Analytical_PLISM–An Excel workbook for simulating water balance of a pit lake

Pit Lake Iterative Simulation Model or PLISM is an Excel workbook for simulating pit lake formation. Open-pit mines that extend below the water table create pit lakes. Assessing post-mining, pit-lake recovery and geochemistry requires a model that simulates time-dependent inflow and outflow components. The transient pit-lake model PLISM is a water-balance model that simulates groundwater exchange with the Jacob-Lohman equation (Lohman, 1972; Fontaine and others, 2003). Precipitation, highwall runoff, evaporation from the pit lake (ET), and external flows from pumping or injection also are flow components of the water budget in addition to groundwater exchange. Lake stage is related to surface area and volume of pit lake with lookup tables of pit geometry.

Lake stage is simulated with a water balance approach that iteratively solves for lake volume and stage. Lake volume at the end of a time step is estimated initially with the surface area at the beginning of the time step. Surface area of the pit lake affects estimated precipitation, highwall runoff, ET, and groundwater exchange volumes during a time step. Lake stage at the end of a time step is interpolated from the user-defined stage-area-volume relation. A revised lake volume at the end of the time step is estimated with a revised surface area from estimated lake stage at the middle of a time step. This process is repeated until estimated lake stages converge on a single value.

Lake stages estimated with PLISM are relatively insensitive to duration of time steps. Time steps for simulating lake stages are independent of times when precipitation and ET are tabulated. Precipitation and ET are specified as lengths (volume per unit area) during tabulated periods. These periods could be a month, a year, or 10 years, which would be lengths of 1, 12, and 120 inches, respectively, for rates of 12 in/yr. Monthly precipitation and ET are integrated if simulation periods are annual and interpolated if simulation periods are less than data tabulation periods. For example, lake stages were simulated for the pit lake characterized in the workbook Analytical_PLISM.v4.xlsm. Simulated lake stages differed little regardless of using monthly, yearly, and 5-year time steps (Figure 1). The maximum difference between solutions was less than 1 ft and errors did not propagate.

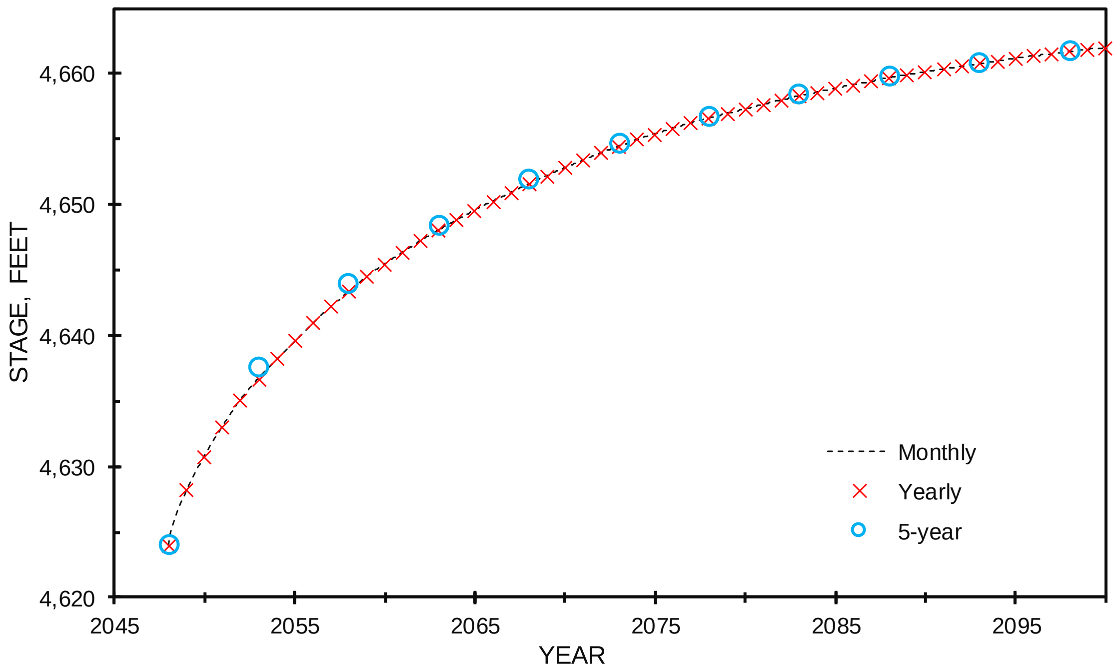


Figure 1.— Pit-lake stage computed at monthly, yearly, and five-year time steps.

Data tabulation, pit-lake representation, and solution method in PLISM differs from traditional water balance models such as CRYPTIC (Fontaine and others, 2003). Data tabulation and lake-stage simulation times can differ in PLISM. Surface area and volume of pit lake are tabulated with lake stage. Stage-area-volume relation in PLISM is interpreted as a continuous function rather than as a limited series of discrete cylinders. Pit-lake stages and volumes are solved iteratively with PLISM rather than with forward differences. PLISM simulates highwall runoff as a function of pit-lake stage, which decreases potential runoff as lake stage increases.

The workbook consists of two pages, DATA and PLISM, and one hidden page, CONTROL (Figure 2). The hidden CONTROL page contains lookup tables, unit conversions, and charting utilities, which users should not need to edit. Pit-lake characteristics, simulated stage, and simulated flow components are reported on the PLISM page. Transmissivity, storage coefficient, percentage of highwall runoff, catchment area, pre-mining water level, and initial, pit-lake water level are specified on the PLISM page (Figure 2). Stage-area-volume relations, time series of precipitation and evaporation (ET) rates, and time series of volumetric pumping or injection rates are entered on the DATA page.

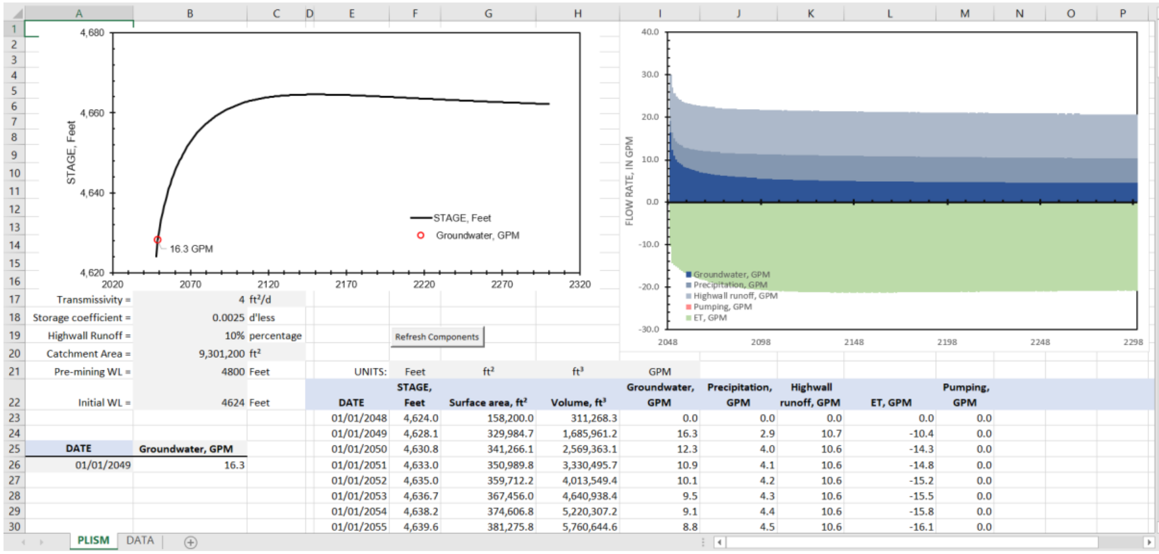


Figure 2.—Site information, pit-lake stage, surface area, and volume, and water-budget components on PLISM page in the in Analytical_PLISM.v4.xlsm.

Analytical_PLISM.v4.xlsm and explanatory PDF can be downloaded with the following link.

References

Fontaine, R.C., Andy Davis, and G.G. Fennemore, 2003, The Comprehensive Realistic Yearly Pit Transient Infilling Code (CRYPTIC): A Novel Pit Lake Analytical Solution, Mine Water and the Environment v.22 pgs. 187–193 https://doi.org/10.1007/s10230-003-0021-z

Jacob, C. E., and Lohman, S. W., 1952, Nonsteady flow to a well of constant drawdown in an extensive aquifer: Am. Geophys. Union Trans., v. 33, p. 559-569. https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/TR033i004p00559

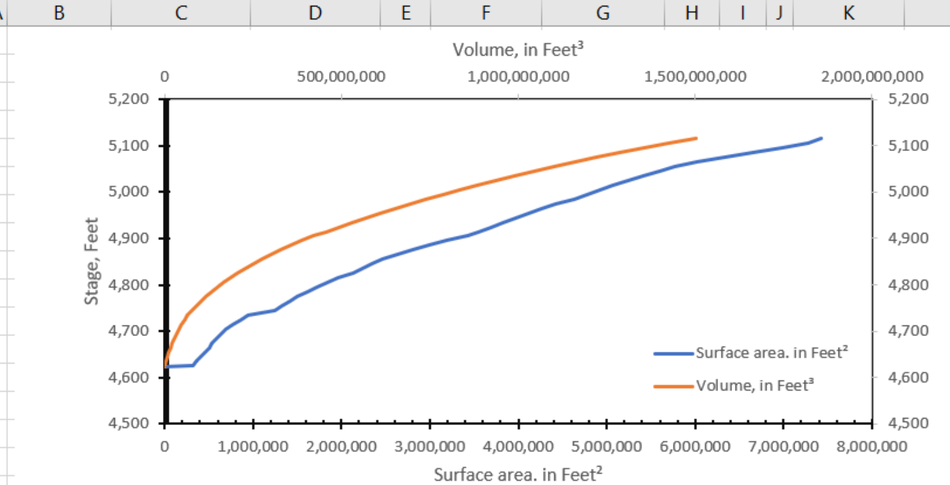
Lohman, S.W., 1972, Ground-Water Hydraulics:U.S. Geological Survey Professional Paper 708, 70 p. https://doi.org/10.3133/pp708

Analytical_PLISM.v4.xlsm Workbook

The workbook consists of two pages, DATA and PLISM, and one hidden page, CONTROL. The hidden CONTROL page contains lookup tables, unit conversions, and charting utilities, which users should not need to edit. Pit-lake characteristics, simulated stage, and simulated flow components are reported on the PLISM page. Transmissivity, storage coefficient, percentage of highwall runoff, catchment area, pre-mining water level, and initial, pit-lake water level are specified on the PLISM page. Stage-area-volume relations, time series of precipitation and evaporation (ET) rates, and time series of volumetric pumping or injection rates are entered on the DATA page.

DATA page

Relation between stage, surface area, and volume of pit lake are specified relative to stage altitudes in columns B-D from row 20 down (Figure 3). Stage, surface area, and volume are specified from lowest to highest altitudes. Precipitation and ET are specified as accumulated as lengths (volume per unit area) between dates in columns F-H from row 20 down (Figure 3). Removing or adding water from pit lake by pumping or injection is specified as volumetric rates in columns K-L from row 20 down.



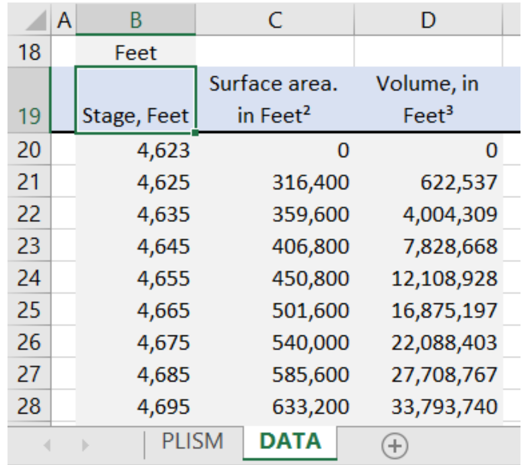
	A	B	C	D	E	F	G	H	I	J	K	L	M
18		Feet											
19		Stage, Feet	Surface area. in Feet²	Volume, in Feet³		DATE	Precipitation.	ET	Inch		DATE	Pumping or Injection.	GPM
20		4,623	0	0		01/01/2048	10	-36			06/25/2020	0	
21		4,625	316,400	622,537		01/01/2049	10	-36			01/01/2092	0	
22		4,635	359,600	4,004,309		01/01/2050	10	-36			01/01/2492	0	
23		4,645	406,800	7,828,668		01/01/2051	10	-36					

PLISM | DATA

Figure 3.—DATA page in the Analytical_PLISM.v4.xlsm workbook where stage-area-volume relation, time series of precipitation and ET lengths, and time series of pumping or injection rates are specified.

Data Page

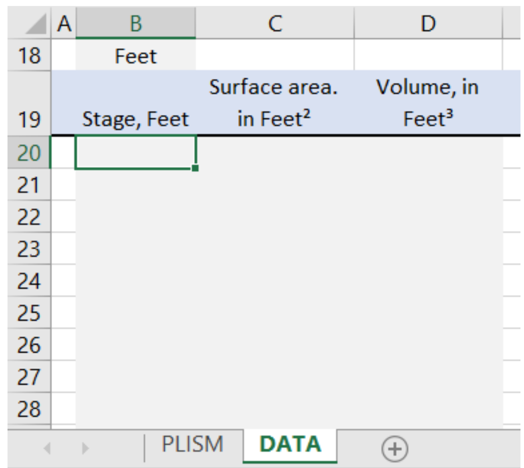
Clear existing data between columns B and D from row 20 to the last entry.



	A	B	C	D
18		Feet		
19		Stage, Feet	Surface area. in Feet²	Volume, in Feet³
20		4,623	0	0
21		4,625	316,400	622,537
22		4,635	359,600	4,004,309
23		4,645	406,800	7,828,668
24		4,655	450,800	12,108,928
25		4,665	501,600	16,875,197
26		4,675	540,000	22,088,403
27		4,685	585,600	27,708,767
28		4,695	633,200	33,793,740

PLISM | DATA

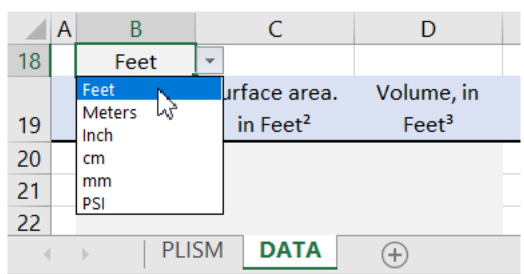
Empty cells before adding your data.



	A	B	C	D
18		Feet		
19		Stage, Feet	Surface area. in Feet²	Volume, in Feet³
20				
21				
22				
23				
24				
25				
26				
27				
28				

PLISM | DATA

Specify units for length in cell B18.

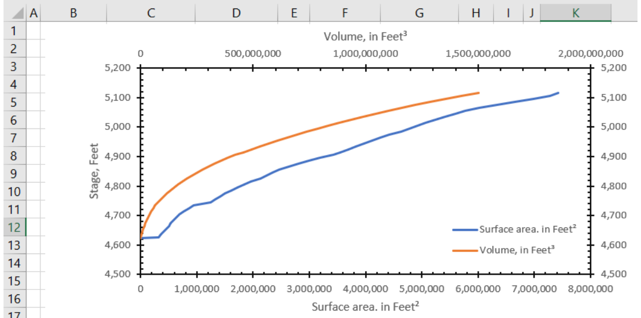


Paste stage, surface area, and volume data in cell B20.

	A	B	C	D
18		Feet		
19		Stage, Feet	Surface area. in Feet²	Volume, in Feet³
20		4,623	0	0
21		4,625	316,400	622,537
22		4,635	359,600	4,004,309
23		4,645	406,800	7,828,668
24		4,655	450,800	12,108,928
25		4,665	501,600	16,875,197
26		4,675	540,000	22,088,403
27		4,685	585,600	27,708,767
28		4,695	633,200	33,793,740

PLISM DATA

Verify stage-area-volume relation in chart above data.



	B	C	D	F	G	H	I	K	
18	Feet								
19	Stage, Feet	Surface area. in Feet²	Volume, in Feet³	DATE	Precipitation.	ET	Inch	DATE	Pum Inje
20	4,623	0	0	01/01/2048	10	-36		06/25/2020	
21	4,625	316,400	622,537	01/01/2049	10	-36		01/01/2092	

PLISM DATA

Paste date, precipitation, and ET data in cell F20, where precipitation and ET are lengths between dates in column F.

	F	G	H	I
19	DATE	Precipitation.	ET	Inch
20	01/01/2048	10.00	-36.00	
21	01/01/2049	10.00	-36.00	
22	01/01/2050	10.00	-36.00	
23	01/01/2051	10.00	-36.00	
24	01/01/2052	10.00	-36.00	
25	01/01/2053	10.00	-36.00	
26	01/01/2054	10.00	-36.00	
27	01/01/2055	10.00	-36.00	
28	01/01/2056	10.00	-36.00	
29	01/01/2057	10.00	-36.00	

PLISM DATA

Precipitation and ET rates in the preceding table and this one are equivalent. Values differ because monthly precipitation and ET volumes were specified.

	F	G	H	I
19	DATE	Precipitation.	ET	Inch
20	01/01/2048	0.85	-3.06	
21	02/01/2048	0.79	-2.86	
22	03/01/2048	0.85	-3.06	
23	04/01/2048	0.82	-2.96	
24	05/01/2048	0.85	-3.06	
25	06/01/2048	0.82	-2.96	
26	07/01/2048	0.85	-3.06	
27	08/01/2048	0.85	-3.06	
28	09/01/2048	0.82	-2.96	
29	10/01/2048	0.85	-3.06	

PLISM DATA

Specify units for length in cell I19.

	F	G	H	I	J
19	DATE	Precipitation.	ET	Inch	D.
20	01/01/2048	10.00	-36	Feet	06/2
21	01/01/2049	10.00	-36	Meters	01/0
22	01/01/2050	10.00	-36	Inch	01/0
23	01/01/2051	10.00	-36	cm	
24	01/01/2052	10.00	-36.00	mm	
				PSI	

PLISM DATA

Paste dates and pumping or injection rates in cell K20.

Negative values are pumping that removes water from pit lake.

Positive values are injection that adds water to pit lake.

	K	L	M
19	DATE	Pumping or Injection.	GPM
20	06/25/2020	0	
21	01/01/2092	0	
22	01/01/2492	0	
23			

PLISM DATA

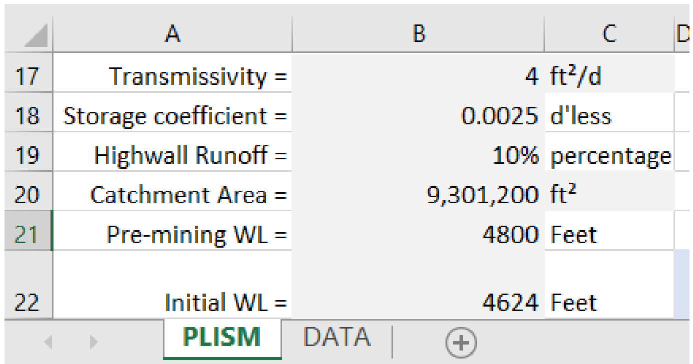
Specify volumetric rates of pumping or injection in cell M19.

	K	L	M	N
19	DATE	Pumping or Injection.	GPM	
20	06/25/2020	0	GPM	
21	01/01/2092	0	ft³/d	
22	01/01/2492	0	ft³/s	
23			m³/d	
			m³/s	
			liters/s	
			liters/min	
			cc/s	

PLISM DAT

PLISM page—Site Information

Construction, depths, material, and site information are specified on the OUTPUT page (Figure 4). Most of this information is descriptive and does not affect estimated hydraulic conductivities, except for well construction. Aquifer material defines broad ranges of permissible hydraulic conductivities, which users should expand or replace with site specific limits. Hydraulic conductivity estimates are affected by casing diameter (cell C30) and screen length as specified by depths to top and bottom of screen (cells B34:B35).



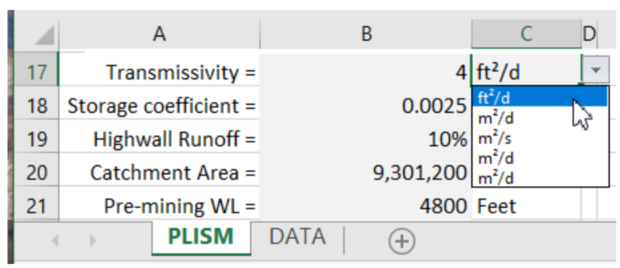
	A	B	C
17	Transmissivity =	4	ft²/d
18	Storage coefficient =	0.0025	d'less
19	Highwall Runoff =	10%	percentage
20	Catchment Area =	9,301,200	ft²
21	Pre-mining WL =	4800	Feet
22	Initial WL =	4624	Feet

Figure 4.—Site information on PLISM page in the Analytical_PLISM.v4.xlsm workbook.

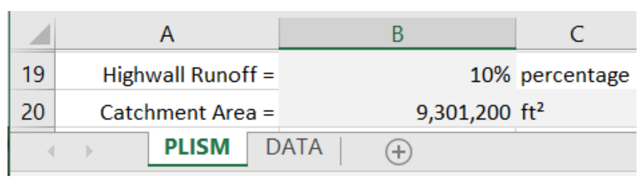
Site Information

Enter gross hydraulic property estimates,
Transmissivity in cells B17,
Storage coefficient in cell B18.

Specify units of transmissivity in cell C17.

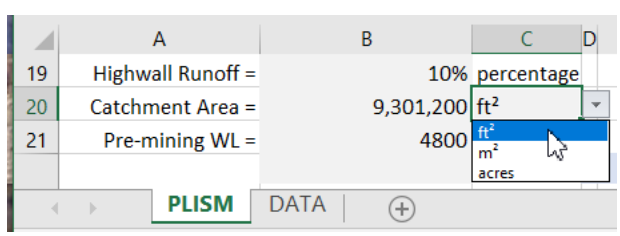


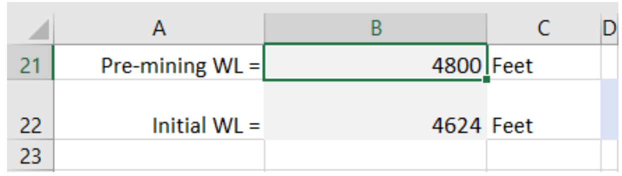
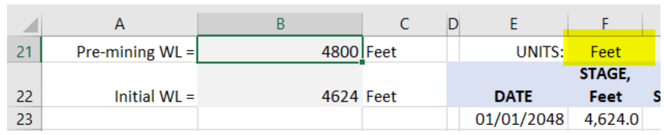
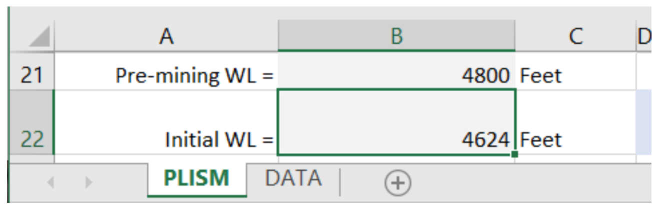
Highwall runoff is a percentage (B19) times cumulative precipitation during a period times catchment area minus surface area of pit lake.



Catchment area is specified in cell B20.

Specify units of catchment area in cell C20.



Pre-mining groundwater level is specified in cell B21.	
Unit of altitude is specified in cell F21. Specified unit is applied to pre-mining groundwater level, initial pit-lake, water level, and stage of pit lake.	
Initial pit-lake, water level is specified in cell B22.	

PLISM page—Analysis

Pit-lake stages and water-budget components are computed and graphed on the PLISM page (Figure 5). Pit-lake evaluation times are specified in column E from row 23 and greater. Equations are paired with newly specified evaluation times with the “Refresh Components” button at cell F19 (Figure 5). Pit-lake stage is computed dynamically as site information, such as transmissivity, is changed. Pit-lake surface areas, pit-lake volumes, and flow components must be revised manually with the “Refresh Components” button at cell F19 (Figure 5). These values in columns G-M are computed with a macro written as values to a table on the CONTROL page. A single flow component at a user-specified time is computed dynamically and posted with corresponding pit-lake stage for limited calibration (Figure 5). Unit conversions are dynamic and will be revised automatically after new units are selected in cells F21:I21 (Figure 5).

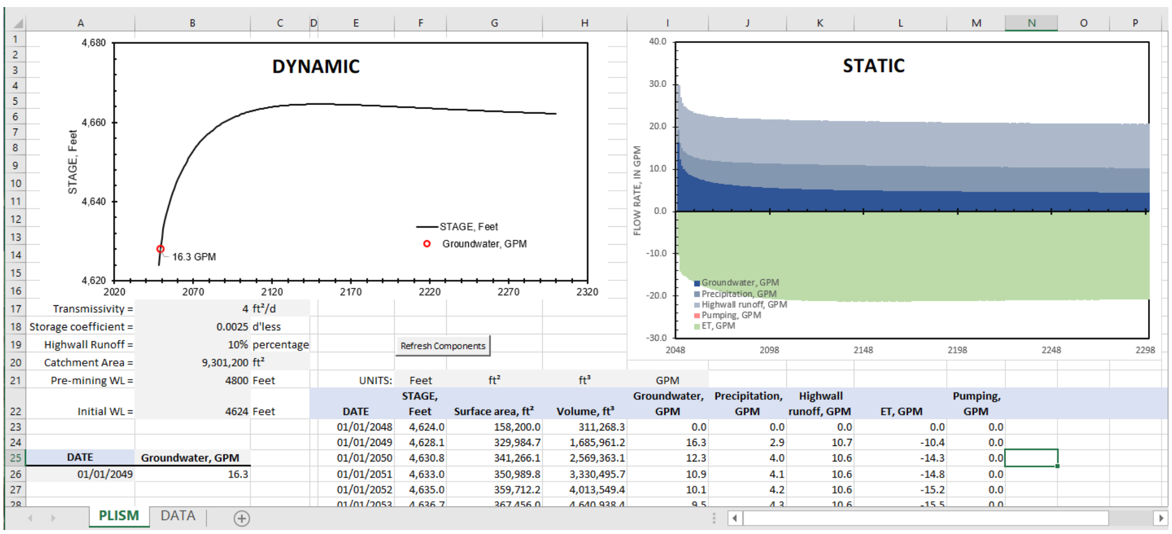


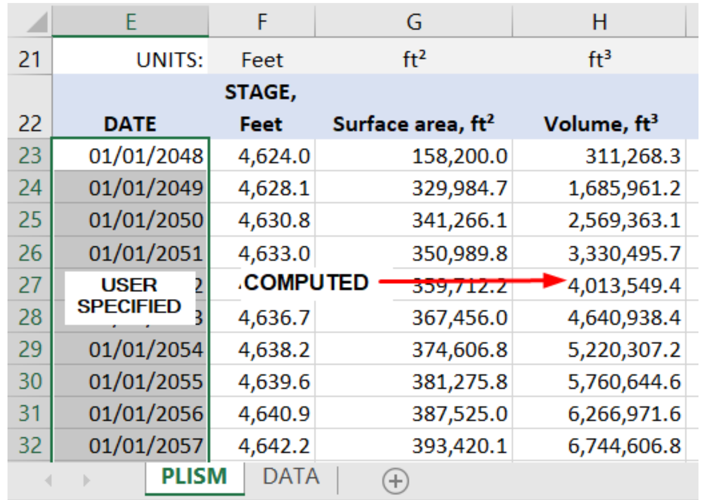
Figure 5.—Pit-lake stage and water-budget components on PLISM page in the Analytical_PLISM.v4.xlsm workbook.

Estimate Pit-Lake Stage

Evaluation times are specified in column E from row 23.

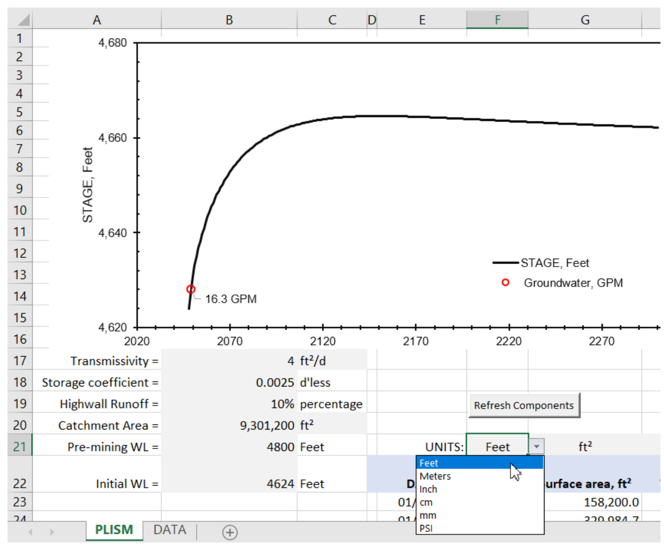
Irregular periods can be defined between evaluation times, which are independent of times in the precipitation-ET and pumping tables on the DATA page.

All values in columns F-M are computed and should not be edited.



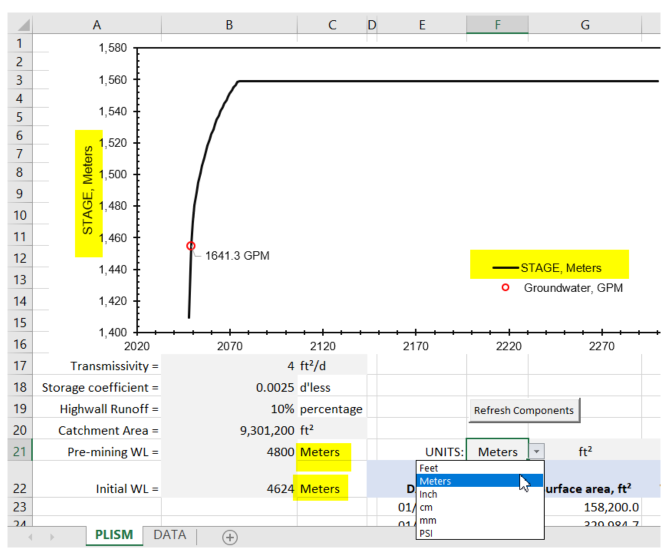
	E	F	G	H
21	UNITS:	Feet	ft²	ft³
22	DATE	STAGE, Feet	Surface area, ft²	Volume, ft³
23	01/01/2048	4,624.0	158,200.0	311,268.3
24	01/01/2049	4,628.1	329,984.7	1,685,961.2
25	01/01/2050	4,630.8	341,266.1	2,569,363.1
26	01/01/2051	4,633.0	350,989.8	3,330,495.7
27	USER 2	COMPUTED	359,712.2	4,013,549.4
28	SPECIFIED 3	4,636.7	367,456.0	4,640,938.4
29	01/01/2054	4,638.2	374,606.8	5,220,307.2
30	01/01/2055	4,639.6	381,275.8	5,760,644.6
31	01/01/2056	4,640.9	387,525.0	6,266,971.6
32	01/01/2057	4,642.2	393,420.1	6,744,606.8

Pit-lake stage can be reported in other units, which are selected in cell F21.



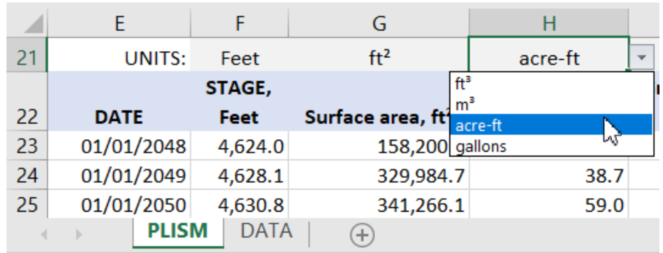
Changing units for stage in cell F21 also changes units for pre-mining groundwater level (C21) and initial pit-lake stage (C22).

Values of pre-mining groundwater level (B21) and initial pit-lake stage (B22) must be revised for consistency with new units.



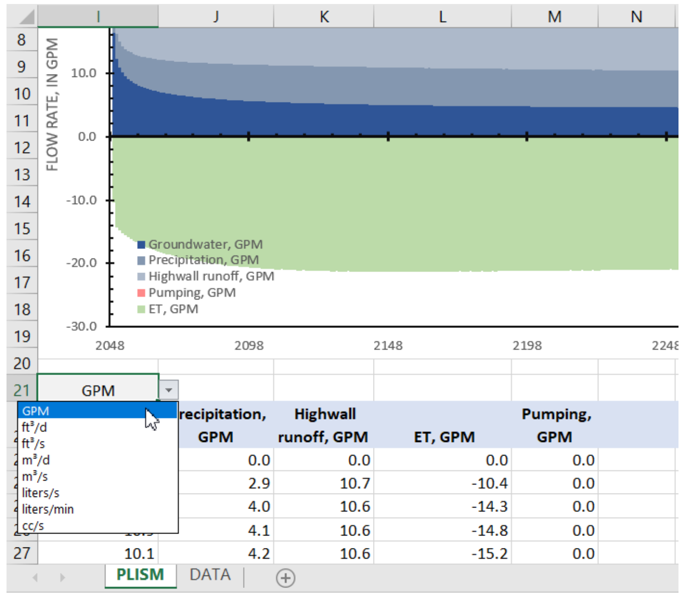
Units of pit-lake surface areas and volumes in columns G and H can be reported in units other than ft² and ft³, respectively.

Alternative units of area and volume are specified in cells G21 and H21, respectively.



Flow components are reported and charted in a user-defined rate, as specified in cell I21.

All flow components are reported and charted in the same units.

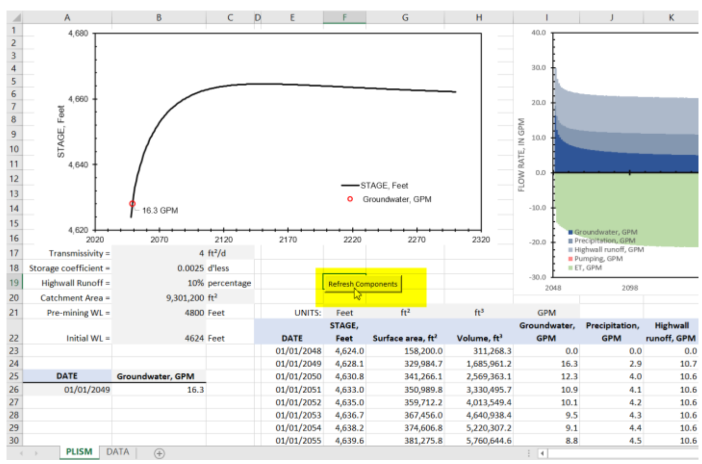


Pressing "Refresh Components" button at cell F19,

1.) Pairs evaluation times in column E with computed values in columns F-M.

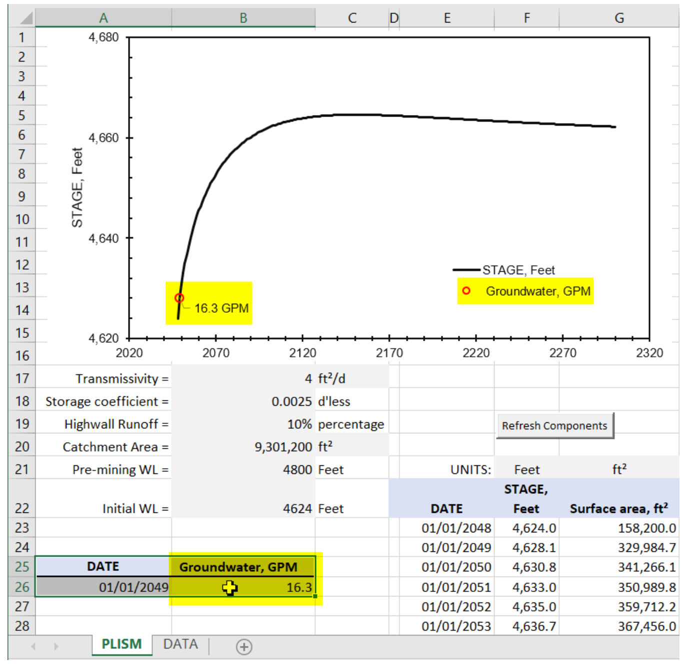
Rows of paired computed values are reduced or expanded to match number of rows with user-specified evaluation times.

2.) Revises static values in columns G-M using current site information and data tables.



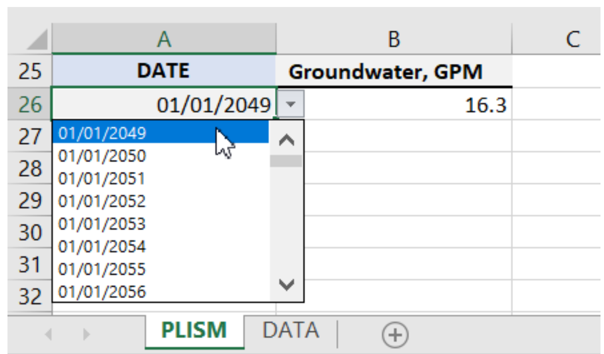
A single flow component is computed dynamically and posted with corresponding pit-lake stage for limited calibration.

Flow component and computation time are specified in range A25:B26.

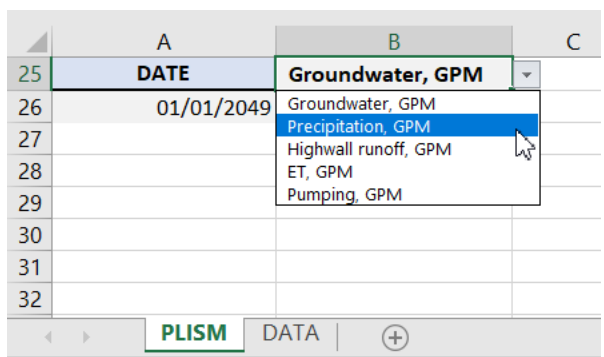


Computation time for single-flow component is specified in cell A26.

Times are user defined in column E.



Flow component is specified in cell B25.



Changes in flow component and computation time are reflected in the chart of pit-lake stage.