL / SEE. / Q. / NAM / mv

The multiplier in cell B5 is the expansion factor used where grid spacing is variable.

	A	B
5	Multiplier:	1.25

Press the GRID button to calculate new grid edges after altering feature specifications in columns B:C.



Miscellaneous Things

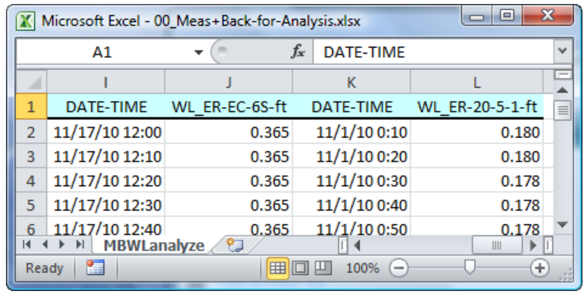
Background+NoiseHydros (cell G13) is the name of an existing SeriesSEE source file that contains measured barometric and water-level fluctuations.

NoiseSource (cell G14) is the name of the series of measured water levels that will be added to all simulated drawdowns.

	F	G
7	**Find**	**TAG in SHEET**
13	Background+NoiseHydros:	00_Meas+Back-for-Analysis.xlsx
14	NoiseSource:	WL_ER-20-5-1-ft

For example, 00_Meas+Back-for-Analysis.xlsx is the existing SeriesSEE source file and series WL_ER-20-5-1-ft (columns K:L) is the noise source.

The series WL_ER-20-5-1-ft will be added to all simulated drawdowns and will be deleted from the created SeriesSEE source file.


Microsoft Excel - 00_Meas+Back-for-Analysis.xlsx

A1 | DATE-TIME

	I	J	K	L
1	DATE-TIME	WL_ER-EC-6S-ft	DATE-TIME	WL_ER-20-5-1-ft
2	11/17/10 12:00	0.365	11/1/10 0:10	0.180
3	11/17/10 12:10	0.365	11/1/10 0:20	0.180
4	11/17/10 12:20	0.365	11/1/10 0:30	0.178
5	11/17/10 12:30	0.365	11/1/10 0:40	0.178
6	11/17/10 12:40	0.365	11/1/10 0:50	0.178

MBWLanalyze

Ready 100%

–●– Previous –●–