# TSFISM–An Excel workbook for simulating the water balance of a Tailings-Storage Facility

Tailings-Storage Facility Iterative Simulation Model or TSFISM is an Excel workbook that simulates the water balance and accumulation of tailings in a tailings-storage facility (TSF). Tailings are introduced into a TSF pool as a slurry comprised of slurry solids ① and slurry water ② (Figure 1). Pool stage usually is managed by pumping reclaimed water ③ from the TSF pool. Other managed waters ④, such as seepage to drains, also can be added or removed from a TSF pool. Slurry solids, slurry water, reclaimed water, and other process flows are managed actively and collectively analyzed as net pumping (Figure 1). Water balance of a TSF pool also is affected by local climate, where precipitation ⑤ and surface-water runoff from tailings beach ⑥ add water and evaporation ⑦ removes water (Figure 1). Flow rates of these three climatic terms depend on the surface area, which changes as tailings accumulate. Pool stage and bathymetry change as tailings accumulate and surface area changes in response to these operational changes (Jackson, et.al., 2026). Water also can seep from unlined facilities as uncaptured groundwater leakage ⑧ (Figure 1).

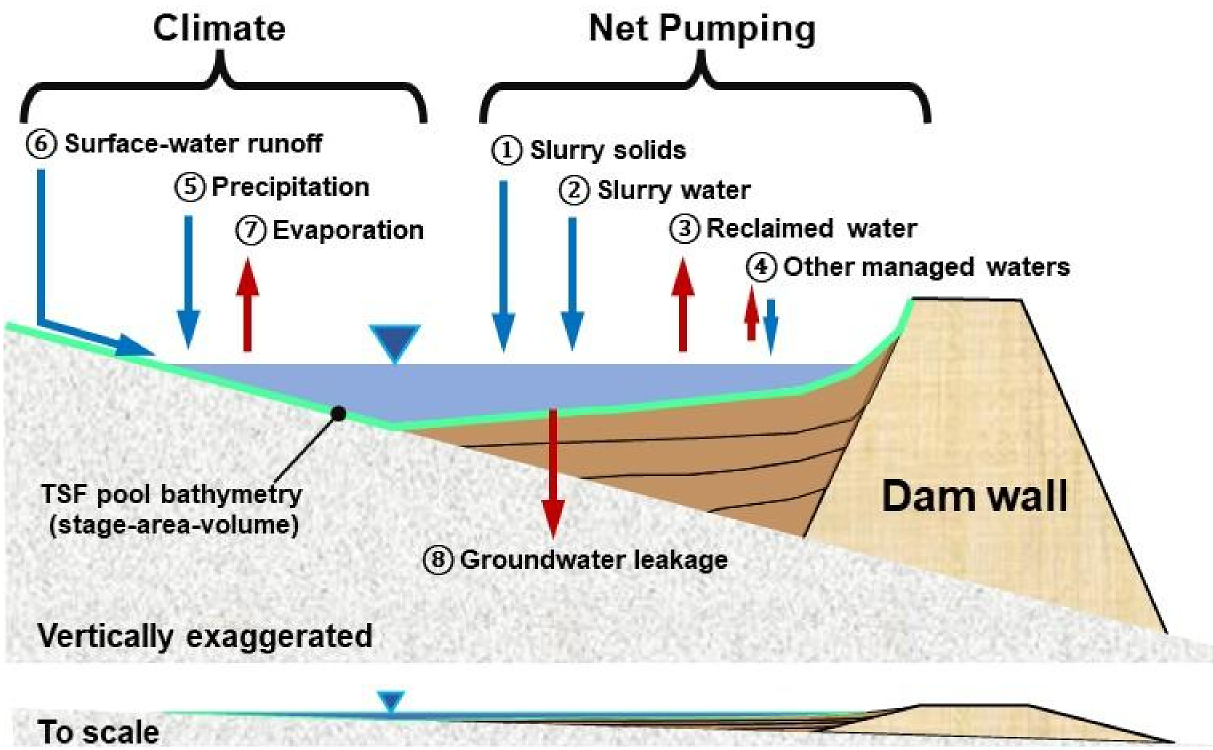



Figure 1.— Schematic of inflow and outflow terms for water-balance of a tailings-storage facility.

## Water-Balance Data

Volumes of slurry solids are estimated from production tailings (Figure 2). Slurry solid flow rates equal tailings production rates divided by specific gravity. These flow rates are reasonably certain because specific gravity of tailings typically average 2.65 with a limited range of specific gravities between 2.5 and 3.0 for gold and copper tailings (Vermeulen, 2001).

Volumes of slurry water are reported as percent of solids (*PoS*) and are more uncertain than volumes of slurry solids (Figure 2). Volume of slurry water in gallons per minute (gpm) is,

$$Q_{Slurry\ water} = \frac{M_{tail}}{\rho_{water}} \times 2000 \times \left(1/_{PoS} - 1\right) \times \frac{7.48\ (gal/ft^3)}{d \times 1440\ (min/d)} \tag{1}$$

where,

*$M_{tail}$ is mass rate of tailings in short tons per month (M/T);*
*$\rho_{water}$ is density of water, 62.4 lbs/ft³ ($M/L^3$);*
*PoS is percent of solids, denoted as a fraction; and*
*d is days (T) in month.*

Estimated slurry water flow rates are disproportionally sensitive to *PoS* estimates. For example, slurry water volumes increase by 70 percent if *PoS* changes from 0.3 to 0.2 and decrease by 35 percent if *PoS* changes from 0.3 to 0.4 (Figure 2). Volumetric flow rate is illustrated with imperial units, but TSFISM also can be report volumetric flow rates in metric units.

Net pumping collectively is all managed water that is pumped from a TSF pool or returned to a TSF pool. Net pumping principally is reclaimed slurry water but also can include other discrete components, such as seepage to drains, which typically comprise less than a few percent of monthly reclaimed water volumes.

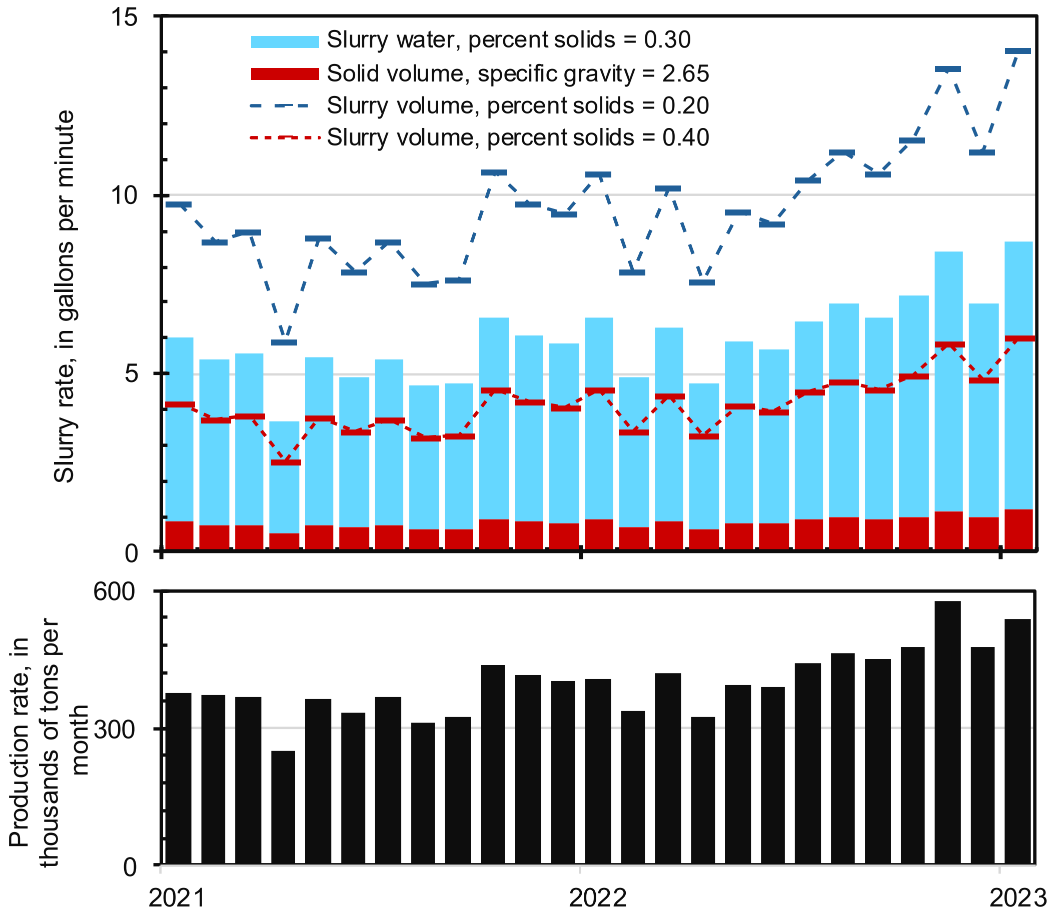



Figure 2.— Volumetric rates of slurry solids and slurry water from monthly production of tailings with estimates of 0.2, 0.3, and 0.4 for percent solids.

Slurry solids, slurry water, and reclaimed water are tracked in the water-balance model as net pumping (Figure 3). Net pumping is tracked because the water-balance model principally is affected by the combined flow of slurry and reclaimed water, not the individual components from plant data (Figure 1).

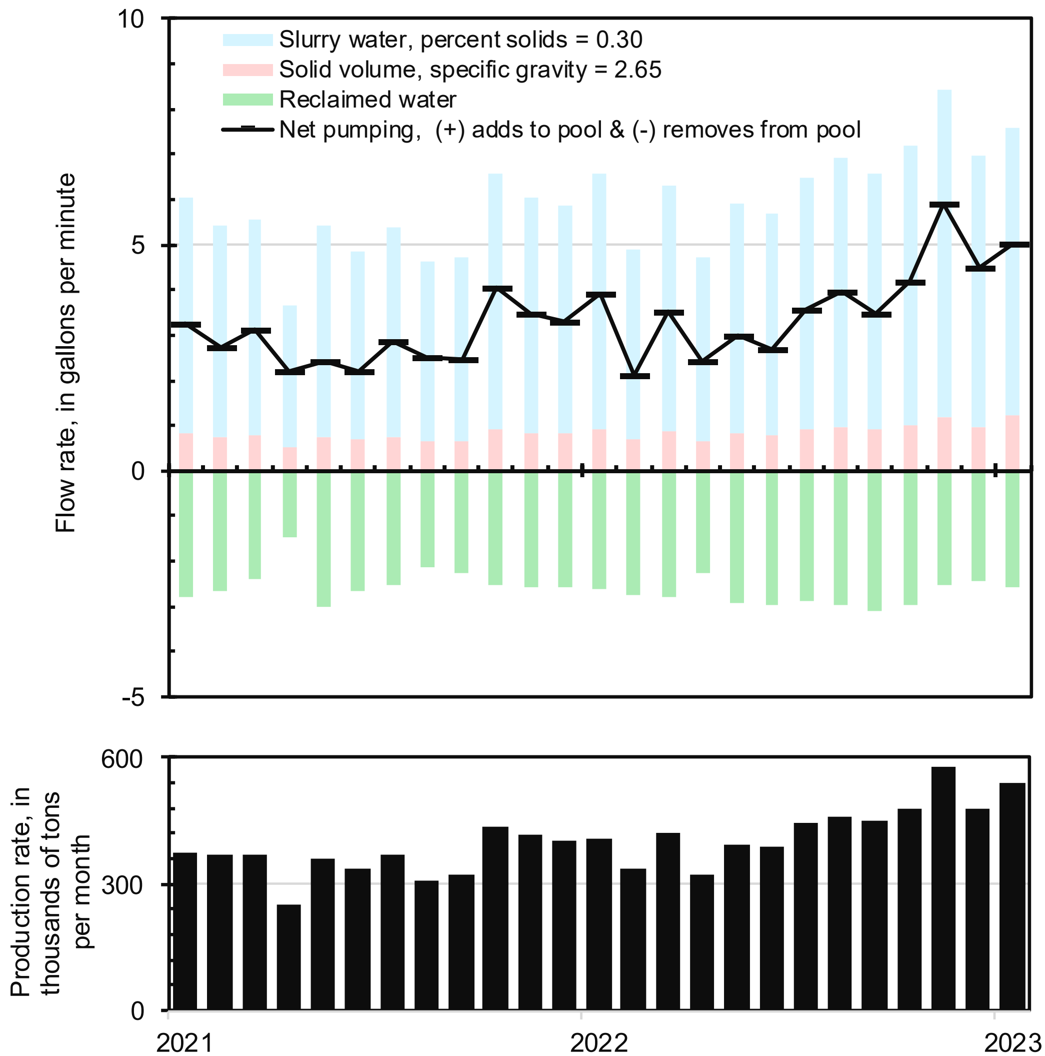



Figure 3.— Net pumping from volumetric rates of slurry solids, slurry water, and reclaimed water.

Climate components of the water balance of a TSF pool principally are defined by monthly measurements of precipitation and evaporation (Figure 4). Precipitation and evaporation typically are predicted by averaging and projecting long-term monthly averages. Alternatively, predicted precipitation and evaporation can be estimated with external models, where results supplant the projected long-term monthly averages.

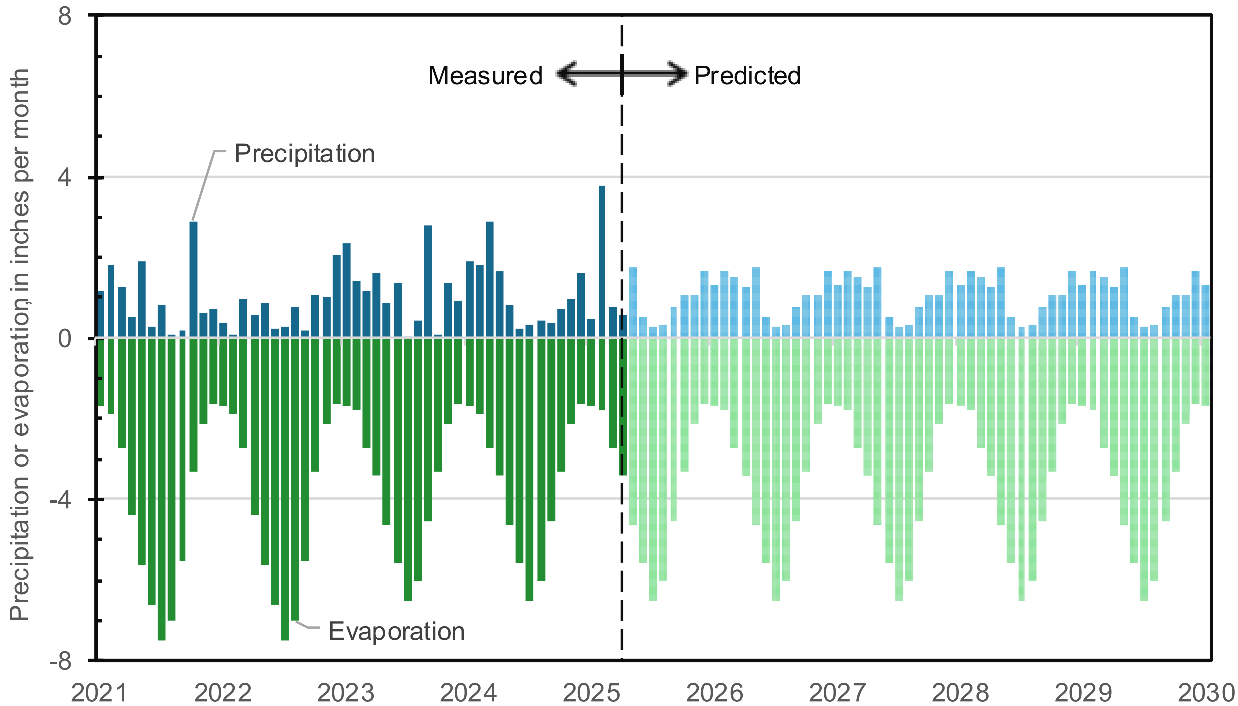



Figure 4.— Example of precipitation and evaporation data that define climate components in water balance.

Surface-water runoff to a TSF pool is estimated from time series of specified precipitation and catchment characteristics. Catchments are defined by area, runoff percentage, and threshold precipitation. These characteristics can change during the life of a TSF and, accordingly, are defined as time series. Surface-water runoff is simulated as available precipitation (L) times runoff percentage times catchment area minus pool area ($L^2$). Available precipitation is specified precipitation minus threshold precipitation and is limited to 0 if threshold precipitation exceeds specified precipitation.

Changes in TSF pool geometry are measured with repeated bathymetric surveys that are summarized as stage-area-volume (SAV) relations (Figure 5). Accumulation of sediment and raising of pool elevation are monitored by increasing elevations of the pool bottom. Climate components of the TSF pool water budget are estimable because pool surface area is a function of stage. Sedimentation volumes in the TSF pool are measured by differencing volumes between repeated bathymetric surveys (Figure 5).

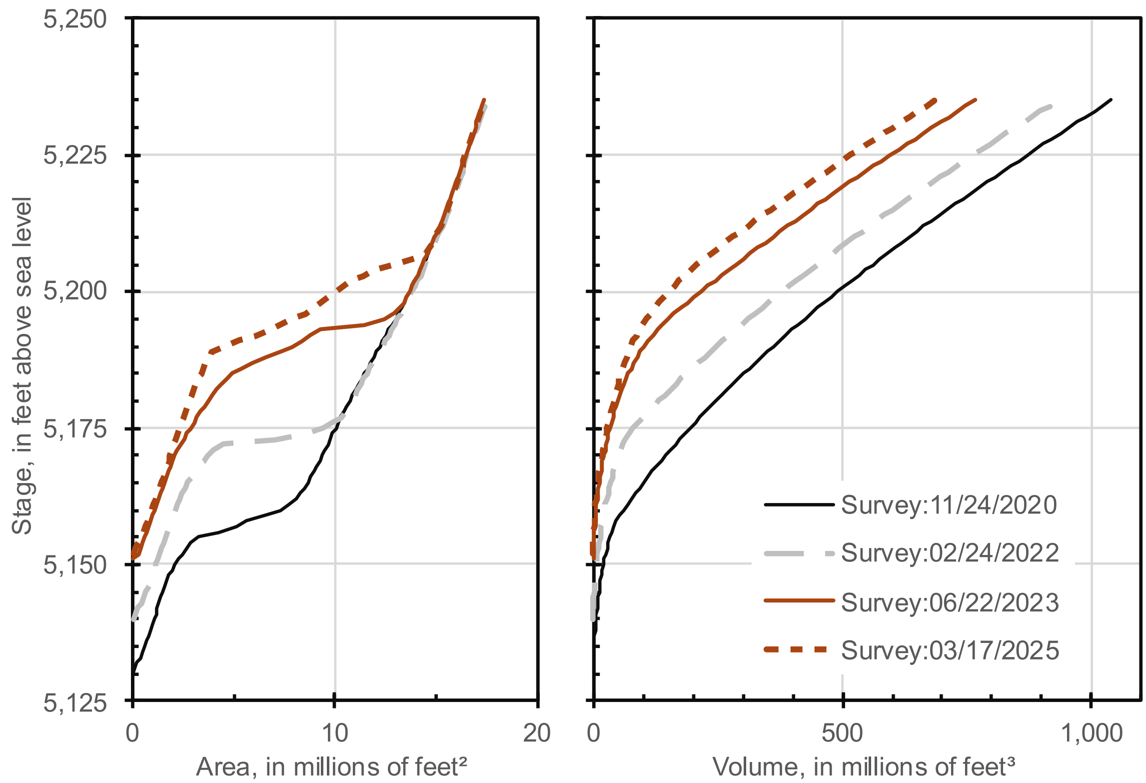



Figure 5.— Multiple stage-area-volume (SAV) relations from repeat bathymetry surveys.

Pool stage is the principal measure of water budget and operability of a TSF (Figure 6). Pool stage directly measures proximity of the water surface to the Maximum Operating Water Level (MOWL) and indirectly measures changes in sedimentation and free-water volumes. These indirect estimates use measured pool stages to interpret sedimentation and free-water volumes from repeated bathymetric surveys (Figure 5).

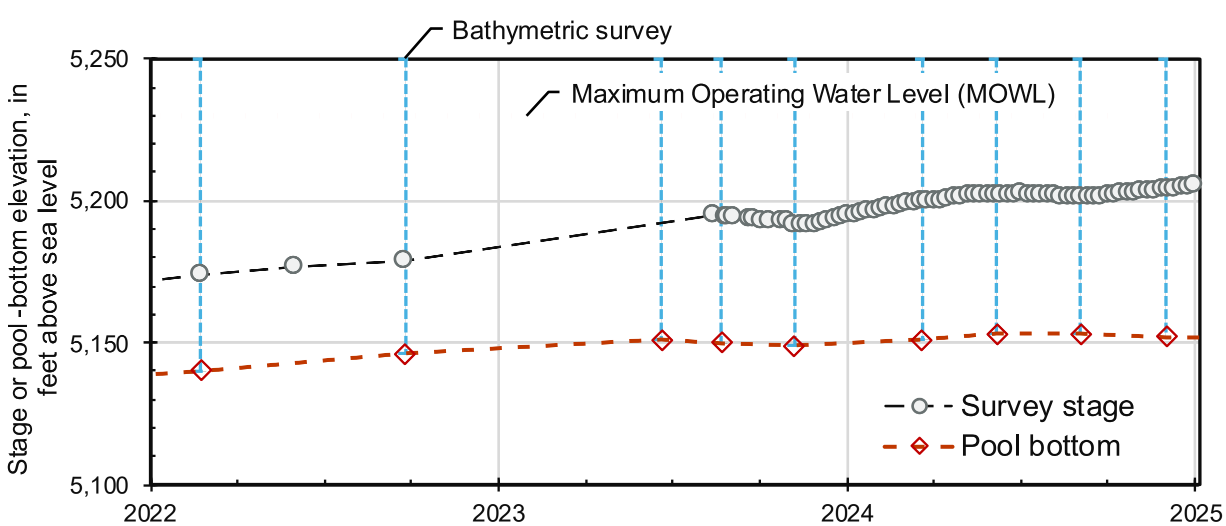



Figure 6.— Surveyed pool stages and estimated pool-bottom elevations.

Sedimentation volume in the TSF pool is estimated each time a new bathymetric survey is measured. Sedimentation volume is the difference between volumes from the previous and new SAVs. These volumes are interpolated from the new surveyed pool stage and volume differences between the new and previous bathymetric surveys (Figure 7). For example, bathymetry was measured on 06/22/2023 when pool stage was 5,191.9 ft. Pool volume from the 06/22/2023 SAV was 119 million ft³ and equaled the volume of free-water because negligible sedimentation was assumed to occur during the bathymetric survey and above the pool stage. Pool volume would have equaled 272 million ft³ from the 02/24/2022 SAV for the same stage of 5,191.9 ft. The difference between these two volumes, $V_2$, equaled a sedimentation volume of 153 million ft³ that was deposited during the 483 days between bathymetric surveys (Figure 7).

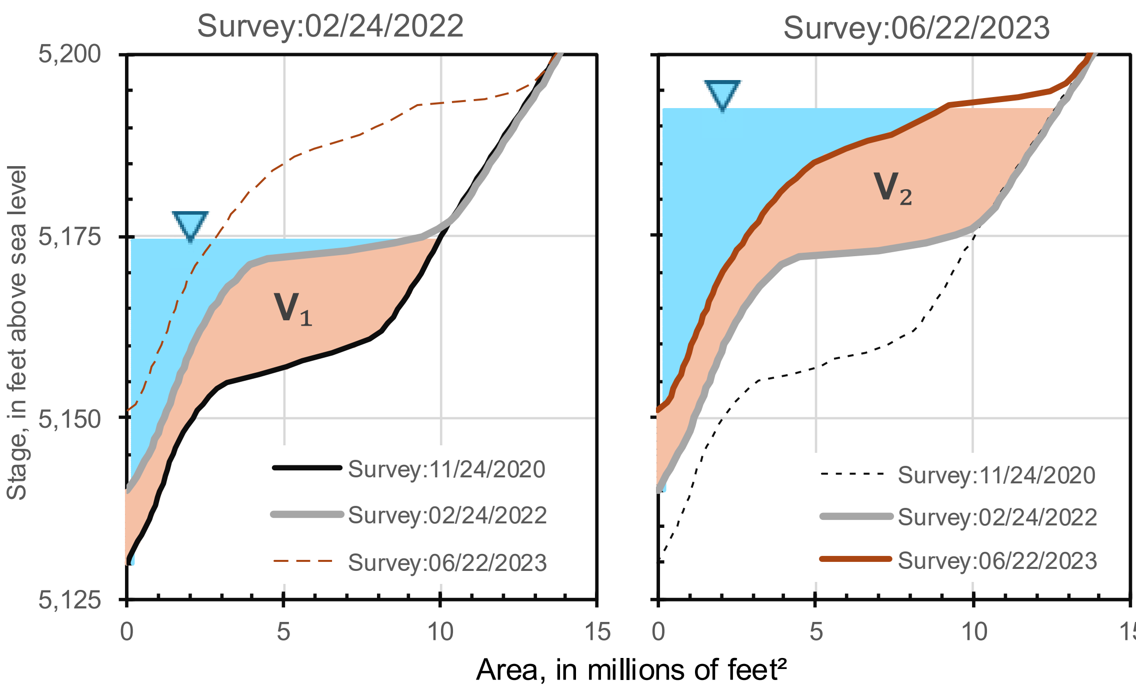



Figure 7.— Schematic of sedimentation volume estimated from bathymetry revisions.

Free-water volume in a TSF equals pool volume from the most recent bathymetric survey minus sedimentation volume since the most recent bathymetric survey. Free-water volume is best estimated immediately after a bathymetric survey when the volume from the SAV equals free-water volume. This interpretation reasonably assumes negligible sedimentation has occurred during the bathymetric survey.

Sedimentation volume is distributed proportionally to cumulative tailings production between bathymetric surveys (Figure 8). For example, pool stage was 5,188.0 ft on 03/31/2023 as interpolated between surveyed pool stages. Cumulative tails production totaled 11.68 million tons or 95 percent of tails production between the 02/24/2022 and 06/22/2023 bathymetric surveys. Cumulative sedimentation volume since the 02/24/2022 bathymetric survey was estimated as 145 million ft³ on 03/31/2023 or 95 percent of 153 million ft³ deposited between bathymetric surveys (Figure 8).

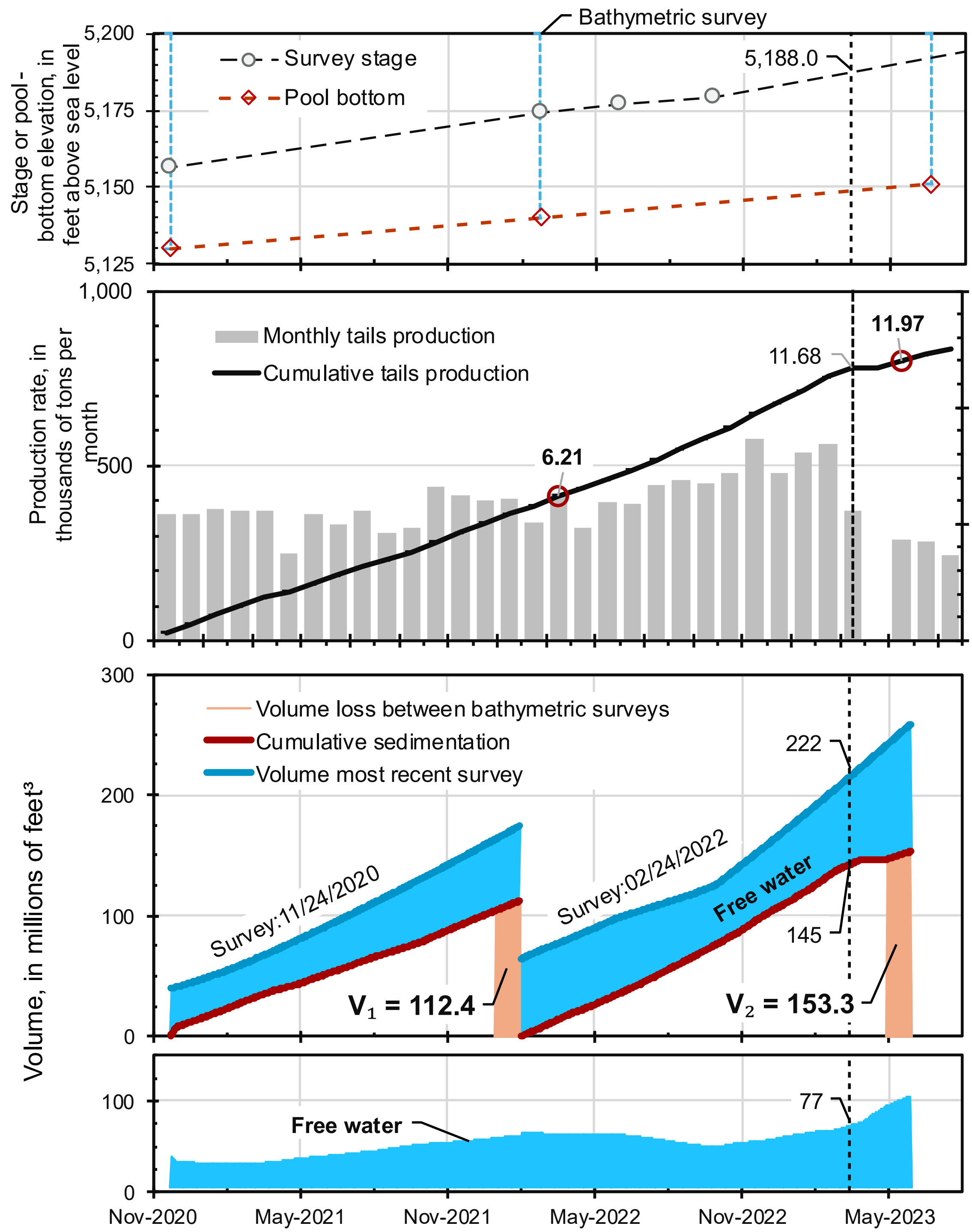



Figure 8.— Mass-weighted distribution of sedimentation volumes and estimation of free-water volumes from surveyed pool stages, monthly tails production, and repeated bathymetry surveys (Sediment volumes $V_1$ and $V_2$ estimated in Figure 7).

Free-water volume can be estimated continuously with temporally distributed sedimentation volumes (Figure 8). For example, free-water volume was 77 million ft³ on 03/31/2023. This was the difference between 222 million ft³ from the 02/24/2022 bathymetric survey minus 145 million ft³ of cumulative sedimentation (Figure 8).

## Water-Balance Model

TSF-pool stage is simulated with a water balance approach that solves iteratively for change in pool volume and stage at the end of a time step (Figure 9). This approach is similar to water-balance models of pit lakes (Fontaine and others, 2003; Halford, 2025). Change in pool volume, $\Delta V$, during a time step is,

$$\Delta V = \Delta t[Q - Q_{GW} + A_{mean}(P - E) + \sum_{i=1}^{n}\left(P - P_{catch-thresh,i}\right) * RO_{catch,i}\left(A_{catch,i}\right) + \left(P - P_{thresh,beach}\right) * RO_{beach}(A_{TSF} - A_{mean}) \quad (2)$$

where,

*$\Delta t$ is the time-step duration, [T];*

*$Q$ is net pumping that sums rates of slurry addition (solids and water), reclaimed water subtraction, and other mine-related components, [$L^3$/T];*

*$Q_{GW}$ is the groundwater-leakage rate, computed using $A_{mean}$ [$L^3$/T];*

*$A_{mean}$ is the pool area from averaging pool areas at the beginning and end of a time step [$L^2$],*

*$P$* is effective precipitation rate, where contributions from snow are tallied when snow melts rather than when snow accumulates, *[L/T]*;

*$E$* is evaporation rate, in *[L/T]*;

$P_{catch-thresh,i}$ is threshold precipitation rate of the $i^{th}$ catchment area at which runoff occurs, in *[L/T]*;

$RO_{catch,i}$ is precipitation runoff efficiency of the $i^{th}$ catchment, dimensionless;

$A_{catch,i}$ is surface area of the $i^{th}$ catchment, *[$L^2$];*

$P_{beach}$ is threshold precipitation rate of the beach at which runoff occurs, in *[L/T]*;

$RO_{beach}$ is precipitation runoff efficiency of the beach, dimensionless; and

$A_{beach}$ is surface area of the beach, *[$L^2$];*

TSFISM sums all time-series of mine-related inflows and outflows to compute net pumping. The user specifies time series of tailings-production rates [M/T], percent solids, and specific gravity for the computation of slurry water and slurry solids. Reclaim water and other managed flows to and from the TSF also are user-defined as separate time series. Precipitation (*P*), open-water evaporation (*E*), runoff coefficients ($RO_{catch,i}$), and catchment areas ($A_{catch,i}$) also are user-specified as time series. The measurement frequency of these user-defined times series can differ from the time-step frequency simulated by TSFISM.

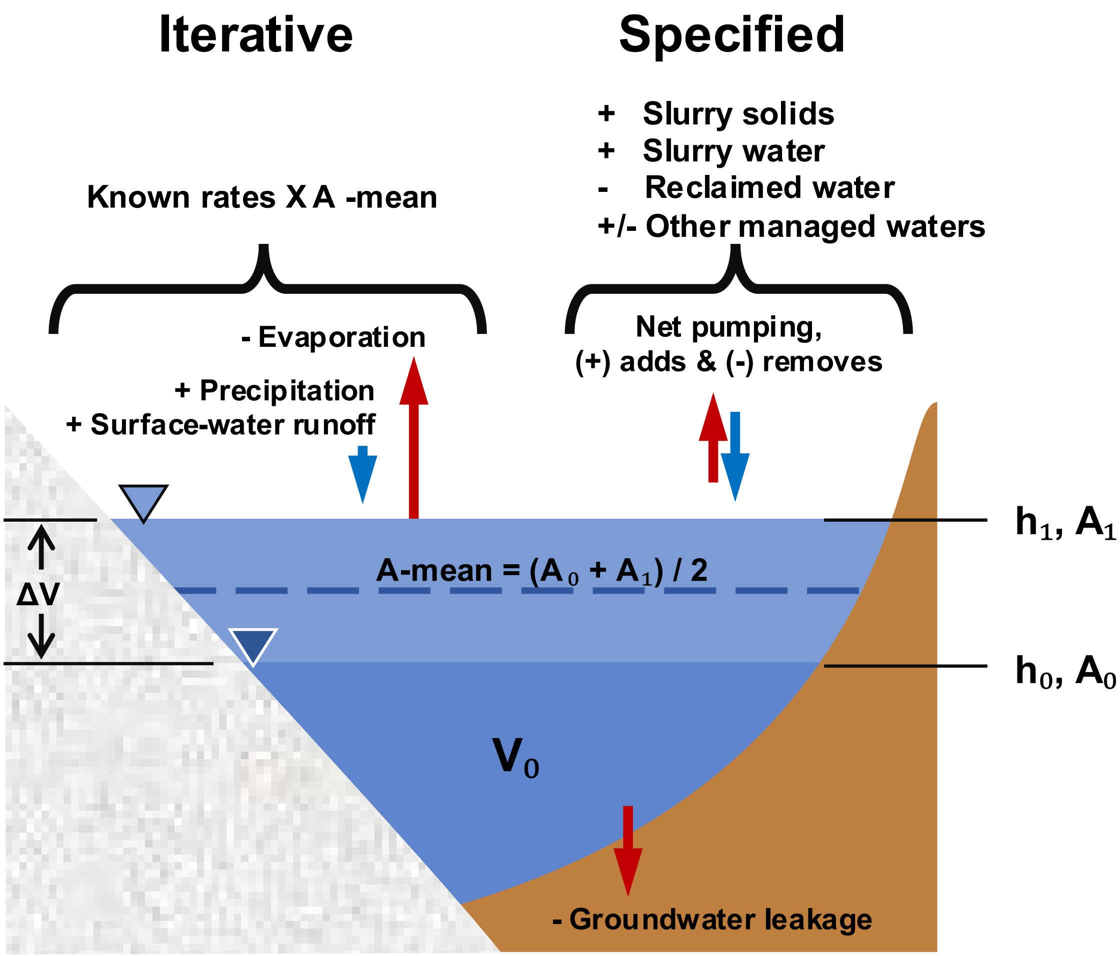



Figure 9.— Schematic of stresses, stage, area, and volume changes in water balance of TSF pool during a time step.

Groundwater leakage (*GW*) can be simulated with either hydraulic conductivity (L/T) or hydraulic conductance (1/T). Hydraulic conductivity is specified if sediments in the TSF are assumed to control leakage and *GW* is hydraulic conductivity (L/T) times a unit gradient (L/L). Hydraulic conductance is specified if pool-bottom sediments in the TSF are assumed to control leakage and *GW* is hydraulic conductance (1/T) times pool depth (L). Lined ponds with no groundwater leakage are simulated by specifying either hydraulic conductivity or hydraulic conductance as zero.

Changes during a time step are solved by initially assuming no change in pool stage so initial and final surface areas are the same during the first iteration. Surface area of the pool affects estimated precipitation, evaporation, groundwater leakage, and surface-water runoff during a time step. Change in pool volume, $\Delta V$, is solved with equation (2) and added to the existing pool volume, $V_0$ (Figure 9). Pool stage at the end of a time step, $h_1$, is interpolated from the user-defined SAV relation with the new volume, $V_0+\Delta V$. A revised pool area at the end of the time step, $A_1$, is interpolated from the SAV with the new pool stage $h_1$. This revises $A_{mean}$, which changes the climatic stresses in equation (2) and revises estimates of $\Delta V$ and $h_1$. This process is repeated until simulated pool stage converges on a single value at the end of the time step (Figure 10).

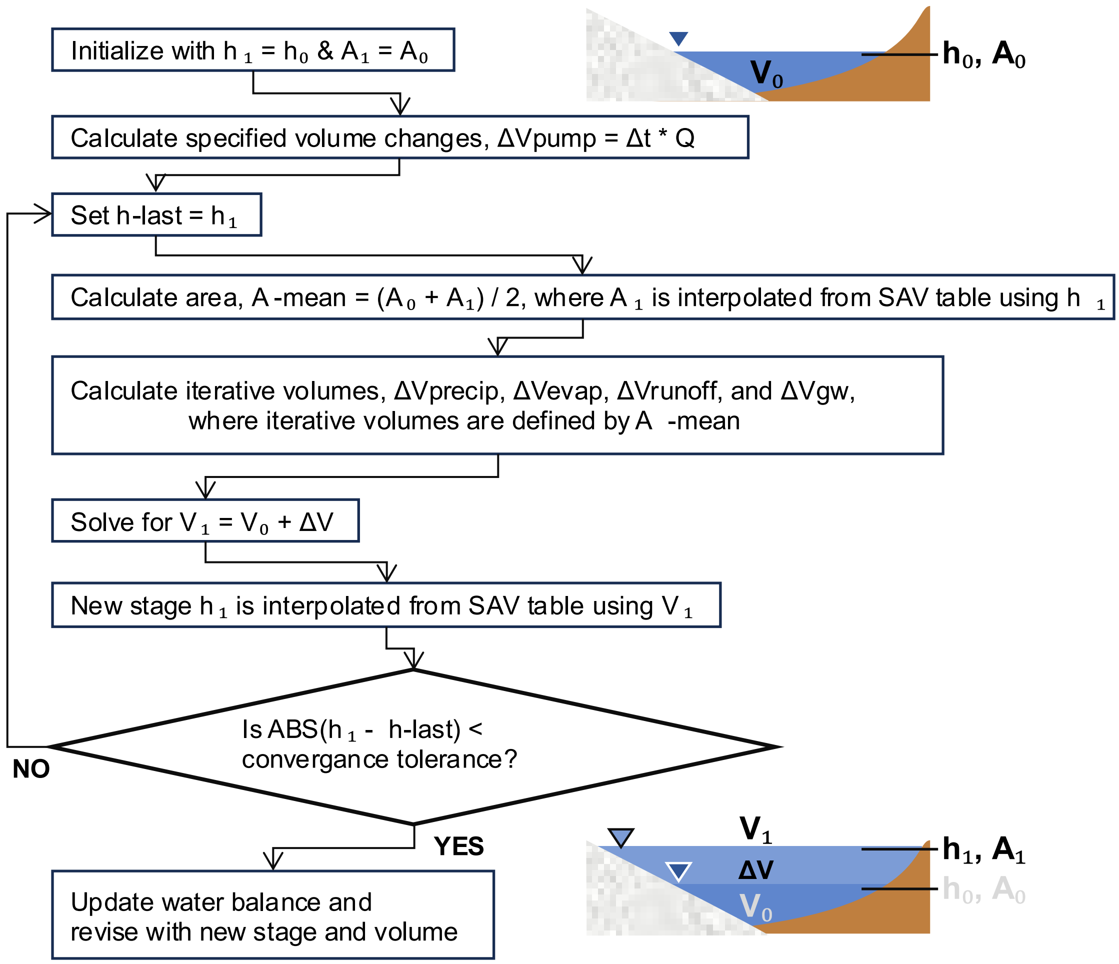



Figure 10.— Flow chart of iterative stage, area, and volume changes as water balance of TSF pool is solved during a time step.

The water balance is solved differently if TSF pool goes dry, which occurs when ΔV is negative, and the magnitude exceeds $V_0$ (Figure 10). ΔV initially is reduced by curtailing groundwater leakage (*GW*), but curtailment cannot exceed magnitude of groundwater leakage (*GW*). Magnitude of ΔV is reduced to equal $V_0$ by curtailing net pumping. Specified and simulated net pumping can differ when simulated TSF pool goes dry (Jackson, et.al., 2026).

Stage and volume changes in a time step are simulated with two periods when a time step straddles a bathymetric survey (Figure 11). The first period simulates stage and volume change from the beginning of the time step to the bathymetric survey using the previous SAV. The second period simulates change from the bathymetric survey to the end of the time step using the new SAV. Simulated sedimentation volume is computed at the bathymetric survey by differencing volumes from previous and new SAVs. This is the same method for estimating surveyed free-water volumes except sedimentation volumes are interpreted with simulated stages rather than surveyed pool stages (Figure 7).

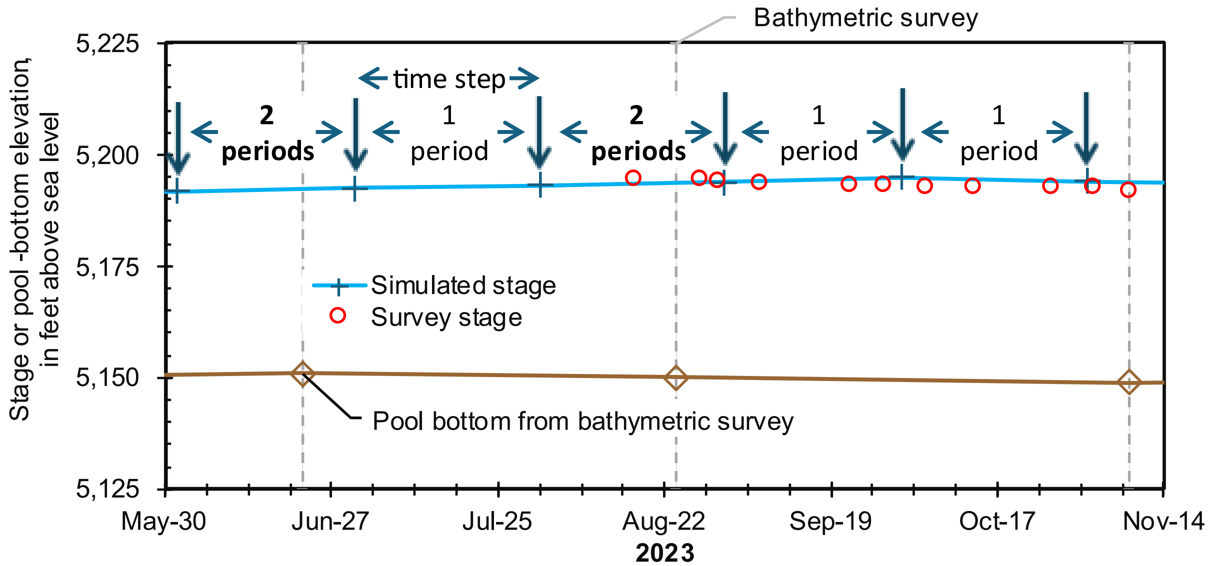



Figure 11.— Splitting time step into two periods when time step straddles a bathymetric survey.

Free-water volumes are simulated continuously by the TSFISM model with simulated stages. This is the same approach for interpreting free-water volumes from surveyed stages except with simulated stages instead (Figure 8). Simulated sedimentation volume is distributed proportionally to cumulative tailings production between bathymetric surveys. Simulated free-water volume equals simulated pool volume minus simulated sedimentation volume since the most recent bathymetric survey (Figure 8).

## Predicting TSF Operations

Predicting future TSF operations requires predicted rates of all water-balance inputs. Tailings production, reclaimed water, other managed waters, precipitation, evaporation, and surface-water runoff are readily forecast from operational plans and climate data. Changes in TSF pool geometry as measured with bathymetric surveys are more difficult to predict without additional analysis.

Measured pool-bottom elevations are correlated with cumulative tails production. Future pool-bottom elevations can be predicted from a regression between pool-bottom elevation and cumulative tails production that are tabulated for each bathymetric survey. For example, pool-bottom elevation increases 1 ft with each additional 819,000 tons of tailings (Figure 12), so adding 4.1 million tons of tails would be expected to raise the TSF pool 5.0 ft. A one-dimensional correlation between elevation and cumulative tails production works because surface area of a TSF changes minimally relative to vertical changes in a TSF (Figure 1; see “To scale”).

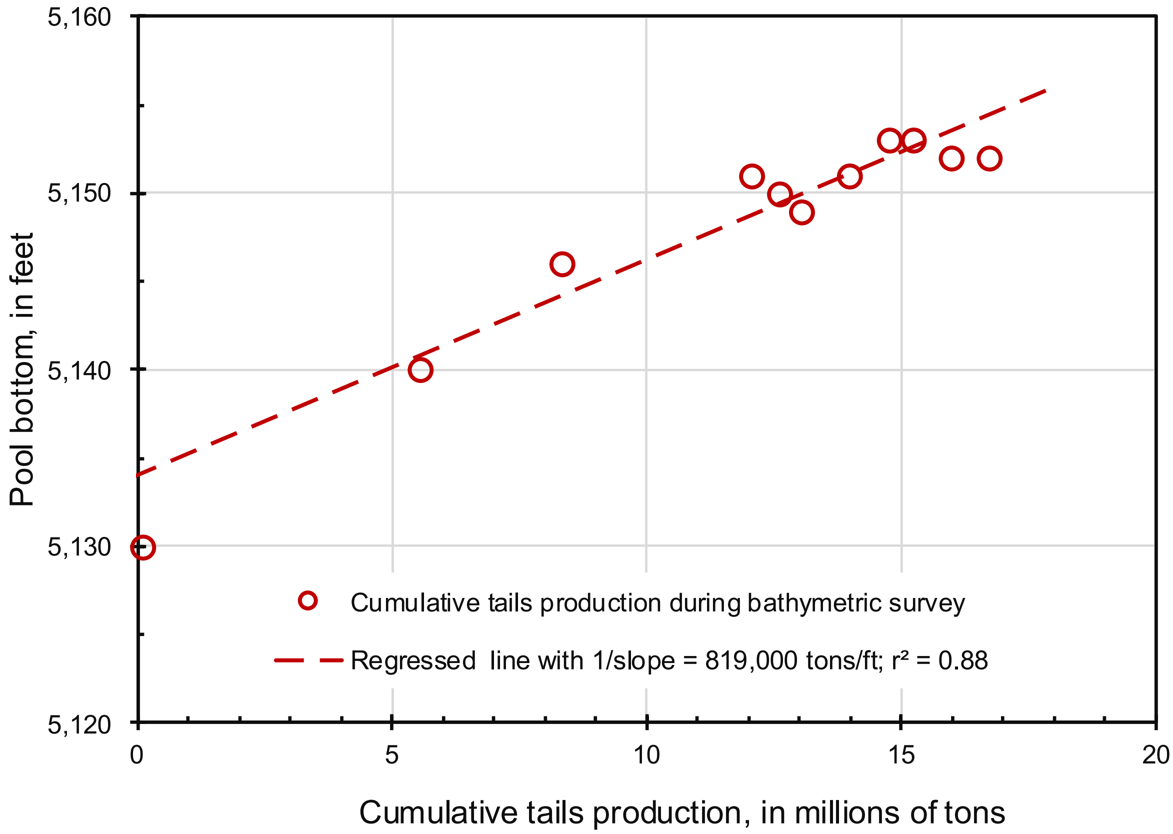



Figure 12.— Correlation between pool bottom elevation and cumulative tailings production.

Future bathymetry can be predicted by assuming historical deposition plans are representative and the pool is simply elevated as tailings are added to a TSF (Figure 13). Future SAV relations remain the same as the SAV from the last bathymetric survey, except stages are elevated. Pool-bottom elevations increase proportionally to forecasted tailings production. For example, an additional 6.8 and 14.3 million tons of tails were forecasted to be added by May 2027 and June 2029, respectively, after March 2025. This raised the forecasted SAV by 8.3 and 17.4 ft since the last bathymetric survey measured March 17, 2025 (Figure 13).

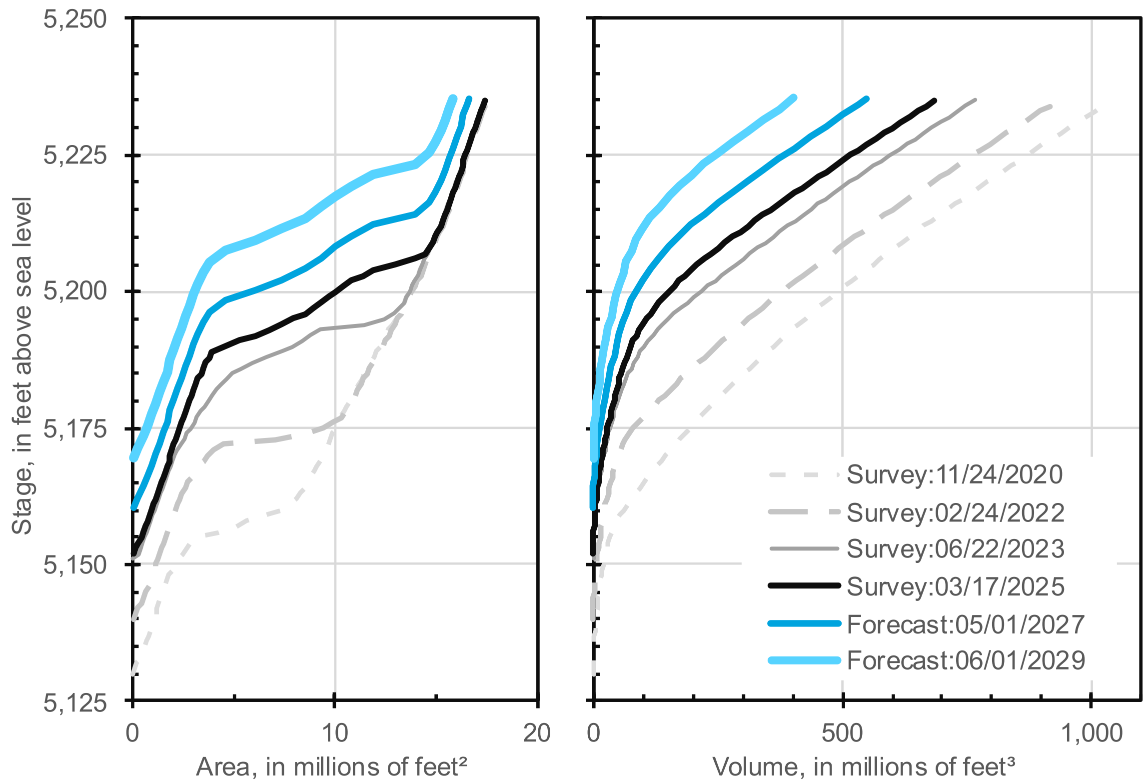



Figure 13.— Forecasted SAV relations from last bathymetric survey on 03/17/2025.

Future deposition plans can change from historical plans and alternative methods of estimating future bathymetries are needed. Future SAV relations can be estimated with other methods and added to existing series of surveyed SAV relations. Surveyed and externally predicted SAV relations are differentiated so that only measured pool-bottom elevations are correlated with cumulative tails production (Figure 12).

Both externally and internally predicted SAV relations can be used in a single simulation (Jackson, et.al., 2026). For example, surveyed, externally predicted, and internally predicted pool bottoms create a continuous pool-bottom elevation (Figure 14). Pool-bottom elevations are surveyed during the measured period. Externally predicted pool bottoms rise steeply in 2025 and 2026 and internally predicted SAV relations define the forecast pool bottom during the predicted period (Figure 14).

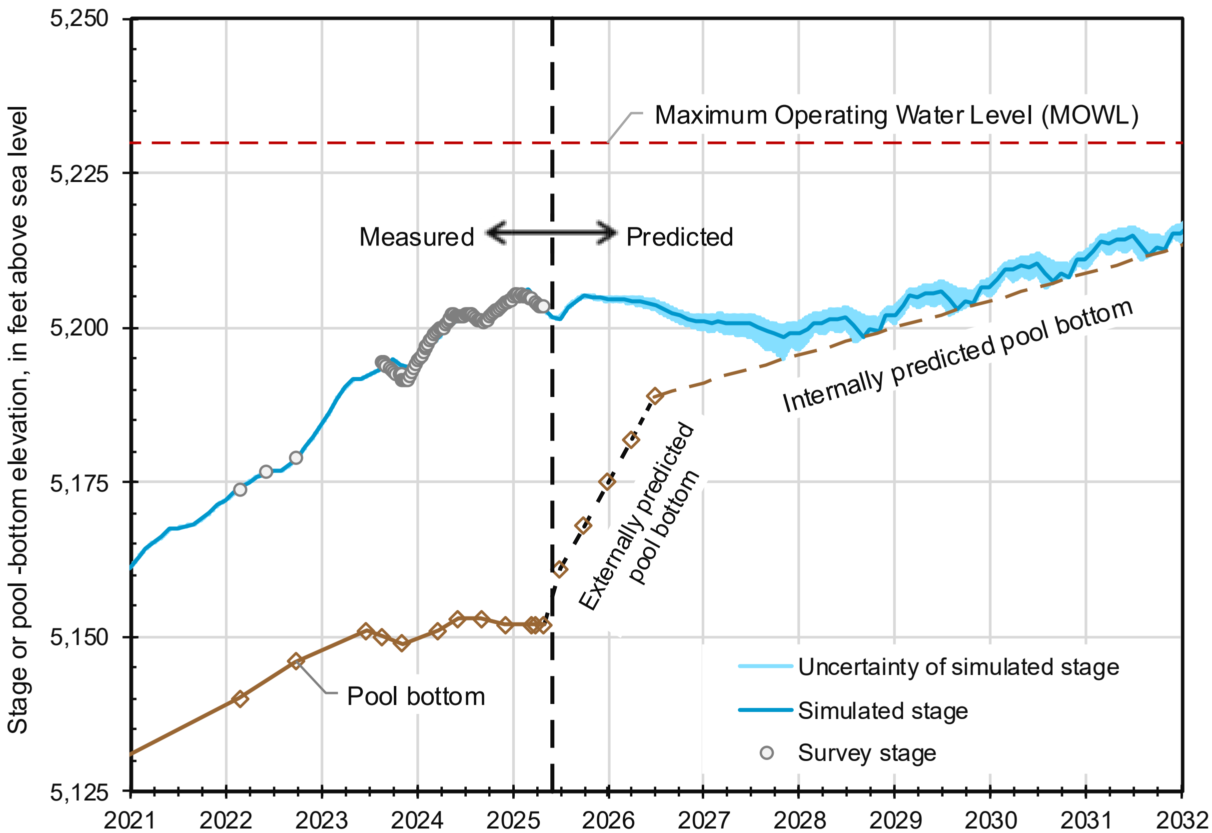



Figure 14.— Predicted TSF pool stage under uncertainty in forecasted precipitation.

Uncertainty in predicted pool stages and free-water volumes principally reflects uncertainty in precipitation forecasts. Annual precipitation can vary markedly between years (Figure 4), which affects TSF pool stages. Uncertainty of annual precipitation is estimated with the log-Pearson Type III distribution, which is used prevalently for flood-frequency analysis (Interagency Advisory Committee on Water Data, 1982; Gotvald et al., 2012; England et al., 2018). Uncertainty of annual precipitation usually is reported as a range where 90 or 95 percent confidence exists that annual precipitation during a given year will be within the estimated range.

Uncertainty in predicted pool stages and free-water volumes are estimated with alternative models that simulate minimum and maximum precipitation within a specified confidence interval. Predicted precipitation in these alternative models scales long-term monthly averages by the ratio of predicted to average annual volumes of precipitation. This approach preserves seasonal variations in precipitation, which can be significant. For example, annual precipitation averaged 13.3 inches (Figure 4). The 95-percent confidence interval of annual precipitation from this distribution ranged between 7.4 and 19.5 inches. Predicted pool stages depart less than 3 ft from the average simulated pool stage, where annual precipitation ranges between 7.4 and 19.5 inches (Figure 14). A similar range of uncertainty also is reported for free-water volumes.

## TSFISM workbook features

The workbook is composed of three groups of pages: TSFISM, local, and TRANSITION (Figure 15). TSFISM pages have a prescribed structure that should not be changed by the user. Local pages are structured and maintained by the user to record tailings production, percent solids, and flow rates of slurry, reclaimed water, and other managed waters (Figure 1). Local pages are supported in the TSFISM workbook to estimate net pumping (*Q* in eq. 2) and track cumulative tailings production for the water-balance model. TRANSITION is a single page for consistently passing data inputs from the local pages to the TSFISM water-balance model (Figure 15).

The TSFISM group consists of four visible pages, DATA, Survey, TRACK, and TSFISM, and two nominally hidden pages CONTROL and FAN (Figure 15). Time series of SAV relations from bathymetric surveys, maximum operating water levels, catchment characteristics, and precipitation, evaporation rates, and net pumping rates are specified on the DATA page. Surveyed stages are specified and interpreted pool areas, and free-water volumes are reported on the Survey page. Pool-bottom elevations and cumulative tailings production are reported and analyzed on the TRACK page. Simulated pool stages and free-water volumes are reported and analyzed on the TSFISM page. The hidden CONTROL page contains lookup tables, unit conversions, charting utilities, and water-balance model. The hidden FAN page is a template for reporting climatic uncertainty analyses. Both hidden pages should not be edited by users.

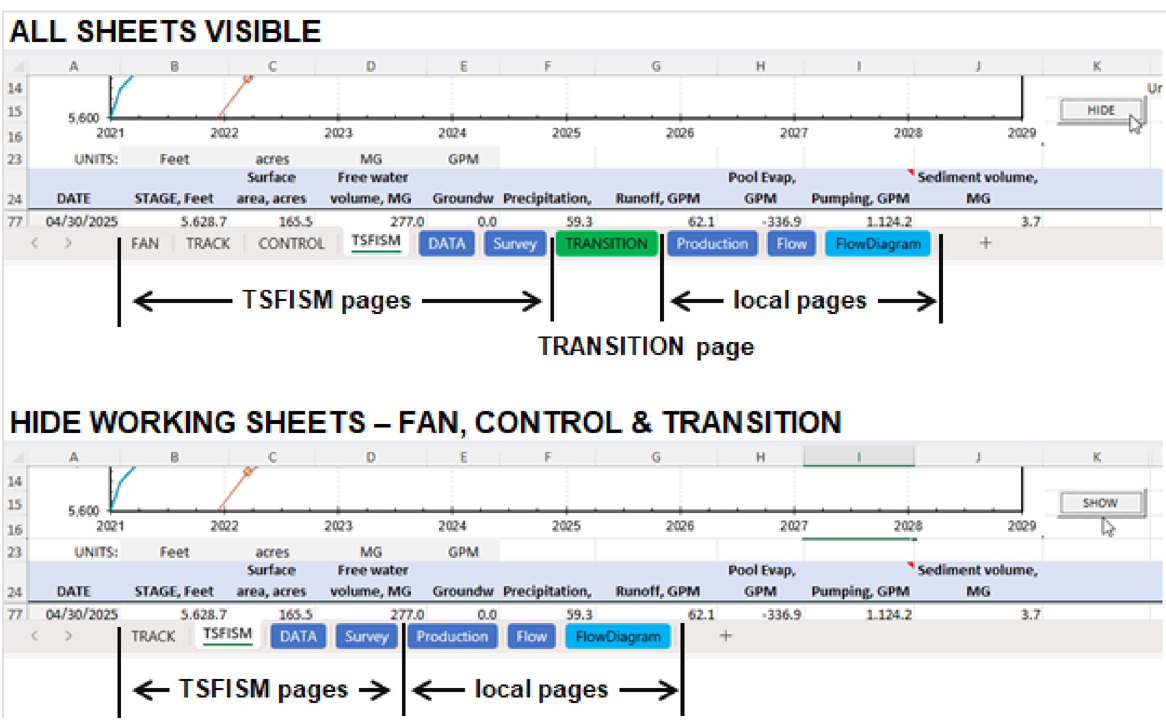



Figure 15.— TSFISM, TRANSITION, and local pages in TSFISM workbook with all worksheets visible and reduction when supporting worksheets are hidden.

Water balance of the TSF pool principally is analyzed from the TSFISM page (Figure 16). Surveyed and simulated stages can be compared and differences minimized by adjusting hydraulic conductivity/vertical leakance on the TSFISM page or groundwater leakage or the time series of *PoS* in the local pages. Surveyed and simulated stages also can be compared to significant references such as the pool bottom and freeboard (MOWL) (Figure 16). Surveyed and simulated free-water volumes also can be compared while minimizing differences (Figure 17; B).

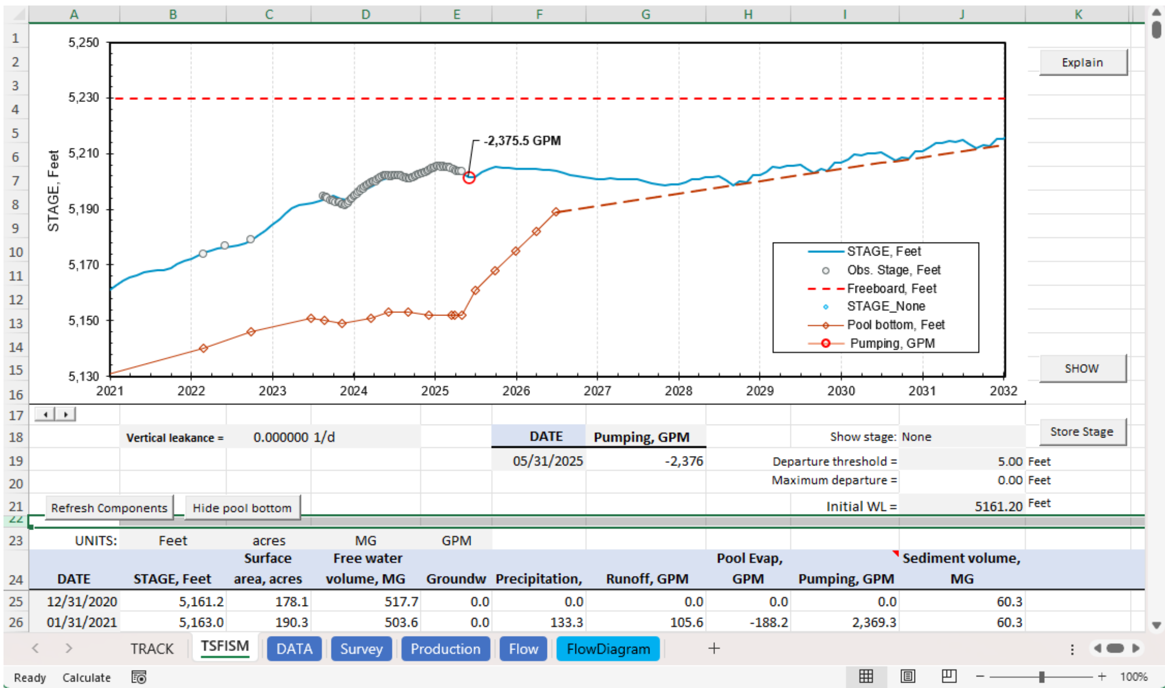



Figure 16.— Example of surveyed and simulated TSF-pool stages and pool-bottom elevations reported by TSFISM workbook.

Surveyed and simulated free-water volumes are displayed on a separate chart from surveyed and simulated stages on the TSFISM page (Figure 17). A third chart also exists that displays flow rates for each water-balance component by time step (Figure 17; C). Display areas of these three charts are maximized by being stacked on top of one another so that only one chart is visible at a time (Figure 16). Chart visibility is changed by a spin button (cell A17) that charts up or down in the stack.

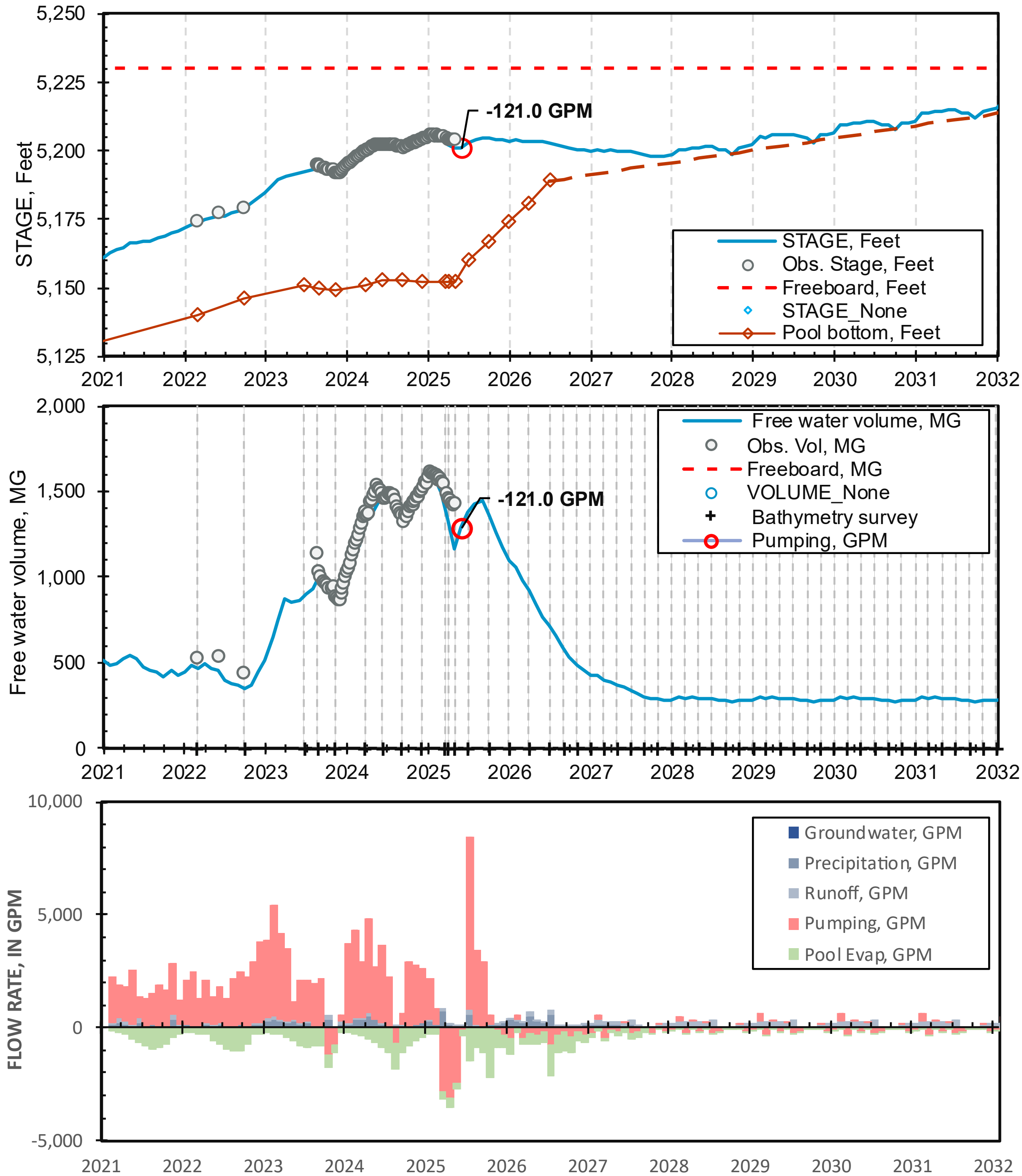
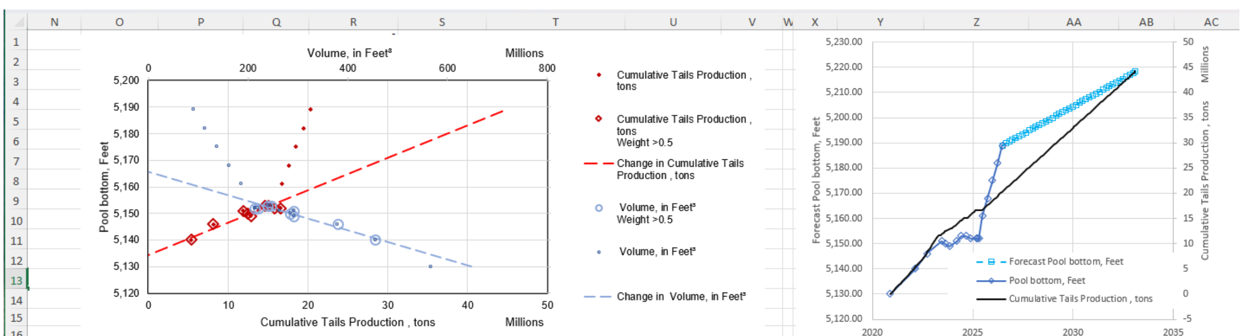



Figure 17.— Reporting of A.) surveyed and simulated TSF-pool stages and pool-bottom elevations, B.) surveyed and simulated free-water volumes, and C.) rates of flow components to and from TSF pool as reported by TSFISM workbook.

Measured pool-bottom elevations and cumulative tails production are synthesized on the TRACK page so that future pool-bottom elevations can be predicted (Figure 18). Macros reduce SAV relations from bathymetric surveys on the DATA page and return cumulative tails production from monthly tails production on the TRANSITION page. Time series of SAV relations are reduced to pool-bottom elevations and free-water volumes relative to a common maximum stage.

Regression between measured pool-bottom elevations and cumulative tails production is controlled by weighting observations (Figure 18). This allows pool-bottom elevations from outlying bathymetric surveys and externally forecasted SAV relations to be excluded. Regressing measured pool-bottom elevations against consistent free-water volumes allows for tailings density to be estimated. This provides an additional test of the plausibility of forecasted rate of pool-bottom elevation rise.

Future SAV relations are elevated with an empirically estimated rate of pool rise per mass of forecasted tailings production. These internally estimated SAV relations are appended to existing SAV relations from bathymetric surveys and external forecasts on the DATA page. These internally predicted SAV relations are differentiated from surveyed and externally predicted SAV relations.




| | | Feet³/Feet | tons/Feet | Density, pcf | | | |
|---|---|---|---|---|---|---|---|
| Pool bottom & Mass | | | | | | | |
| vey Maximum + freeboard = | 5,205.38 | Slope = | (18,161,797) | 817,658 | 90.04 | Maximum change in tailings = | 500,000 tons | Create internal SAV |
| Weight > 0.5 | | r² = | 0.9260 | 0.8782 | | Sample frequency= | 3 months |

| Weight | Date_PBmass | Pool bottom, Feet | Volume, in Feet³ | Cumulative Tails Production , tons | Cumulative Tails Production , tons Weight >0.5 | Volume, in Feet³ Weight >0.5 | Pool bottom, Feet | Date_Forecast | Forecast Cumulative Tails Production , tons | Forecast Pool bottom, Feet |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 11/24/2020 | 5,130.00 | 565,988,418 | -70,083 | -100 | -100 | 5,130.0 | 06/30/2026 | 20,315,649 | 5,189.00 |
| 1 | 02/24/2022 | 5,140.00 | 455,269,646 | 5,394,035 | 5,394,035 | 455,269,646 | 5,140.0 | 08/31/2026 | 20,915,649 | 5,189.73 |
| 1 | 09/26/2022 | 5,146.00 | 379,383,461 | 8,158,552 | 8,158,552 | 379,383,461 | 5,146.0 | 10/31/2026 | 21,515,649 | 5,190.47 |
| 1 | 06/22/2023 | 5,151.00 | 291,958,922 | 11,891,573 | 11,891,573 | 291,958,922 | 5,151.0 | 12/31/2026 | 22,115,649 | 5,191.20 |
| 1 | 08/24/2023 | 5,150.00 | 284,686,974 | 12,443,083 | 12,443,083 | 284,686,974 | 5,150.0 | 02/28/2027 | 22,715,649 | 5,191.94 |
| 1 | 11/08/2023 | 5,149.00 | 291,543,665 | 12,877,653 | 12,877,653 | 291,543,665 | 5,149.0 | 04/30/2027 | 23,315,649 | 5,192.67 |
| 0 | 03/21/2024 | 5,151.00 | 262,825,125 | 13,830,219 | -100 | -100 | 5,151.0 | 06/30/2027 | 23,915,649 | 5,193.40 |
| 1 | 06/08/2024 | 5,153.00 | 245,544,849 | 14,589,619 | 14,589,619 | 245,544,849 | 5,153.0 | 08/31/2027 | 24,515,649 | 5,194.14 |
| 1 | 09/04/2024 | 5,153.00 | 239,852,392 | 15,070,533 | 15,070,533 | 239,852,392 | 5,153.0 | 10/31/2027 | 25,115,649 | 5,194.87 |
| 1 | 12/03/2024 | 5,152.00 | 219,501,909 | 15,803,591 | 15,803,591 | 219,501,909 | 5,152.0 | 12/31/2027 | 25,715,649 | 5,195.60 |
| 1 | 03/17/2025 | 5,152.00 | 213,341,296 | 16,565,649 | 16,565,649 | 213,341,296 | 5,152.0 | 02/29/2028 | 26,315,649 | 5,196.34 |
| 0 | 04/01/2025 | 5,152.00 | 213,691,380 | 16,565,649 | -100 | -100 | 5,152.0 | 04/30/2028 | 26,915,649 | 5,197.07 |
| 0 | 05/01/2025 | 5,152.00 | 213,691,380 | 16,565,649 | -100 | -100 | 5,152.0 | 06/30/2028 | 27,515,649 | 5,197.81 |
| 0 | 06/30/2025 | 5,161.00 | 185,796,003 | 16,715,649 | -100 | -100 | 5,161.0 | 08/31/2028 | 28,115,649 | 5,198.54 |
| 0 | 09/30/2025 | 5,168.00 | 161,661,080 | 17,615,649 | -100 | -100 | 5,168.0 | 10/31/2028 | 28,715,649 | 5,199.27 |
| 0 | 12/31/2025 | 5,175.00 | 137,526,157 | 18,515,649 | -100 | -100 | 5,175.0 | 12/31/2028 | 29,315,649 | 5,200.01 |
| 0 | 03/31/2026 | 5,182.00 | 113,915,906 | 19,415,649 | -100 | -100 | 5,182.0 | 02/28/2029 | 29,915,649 | 5,200.74 |

TRACK TSFISM DATA Survey Production Flow FlowDiagram

Figure 18.— Pool-bottom elevation, cumulative tailings production, and free-water volume used for regressions and time series on TRACK page.

Macros were developed in Microsoft Excel® 365 and are not backward compatible to earlier versions of Excel. This is because user-defined functions use previously unavailable SPILL functionality to return two-dimensional arrays.

### VBA macros & Trust Center

More macro functions default to being disabled through either Microsoft updates or IT departments engaging in their natural function. Please check your Trust Center settings.

Zip file can be downloaded with the following link
https://halfordhydrology.com/tsfism

The file TSFISM.v12.zip contains,

- ***TSFISM.v12.xlsm*** – Workbook with TSFISM model;
- ***FullRainfall-StormAnalysis.xlsx*** – Example of annual precipitation analysis to estimate range of predicted pool stages and volumes in a tailings-storage facility; and
- **TSFISM-EXPLAIN.v12.pdf** – Explanatory document.

### Revisions

March 31, 2026—Revisions through version 10 comprise initial release.

April 17, 2026— Revisions in version 11 include the following. Corrected errors in function ***vShiftLastRESID*** that failed where simulation period less than SAV frequency. Corrected error in catchment-runoff table, where only last row was used instead of all rows for a given time. Cleaned excess cell styles that were introduced accidentally to the TSFISM example/template.

May 18, 2026— Revisions in version 12 include the following. Corrected conversion errors for freeboard and pool elevations. Revised suggested citation to published article.

### Suggested Citation

Jackson, T.R., Halford, K.J. & Zhan, G., 2026, Tailings Storage Facility Iterative Simulation Model (TSFISM): A Dynamic Simulator, Mine Water and the Environment, https://doi.org/10.1007/s10230-026-01124-w

or

Halford, Keith, 2026, TSFISM–An Excel workbook for simulating the water balance of a tailings-storage facility, version 12, Halford Hydrology LLC web page, accessed May 2026, at https://halfordhydrology.com/tsfism/

## *References*

England, J.F., Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas, W.O., Jr., Veilleux, A.G., Kiang, J.E., and Mason, R.R., Jr., 2018, Guidelines for determining flood flow frequency — Bulletin 17C (ver. 1.1, May 2019): U.S. Geological Survey Techniques and Methods, book 4, chap. B5, 148 p., https://doi.org/10.3133/tm4B5

Fontaine, R.C., A. 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

Gotvald, A.J., Barth, N.A., Veilleux, A.G., and Parrett, C., 2012, Methods for determining magnitude and frequency of floods in California, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2012–5113, 38 p., 1 pl., https://doi.org/10.3133/sir20125113

Halford, K., 2025, Analytical_PLISM–An Excel workbook for simulating water balance of a pit lake, version 5, Halford Hydrology LLC web page, accessed March 2025, at https://halfordhydrology.com/plism/

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: Hydrology Subcommittee Bulletin 17B, 28 p., 14 app., 1 pl. https://water.usgs.gov/osw/bulletin17b/dl_flow.pdf

Jackson, T.R., Halford, K.J. & Zhan, G., 2026, Tailings Storage Facility Iterative Simulation Model (TSFISM): A Dynamic Simulator, Mine Water and the Environment, https://doi.org/10.1007/s10230-026-01124-w

Vermeulen, N.J., 2001, The Composition and State of Gold Tailings: University of Pretoria Doctoral Thesis, 441 p. http://hdl.handle.net/2263/23079

# TSFISM.v12.xlsm Workbook

The TSFISM group consists of four visible pages, DATA, Survey, TRACK, and TSFISM, and two nominally hidden pages CONTROL and FAN (Figure 15). Time series of SAV relations from bathymetric surveys, maximum operating water levels, catchment characteristics, and precipitation, evaporation rates, and net pumping rates are specified on the DATA page. Surveyed stages are specified and interpreted pool areas, and free-water volumes are reported on the Survey page. Pool-bottom elevations and cumulative tailings production are reported and analyzed on the TRACK page. Simulated pool stages and free-water volumes are reported and analyzed on the TSFISM page. The hidden CONTROL page contains lookup tables, unit conversions, charting utilities, and water-balance model. The hidden FAN page is a template for reporting climatic uncertainty analyses. Both hidden pages should not be edited by users. Site-specific production data in the local pages are connected with the TSFISM model through the TRANSITION page (Figure 15).

## *DATA page*

Time series of SAV relations of TSF pool are specified in columns A-E from row 20 down (Figure 19). Survey dates are specified in column A. Stage, surface area, and volume during each survey are specified from lowest to highest altitudes. Each SAV relation is flagged as survey, external predicted, or internal predicted in column E for analysis of pool-bottom elevations and revising internal predictions. Freeboard (MOWL) elevations are specified as a time series in columns G-H from row 20 down (Figure 19). TSF catchment area, runoff percentage, and precipitation threshold are specified as a time series in columns J-N from row 20 down (Figure 19). Precipitation and evaporation are specified as accumulated as lengths (volume per unit area) between dates in columns P-R from row 20 down (Figure 19). Net pumping rates from TSF pool as volumetric rates are supplied by equations linked to TRANSITION page in columns U-V from row 20 down (Figure 19). Monthly estimates of long-term average precipitation and evaporation lengths are specified in columns Z-AA from row 20 down (Figure 19).

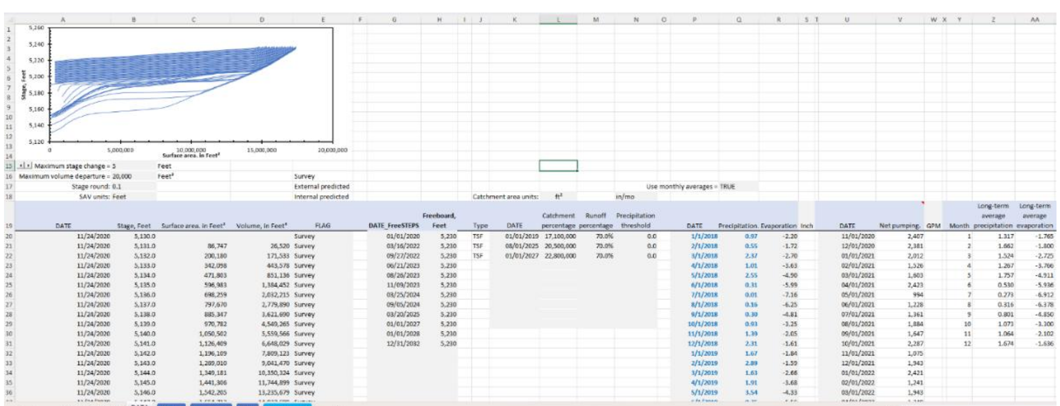


Figure 19.— DATA page in the TSFISM workbook where time series of stage-area-volume (SAV) relations, freeboard elevations, catchment characteristics, precipitation and evaporation lengths, net pumping, and long-term average precipitation and evaporation lengths are specified.

***Data Page***

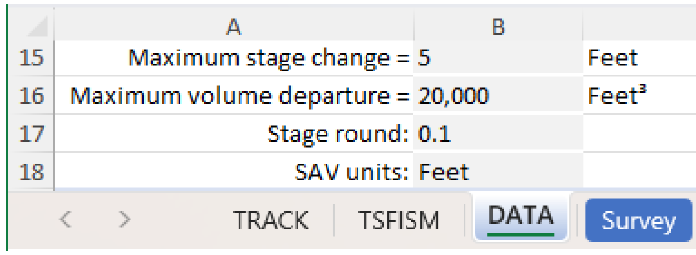
Consistent SAV tables on CONTROL page are reduced from DATA page.

Each SAV relation is reduced so,

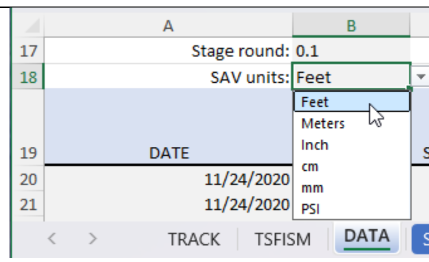
Subsequent stages do not differ by greater than “maximum stage change”, cell B15.

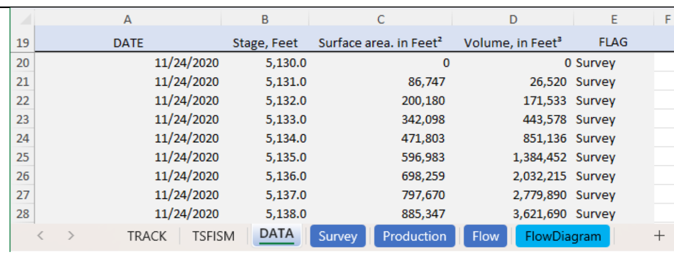
Linear volume change in reduced SAV relation does not differ from original by greater than “maximum volume departure”, cell B16.

Minimum difference between stages specified by “stage round”, cell B17.




Specify units for input length, cell B18



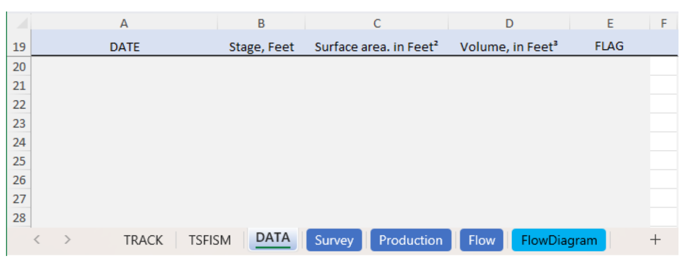



| | A | B | C | D | E |
|---|---|---|---|---|---|
| 19 | DATE | Stage, Feet | Surface area. in Feet² | Volume, in Feet³ | FLAG |
| 20 | 11/24/2020 | 5,130.0 | 0 | 0 | Survey |
| 21 | 11/24/2020 | 5,131.0 | 86,747 | 26,520 | Survey |
| 22 | 11/24/2020 | 5,132.0 | 200,180 | 171,533 | Survey |
| 23 | 11/24/2020 | 5,133.0 | 342,098 | 443,578 | Survey |
| 24 | 11/24/2020 | 5,134.0 | 471,803 | 851,136 | Survey |
| 25 | 11/24/2020 | 5,135.0 | 596,983 | 1,384,452 | Survey |
| 26 | 11/24/2020 | 5,136.0 | 698,259 | 2,032,215 | Survey |
| 27 | 11/24/2020 | 5,137.0 | 797,670 | 2,779,890 | Survey |
| 28 | 11/24/2020 | 5,138.0 | 885,347 | 3,621,690 | Survey |



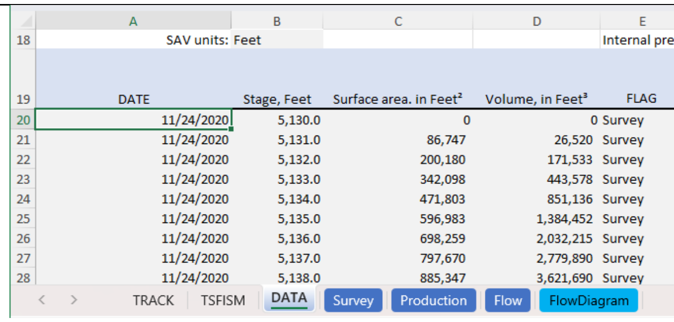
Clear existing data between columns A and E from row 20 to the last entry.

Empty cells before adding your data.



Paste survey date, stage, surface area, volume, and flag data, cell A20.

Paste as values better approach.



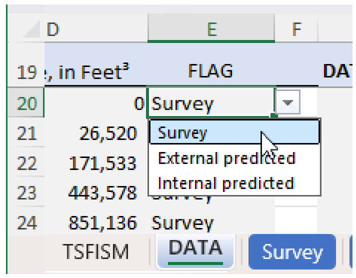
| | A | B | C | D | E |
|---|---|---|---|---|---|
| 18 | SAV units: | Feet | | | Internal pred |
| 19 | DATE | Stage, Feet | Surface area. in Feet² | Volume, in Feet³ | FLAG |
| 20 | 11/24/2020 | 5,130.0 | 0 | 0 | Survey |
| 21 | 11/24/2020 | 5,131.0 | 86,747 | 26,520 | Survey |
| 22 | 11/24/2020 | 5,132.0 | 200,180 | 171,533 | Survey |
| 23 | 11/24/2020 | 5,133.0 | 342,098 | 443,578 | Survey |
| 24 | 11/24/2020 | 5,134.0 | 471,803 | 851,136 | Survey |
| 25 | 11/24/2020 | 5,135.0 | 596,983 | 1,384,452 | Survey |
| 26 | 11/24/2020 | 5,136.0 | 698,259 | 2,032,215 | Survey |
| 27 | 11/24/2020 | 5,137.0 | 797,670 | 2,779,890 | Survey |
| 28 | 11/24/2020 | 5,138.0 | 885,347 | 3,621,690 | Survey |



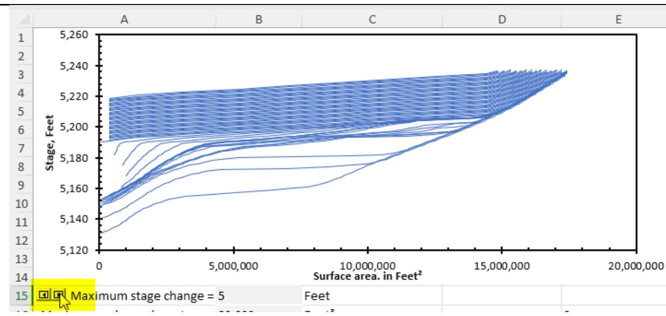
Flags in column E are,

– Survey,
– External predicted, or
– Internal predicted.

Internal predicted rows are deleted and recreated by macros on TRACK page.

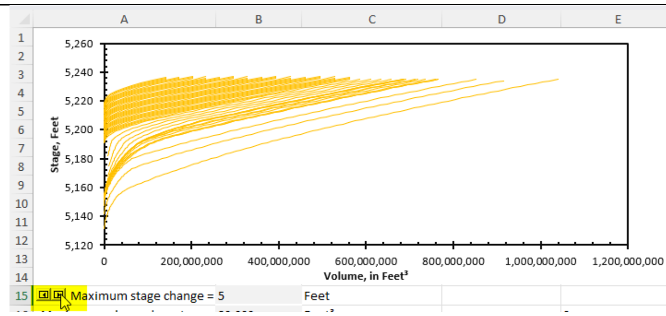



View stage-area relations in chart in upper, left corner of DATA page.




Click spin button (A15) to change chart.

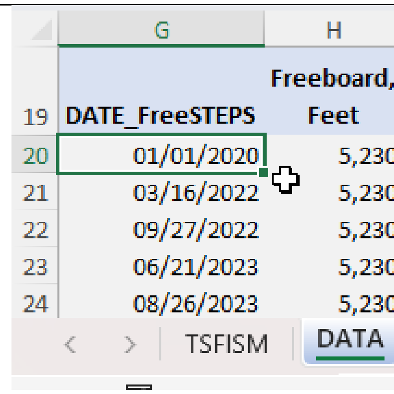
Toggle between stage-area & stage-volume charts in upper, left corner of DATA page.



Time series of freeboard (MOWL) elevations, columns G and H.

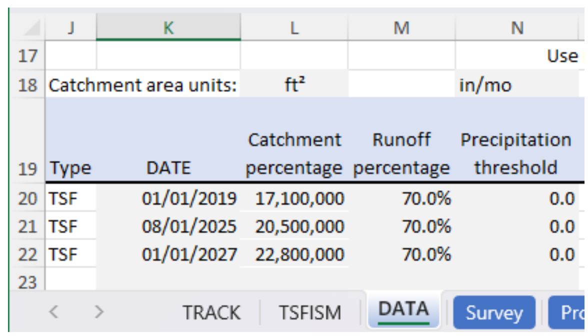
Paste date and freeboard elevation, cell G20.

Freeboard elevation is a time series because free-water volumes can differ even if freeboard elevation is a constant.

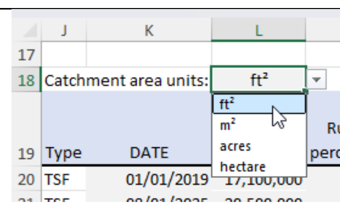



Catchment characteristics are specified in columns J-N from row 20 to the last entry.

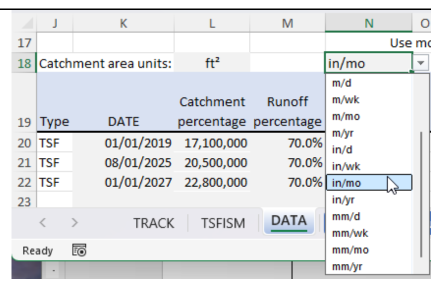
– Sub-area name in column J,
– Start date for sub-area characteristics in column K,
– Catchment area in input units (L18) in column L,
– Runoff percentage in column M, &
– Precipitation threshold rate in input units (N18) in column N.




Specify input units of catchment area, cell L18.

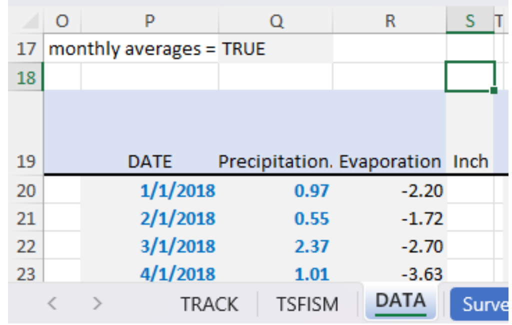



Specify input units of precipitation threshold rate, cell N18.

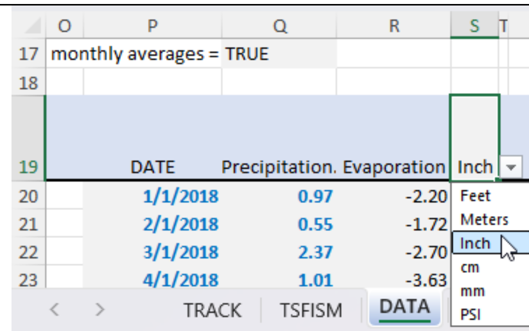


Paste date, precipitation, and evaporation data in cell P20, where precipitation and evaporation are lengths between dates in column P.

Predicted precipitation will be replaced with long-term averages if monthly averages = TRUE, cell Q17.

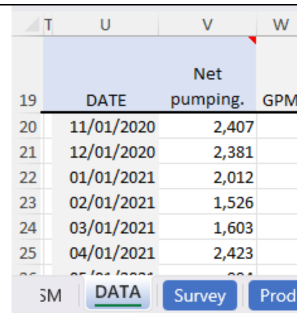



Specify units for precipitation and evaporation lengths in cell S19.




Dates and net pumping, columns U-V, are handled differently.

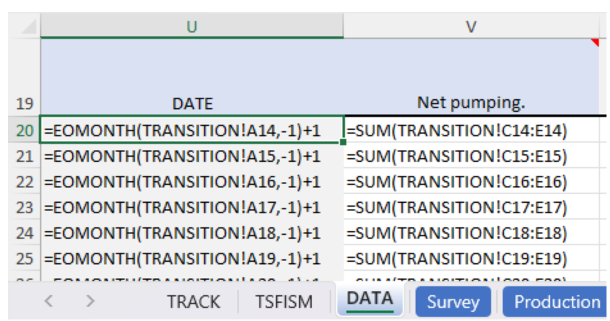
Entries in columns U-V from row 20 and below are equations that reduce data from the TRANSITION page.

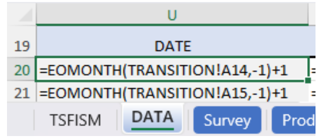


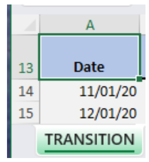

Equations in column U ensure dates follow Excel notation, where a value in adjacent column V applies from this time until the next time in the following row.

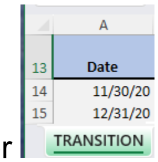
Equations in column V sum multiple managed flows specified on TRANSITION page.

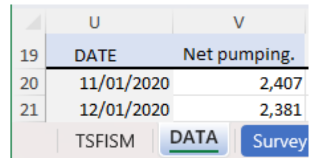
Positive (+) values add solids and water, while negative (-) values remove water.

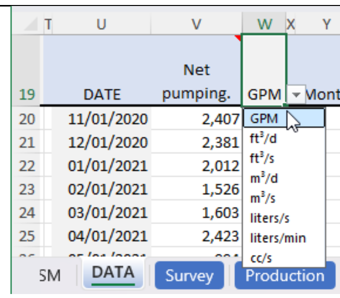


<table>
<tr>
<td>Transforming dates in column U is necessary so all tables in the TSFISM group of pages use Excel notation.<br><br>Production data frequently is reported for the end of month (EoM) and dates can be either beginning of month or EoM on the TRANSITION page.<br><br>Suggested equation in U20 handles ambiguity on TRANSITION page and consistently shifts dates in tables to Excel notation.</td>
<td>


<br>Consistent shift to Excel notation on DATA page<br>


or


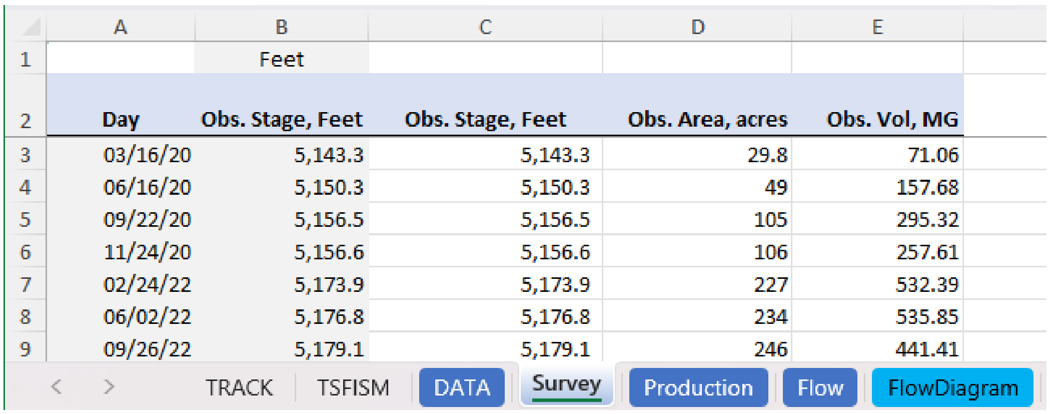
>


</td>
</tr>
<tr>
<td>Specify volumetric rates of net pumping, cell W19.</td>
<td>


</td>
</tr>
<tr>
<td>Monthly lengths of long-term, average precipitation and evaporation are specified in range Z20:AA31.<br><br>Monthly lengths are in units that were specified in cell S19.</td>
<td>
<table>
<tr><th></th><th>Y</th><th>Z</th><th>AA</th></tr>
<tr><td>19</td><td>Month</td><td>Long-term average precipitation</td><td>Long-term average evaporation</td></tr>
<tr><td>20</td><td>1</td><td>1.317</td><td>-1.765</td></tr>
<tr><td>21</td><td>2</td><td>1.662</td><td>-1.800</td></tr>
<tr><td>22</td><td>3</td><td>1.524</td><td>-2.725</td></tr>
<tr><td>23</td><td>4</td><td>1.267</td><td>-3.766</td></tr>
<tr><td>24</td><td>5</td><td>1.757</td><td>-4.911</td></tr>
<tr><td>25</td><td>6</td><td>0.530</td><td>-5.936</td></tr>
<tr><td>26</td><td>7</td><td>0.273</td><td>-6.912</td></tr>
<tr><td>27</td><td>8</td><td>0.316</td><td>-6.378</td></tr>
<tr><td>28</td><td>9</td><td>0.801</td><td>-4.850</td></tr>
<tr><td>29</td><td>10</td><td>1.073</td><td>-3.300</td></tr>
<tr><td>30</td><td>11</td><td>1.064</td><td>-2.102</td></tr>
<tr><td>31</td><td>12</td><td>1.674</td><td>-1.636</td></tr>
</table>
DATA | Survey | Production
</td>
</tr>
</table>

## *SURVEY page*

Surveyed stages of TSF pool are specified in columns A-B on SURVEY page (Figure 20). Observed stage, surface area, and free-water volume are returned in reporting units.

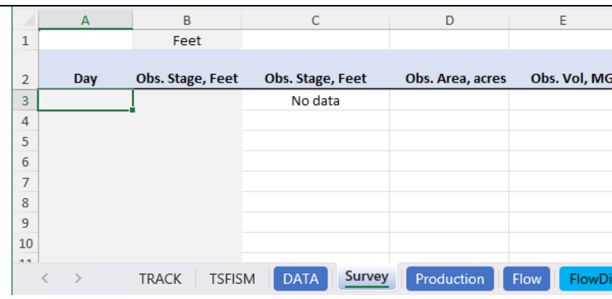
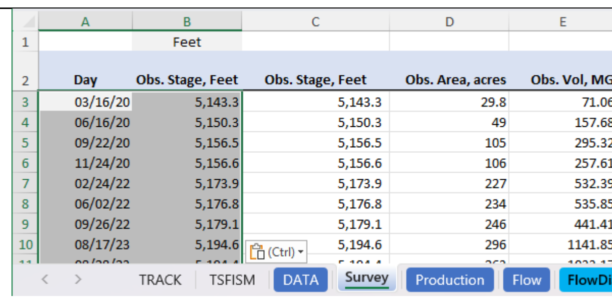
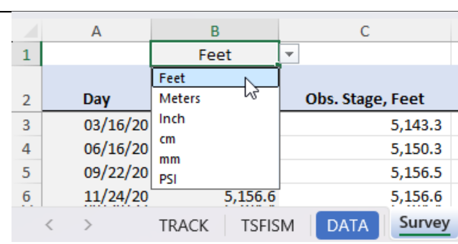


| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | | Feet | | | |
| 2 | Day | Obs. Stage, Feet | Obs. Stage, Feet | Obs. Area, acres | Obs. Vol, MG |
| 3 | 03/16/20 | 5,143.3 | 5,143.3 | 29.8 | 71.06 |
| 4 | 06/16/20 | 5,150.3 | 5,150.3 | 49 | 157.68 |
| 5 | 09/22/20 | 5,156.5 | 5,156.5 | 105 | 295.32 |
| 6 | 11/24/20 | 5,156.6 | 5,156.6 | 106 | 257.61 |
| 7 | 02/24/22 | 5,173.9 | 5,173.9 | 227 | 532.39 |
| 8 | 06/02/22 | 5,176.8 | 5,176.8 | 234 | 535.85 |
| 9 | 09/26/22 | 5,179.1 | 5,179.1 | 246 | 441.41 |



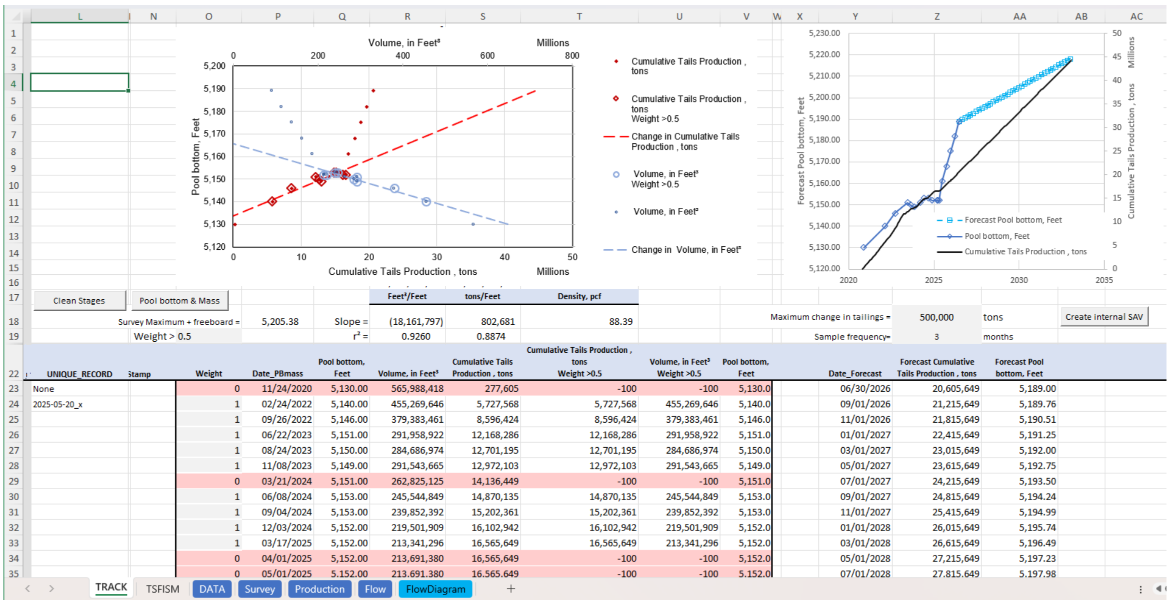
Figure 20.— SURVEY page in the TSFISM workbook where time series of surveyed stage are specified and observed stage, area, and free-water volume are returned in reporting units as specified on TSFISM page.

***Survey Page***

| | |
|---|---|
| Clear existing data in columns A-B from row 3 to the last entry.<br><br>Computed observed stage, area, and free-water volume are returned in reporting units are replaced with “No data”, cell C3. |  |
| Paste dates and surveyed stages, cell A3.<br><br>Observed stage, surface area, and free-water volume appear in reporting units will appear. |  |
| Specify input units of surveyed stages, cell B1. |  |

## *TRACK page*

Measured pool-bottom elevations and cumulative tails production are synthesized on the TRACK page so that future pool-bottom elevations can be predicted (Figure 21). Regression between measured pool-bottom elevations and cumulative tails production is evaluated as weights are changed in column O. Density of tailings also are estimated from free-water volumes and cumulative tails production. SAV relations are managed and projected with forecasted tailings production.




| | Feet³/Feet | tons/Feet | Density, pcf |
|---|---|---|---|
| Survey Maximum + freeboard = 5,205.38 Slope = | (18,161,797) | 802,681 | 88.39 |
| Weight > 0.5 r² = | 0.9260 | 0.8874 | |

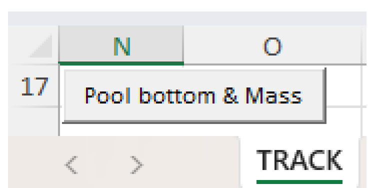
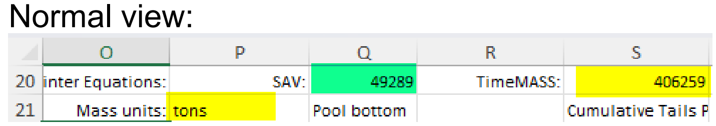
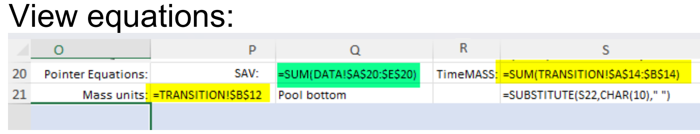
Maximum change in tailings = 500,000 tons

Sample frequency= 3 months

| UNIQUE_RECORD | Stamp | Weight | Date_PBmass | Pool bottom, Feet | Volume, in Feet³ | Cumulative Tails Production , tons | Cumulative Tails Production , tons Weight >0.5 | Volume, in Feet³ Weight >0.5 | Pool bottom, Feet | Date_Forecast | Forecast Cumulative Tails Production , tons | Forecast Pool bottom, Feet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| None | | 0 | 11/24/2020 | 5,130.00 | 565,988,418 | 277,605 | -100 | -100 | 5,130.0 | 06/30/2026 | 20,605,649 | 5,189.00 |
| 2025-05-20_x | | 1 | 02/24/2022 | 5,140.00 | 455,269,646 | 5,727,568 | 5,727,568 | 455,269,646 | 5,140.0 | 09/01/2026 | 21,215,649 | 5,189.76 |
| | | 1 | 09/26/2022 | 5,146.00 | 379,383,461 | 8,596,424 | 8,596,424 | 379,383,461 | 5,146.0 | 11/01/2026 | 21,815,649 | 5,190.51 |
| | | 1 | 06/22/2023 | 5,151.00 | 291,958,922 | 12,168,286 | 12,168,286 | 291,958,922 | 5,151.0 | 01/01/2027 | 22,415,649 | 5,191.25 |
| | | 1 | 08/24/2023 | 5,150.00 | 284,686,974 | 12,701,195 | 12,701,195 | 284,686,974 | 5,150.0 | 03/01/2027 | 23,015,649 | 5,192.00 |
| | | 1 | 11/08/2023 | 5,149.00 | 291,543,665 | 12,972,103 | 12,972,103 | 291,543,665 | 5,149.0 | 05/01/2027 | 23,615,649 | 5,192.75 |
| | | 0 | 03/21/2024 | 5,151.00 | 262,825,125 | 14,136,449 | -100 | -100 | 5,151.0 | 07/01/2027 | 24,215,649 | 5,193.50 |
| | | 1 | 06/08/2024 | 5,153.00 | 245,544,849 | 14,870,135 | 14,870,135 | 245,544,849 | 5,153.0 | 09/01/2027 | 24,815,649 | 5,194.24 |
| | | 1 | 09/04/2024 | 5,153.00 | 239,852,392 | 15,202,361 | 15,202,361 | 239,852,392 | 5,153.0 | 11/01/2027 | 25,415,649 | 5,194.99 |
| | | 1 | 12/03/2024 | 5,152.00 | 219,501,909 | 16,102,942 | 16,102,942 | 219,501,909 | 5,152.0 | 01/01/2028 | 26,015,649 | 5,195.74 |
| | | 1 | 03/17/2025 | 5,152.00 | 213,341,296 | 16,565,649 | 16,565,649 | 213,341,296 | 5,152.0 | 03/01/2028 | 26,615,649 | 5,196.49 |
| | | 0 | 04/01/2025 | 5,152.00 | 213,691,380 | 16,565,649 | -100 | -100 | 5,152.0 | 05/01/2028 | 27,215,649 | 5,197.23 |
| | | 0 | 05/01/2025 | 5,152.00 | 213,691,380 | 16,565,649 | -100 | -100 | 5,152.0 | 07/01/2028 | 27,815,649 | 5,197.98 |

Figure 21.— Regression between measured pool-bottom elevations and cumulative tails production and projected pool-bottom elevations on TRACK page.

### *TRACK Page –Regression for pool-bottom rise rate*

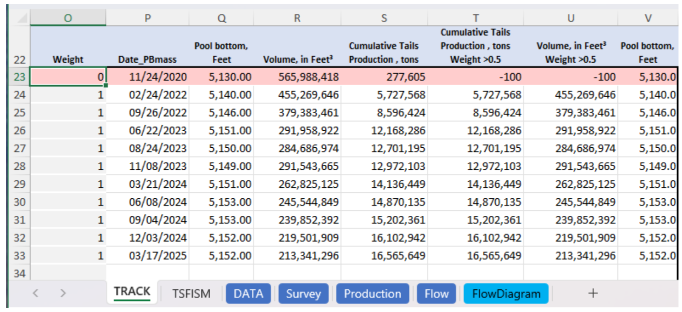
<table>
<tr>
<td>Press “Pool bottom & Mass” button, cell N17 to rebuild table of pool-bottom elevations and cumulative tails production during bathymetric surveys and retrieve time series of cumulative tails production.</td>
<td>
</td>
</tr>
<tr>
<td>Macro retrieves tables of SAV relations from DATA and monthly tails production from TRANSITION page.<br><br>Heading and tables are identified by highlighted equations that point to first row of tables.<br><br>● GREEN points to DATA page<br>● YELLOW points to TRANSITION page</td>
<td>Normal view:<br>
<br>View equations:<br>
</td>
</tr>
</table>

Macro revises table in columns O-V.

Existing weights in column O are preserved or populated with 1 if empty.

Columns P-S are values synthesized from tables on DATA and TRANSITION pages.

Columns T-V are equations for plotting that
- Allow 0 weight values to be viewed (columns T-S)
- Convert pool-bottom elevations from input units to reported units (column V).



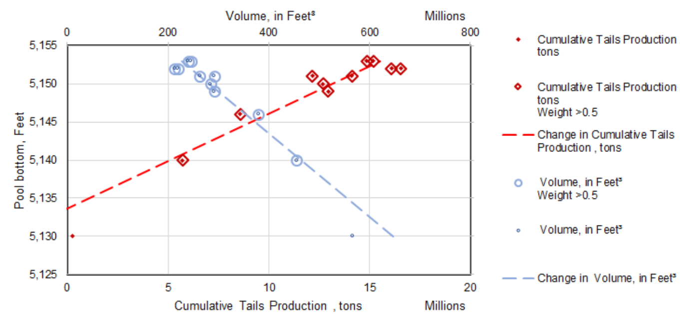
| | O | P | Q | R | S | T | U | V |
|---|---|---|---|---|---|---|---|---|
| 22 | Weight | Date_PBmass | Pool bottom, Feet | Volume, in Feet³ | Cumulative Tails Production , tons | Cumulative Tails Production , tons Weight >0.5 | Volume, in Feet³ Weight >0.5 | Pool bottom, Feet |
| 23 | 0 | 11/24/2020 | 5,130.00 | 565,988,418 | 277,605 | -100 | -100 | 5,130.0 |
| 24 | 1 | 02/24/2022 | 5,140.00 | 455,269,646 | 5,727,568 | 5,727,568 | 455,269,646 | 5,140.0 |
| 25 | 1 | 09/26/2022 | 5,146.00 | 379,383,461 | 8,596,424 | 8,596,424 | 379,383,461 | 5,146.0 |
| 26 | 1 | 06/22/2023 | 5,151.00 | 291,958,922 | 12,168,286 | 12,168,286 | 291,958,922 | 5,151.0 |
| 27 | 1 | 08/24/2023 | 5,150.00 | 284,686,974 | 12,701,195 | 12,701,195 | 284,686,974 | 5,150.0 |
| 28 | 1 | 11/08/2023 | 5,149.00 | 291,543,665 | 12,972,103 | 12,972,103 | 291,543,665 | 5,149.0 |
| 29 | 1 | 03/21/2024 | 5,151.00 | 262,825,125 | 14,136,449 | 14,136,449 | 262,825,125 | 5,151.0 |
| 30 | 1 | 06/08/2024 | 5,153.00 | 245,544,849 | 14,870,135 | 14,870,135 | 245,544,849 | 5,153.0 |
| 31 | 1 | 09/04/2024 | 5,153.00 | 239,852,392 | 15,202,361 | 15,202,361 | 239,852,392 | 5,153.0 |
| 32 | 1 | 12/03/2024 | 5,152.00 | 219,501,909 | 16,102,942 | 16,102,942 | 219,501,909 | 5,152.0 |
| 33 | 1 | 03/17/2025 | 5,152.00 | 213,341,296 | 16,565,649 | 16,565,649 | 213,341,296 | 5,152.0 |
| 34 | | | | | | | | |

TRACK | TSFISM | DATA | Survey | Production | Flow | FlowDiagram

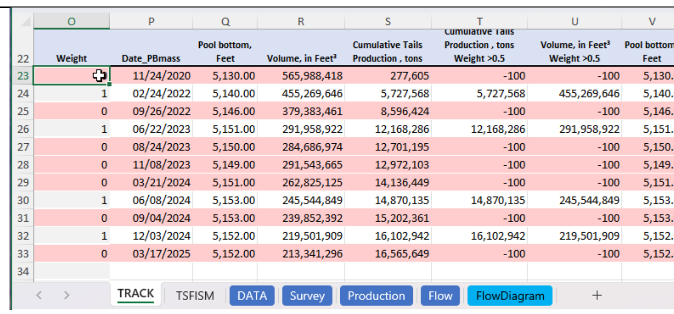
Example with 10 of 11 bathymetry survey results weighted to 1.

Pool bottom rises 1 ft by adding 804,572 tons of tailings to TSF.

| | Q | R | S | T |
|---|---|---|---|---|
| 17 | | Feet³/Feet | tons/Feet | Density, pcf |
| 18 | Slope = | (18,181,397) | 804,572 | 88.50 |
| 19 | r² = | 0.9269 | 0.8888 | |




Change weights from 1 to 0 so that 4 of 11 bathymetry survey results weighted to 1.



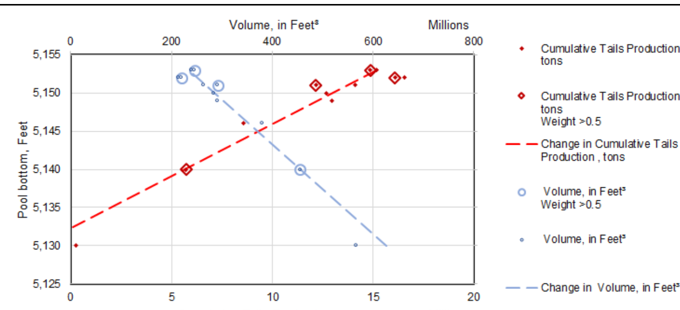
| | O | P | Q | R | S | T | U | V |
|---|---|---|---|---|---|---|---|---|
| 22 | Weight | Date_PBmass | Pool bottom, Feet | Volume, in Feet³ | Cumulative Tails Production , tons | Cumulative Tails Production , tons Weight >0.5 | Volume, in Feet³ Weight >0.5 | Pool bottom, Feet |
| 23 | [illegible] | 11/24/2020 | 5,130.00 | 565,988,418 | 277,605 | -100 | -100 | 5,130.0 |
| 24 | 1 | 02/24/2022 | 5,140.00 | 455,269,646 | 5,727,568 | 5,727,568 | 455,269,646 | 5,140.0 |
| 25 | 0 | 09/26/2022 | 5,146.00 | 379,383,461 | 8,596,424 | -100 | -100 | 5,146.0 |
| 26 | 1 | 06/22/2023 | 5,151.00 | 291,958,922 | 12,168,286 | 12,168,286 | 291,958,922 | 5,151.0 |
| 27 | 0 | 08/24/2023 | 5,150.00 | 284,686,974 | 12,701,195 | -100 | -100 | 5,150.0 |
| 28 | 0 | 11/08/2023 | 5,149.00 | 291,543,665 | 12,972,103 | -100 | -100 | 5,149.0 |
| 29 | 0 | 03/21/2024 | 5,151.00 | 262,825,125 | 14,136,449 | -100 | -100 | 5,151.0 |
| 30 | 1 | 06/08/2024 | 5,153.00 | 245,544,849 | 14,870,135 | 14,870,135 | 245,544,849 | 5,153.0 |
| 31 | 0 | 09/04/2024 | 5,153.00 | 239,852,392 | 15,202,361 | -100 | -100 | 5,153.0 |
| 32 | 1 | 12/03/2024 | 5,152.00 | 219,501,909 | 16,102,942 | 16,102,942 | 219,501,909 | 5,152.0 |
| 33 | 0 | 03/17/2025 | 5,152.00 | 213,341,296 | 16,565,649 | -100 | -100 | 5,152.0 |
| 34 | | | | | | | | |

TRACK | TSFISM | DATA | Survey | Production | Flow | FlowDiagram

Only 4 pool-bottom elevations with bold symbols.

Pool bottom rises 1 ft by adding 732,526 tons of tailings to TSF.

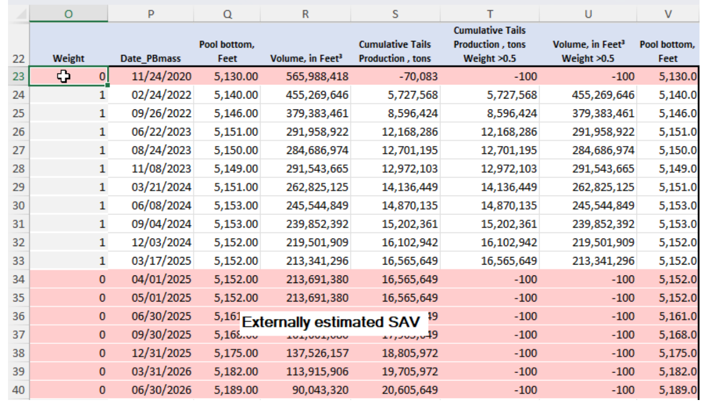
| | Q | R | S | T |
|---|---|---|---|---|
| 17 | | Feet³/Feet | tons/Feet | Density, pcf |
| 18 | Slope = | (17,025,671) | 732,526 | 86.05 |
| 19 | r² = | 0.9495 | 0.9186 | |



"Pool bottom & Mass" macro,

Compiles SAV relations flagged as, Survey or Externally predicted in column E on the DATA page.

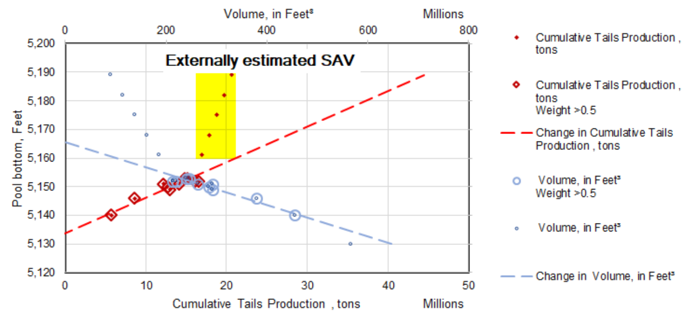
Externally predicted SAV relations are weighted as 0, which denotes them as fantasy.



| | O | P | Q | R | S | T | U | V |
|---|---|---|---|---|---|---|---|---|
| 22 | Weight | Date_PBmass | Pool bottom, Feet | Volume, in Feet³ | Cumulative Tails Production , tons | Cumulative Tails Production , tons Weight >0.5 | Volume, in Feet³ Weight >0.5 | Pool bottom, Feet |
| 23 | 0 | 11/24/2020 | 5,130.00 | 565,988,418 | -70,083 | -100 | -100 | 5,130.0 |
| 24 | 1 | 02/24/2022 | 5,140.00 | 455,269,646 | 5,727,568 | 5,727,568 | 455,269,646 | 5,140.0 |
| 25 | 1 | 09/26/2022 | 5,146.00 | 379,383,461 | 8,596,424 | 8,596,424 | 379,383,461 | 5,146.0 |
| 26 | 1 | 06/22/2023 | 5,151.00 | 291,958,922 | 12,168,286 | 12,168,286 | 291,958,922 | 5,151.0 |
| 27 | 1 | 08/24/2023 | 5,150.00 | 284,686,974 | 12,701,195 | 12,701,195 | 284,686,974 | 5,150.0 |
| 28 | 1 | 11/08/2023 | 5,149.00 | 291,543,665 | 12,972,103 | 12,972,103 | 291,543,665 | 5,149.0 |
| 29 | 1 | 03/21/2024 | 5,151.00 | 262,825,125 | 14,136,449 | 14,136,449 | 262,825,125 | 5,151.0 |
| 30 | 1 | 06/08/2024 | 5,153.00 | 245,544,849 | 14,870,135 | 14,870,135 | 245,544,849 | 5,153.0 |
| 31 | 1 | 09/04/2024 | 5,153.00 | 239,852,392 | 15,202,361 | 15,202,361 | 239,852,392 | 5,153.0 |
| 32 | 1 | 12/03/2024 | 5,152.00 | 219,501,909 | 16,102,942 | 16,102,942 | 219,501,909 | 5,152.0 |
| 33 | 1 | 03/17/2025 | 5,152.00 | 213,341,296 | 16,565,649 | 16,565,649 | 213,341,296 | 5,152.0 |
| 34 | 0 | 04/01/2025 | 5,152.00 | 213,691,380 | 16,565,649 | -100 | -100 | 5,152.0 |
| 35 | 0 | 05/01/2025 | 5,152.00 | 213,691,380 | 16,565,649 | -100 | -100 | 5,152.0 |
| 36 | 0 | 06/30/2025 | 5,161[illegible] | [illegible] | [illegible]49 | -100 | -100 | 5,161.0 |
| 37 | 0 | 09/30/2025 | 5,168.[illegible] | [illegible] | [illegible]49 | -100 | -100 | 5,168.0 |
| 38 | 0 | 12/31/2025 | 5,175.00 | 137,526,157 | 18,805,972 | -100 | -100 | 5,175.0 |
| 39 | 0 | 03/31/2026 | 5,182.00 | 113,915,906 | 19,705,972 | -100 | -100 | 5,182.0 |
| 40 | 0 | 06/30/2026 | 5,189.00 | 90,043,320 | 20,605,649 | -100 | -100 | 5,189.0 |

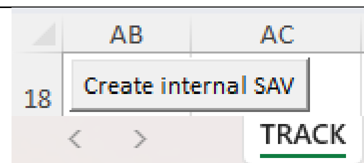


Pool bottoms from externally predicted SAV relations appear in chart as smaller symbols.




## *TRACK Page –Projecting SAV relations*

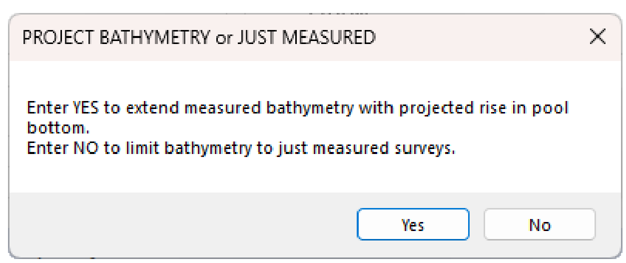
Press "Create internal SAV" button, cell AB18 to manage SAV relations.

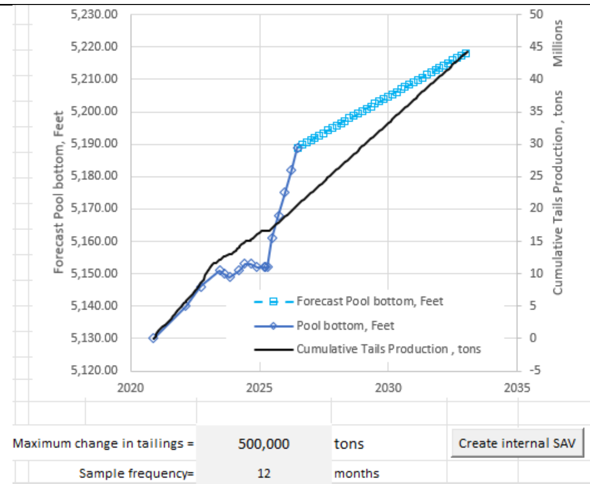
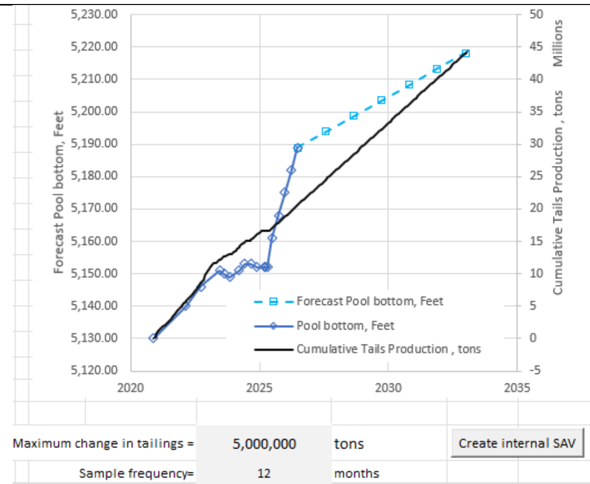
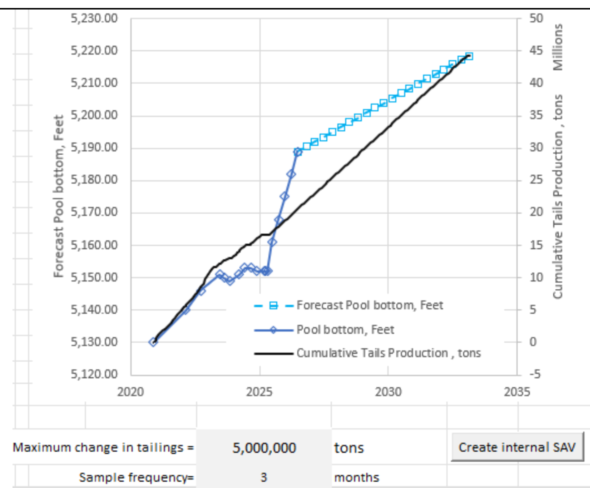



Survey and external predicted SAV relations on DATA page are always retained.

Select YES,
Internal predicted SAV created & written to DATA page.

Select NO,
No internal predicted SAV created.



| | |
|---|---|
| Frequency of internally predicted SAV relations depends on,<br><br>Forecasted tails production &<br>Time between predictions.<br><br>A SAV relation is predicted when forecasted tails production exceeds 500,000 tons or greater than 12 months elapse since previously predicted SAV relation. |  |
| Frequency of internally predicted SAV relations decreases where,<br><br>SAV relation is predicted when forecasted tails production exceeds 5,000,000 tons or greater than 12 months elapse since previously predicted SAV relation. |  |
| Frequency of internally predicted SAV relations increases where,<br><br>A SAV relation is predicted when forecasted tails production exceeds 5,000,000 tons or greater than 3 months elapse since previously predicted SAV relation. |  |

## TSFISM page—Site Information

Groundwater leakage, reporting units, and initial stage of TSF pool are specified on TSFISM page (Figure 22).

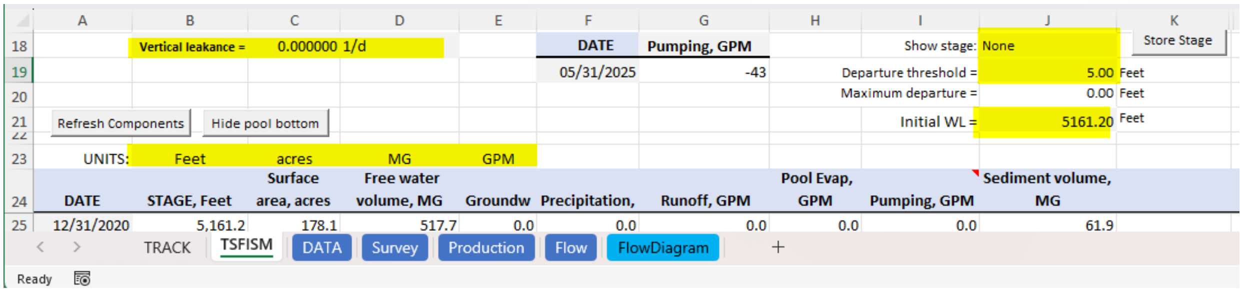
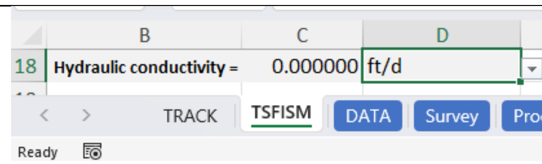
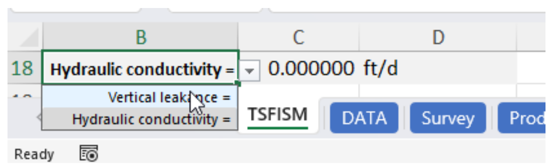



Figure 22.— Site information on TSFISF page in the TSFISM workbook.

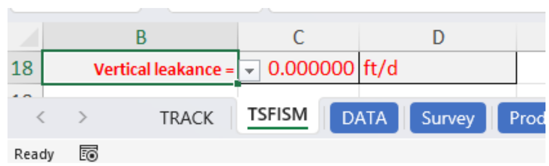
### TSFISM page—Site Information



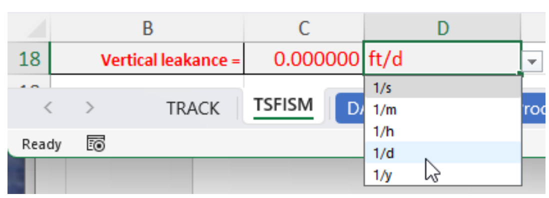

Select hydraulic conductivity or vertical leakance to define groundwater leakage, cell B18



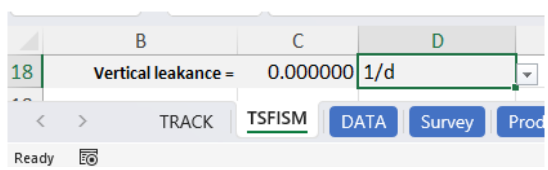

Text in cells B18:D18 turns red if hydraulic property (B18) and units (D18) are inconsistent.

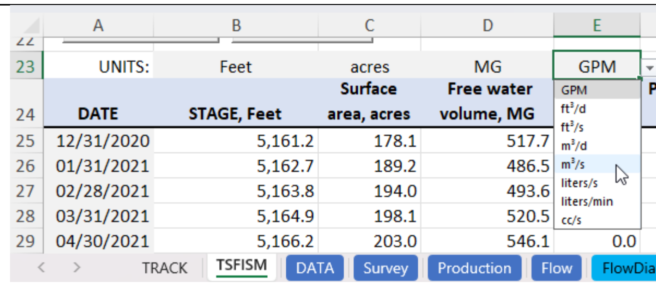
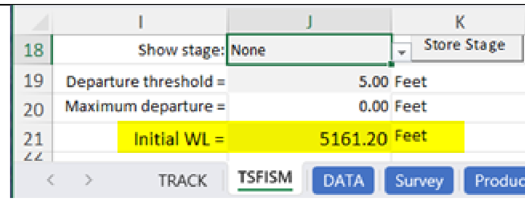



Select correct hydraulic property units, D18.




Error highlighting cells B18:D18 disappears after selected hydraulic property (B18) and units (D18) agree.



| | |
|---|---|
| Reporting units are specified, cells B23:E23.<br><br>Available units are selected from pull-down menus. |  |
| Initial TSF pool stage is specified, cell J21. |  |

## *TSFISM page—Analysis*

Water balance of the TSF pool principally is analyzed from the TSFISM page (Figure 23). Pool evaluation times are specified in column A from row 25 and greater. Equations are paired with newly specified evaluation times with the “Refresh Components” button at cell A21 (Figure 23). Pool stage, area, free-water volume, and flow rates of water-budget components are computed dynamically as site information, such as vertical leakance or *PoS*, are changed. A single flow component at a user-specified time can be sampled (cells F18:G19) and is reported on charts of pool stages and free-water volumes (Figure 23). Unit conversions are dynamic and revised automatically after new units are selected in cells B23:E23 (Figure 23).

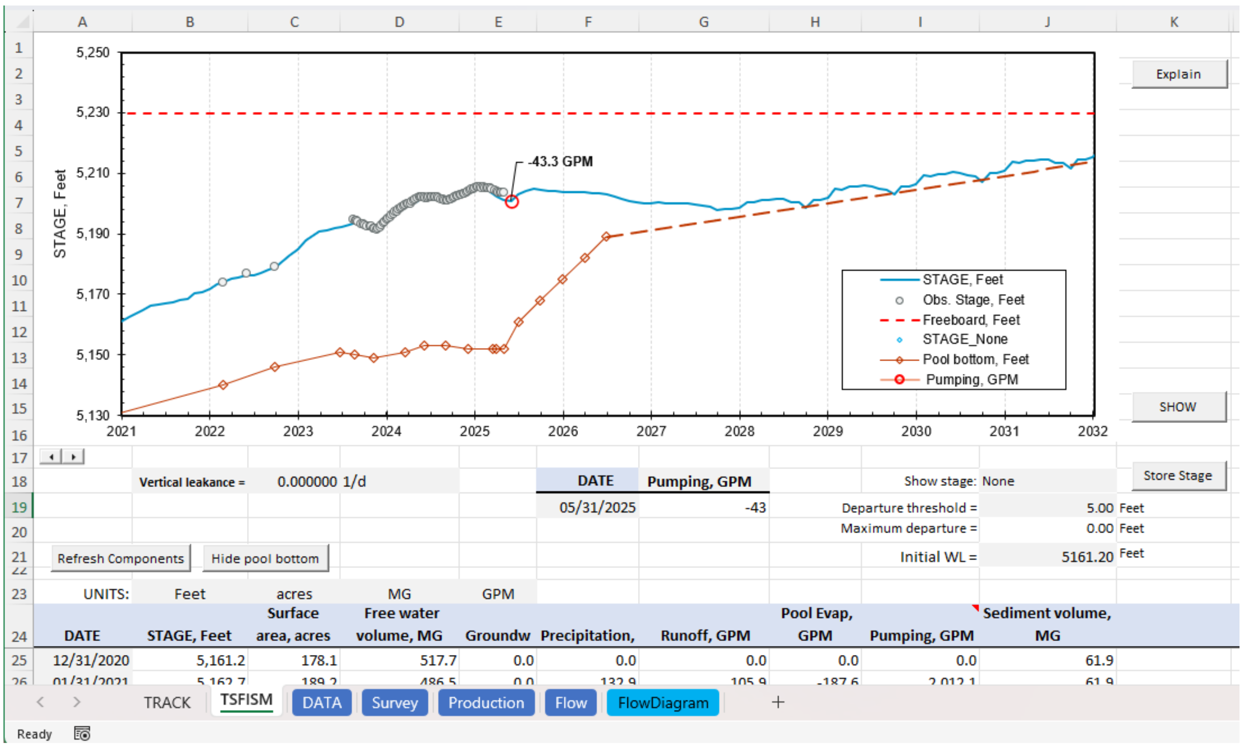


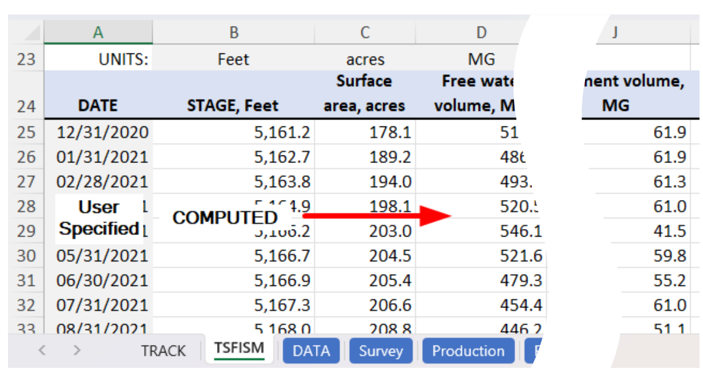

Figure 23.— Analysis results on TSFISF page in the TSFISM workbook.

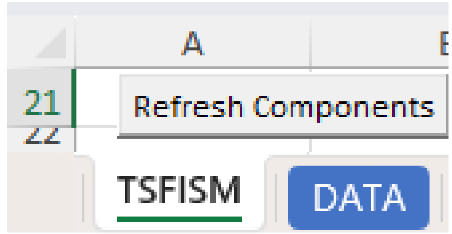
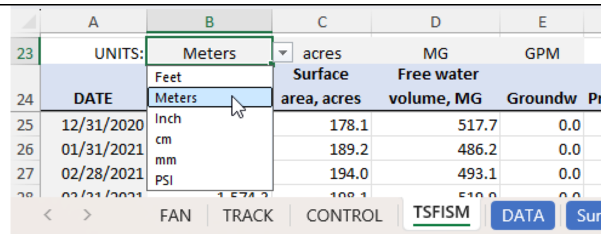
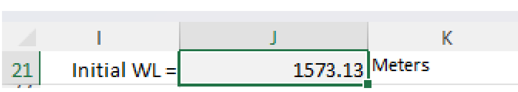
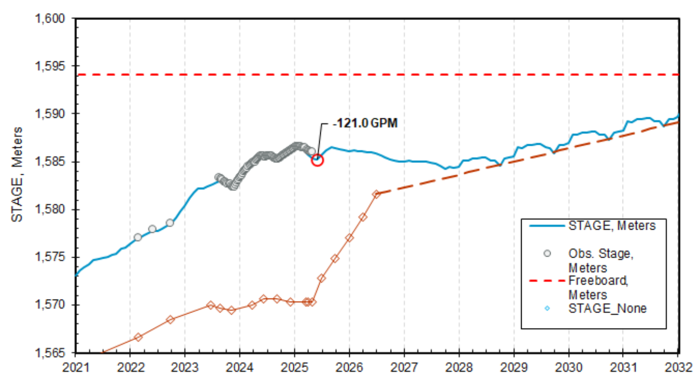
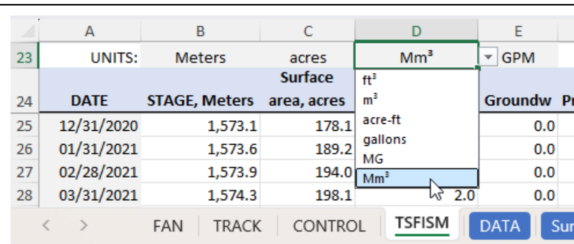
### *TSFISM page—Analysis*

TSF pool simulation times are specified in column A from row 25.

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

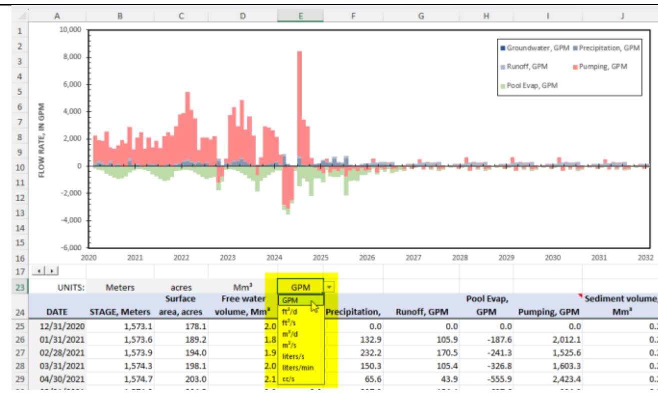
All values in columns B-J from row 25 and below are computed and should not be edited.



| | |
|---|---|
| Press “Refresh Components” button, cell A21 to revise,<br><br>– Reduced SAV relations on CONTROL page,<br>– Climate and net pumping references on CONTROL page with tables on DATA page, and<br>– Synchronize simulated times on CONTROL page with specified times in column A on TSFISM page. |  |
| Pool stage can be reported in other units, which are selected in cell B23. |  |
| Changing units for stage in cell B23 also changes units for initial TSF pool stage (J21).<br><br>Values of initial TSF pool stage (J21) must be revised for consistency with new units.<br><br> |  |
| Units of TSF pool surface area and free-water volume in columns C and D are reported in user-selected units.<br><br>These units of area and volume are selected in cells C23 and D23, respectively. |  |

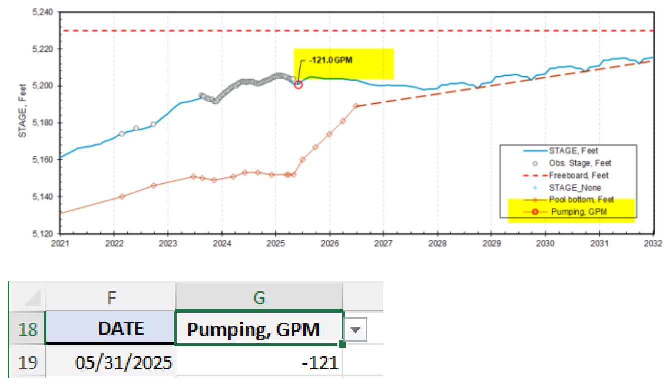
Flow components are reported and charted in the user-defined rate specified in cell E23.

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



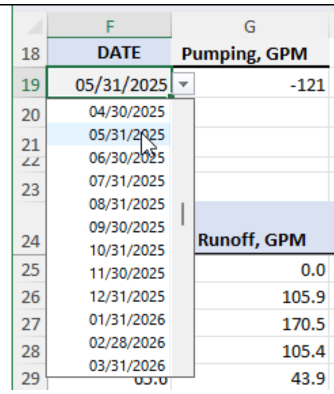

A single flow component at a user-specified time is sampled and reported on charts of pool stages and free-water volumes.

Flow component and computation time are specified in range F18:G19.

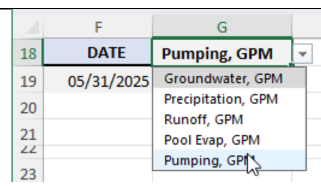



Computation time for single-flow component is specified in cell F19.

Times are user defined in column A.

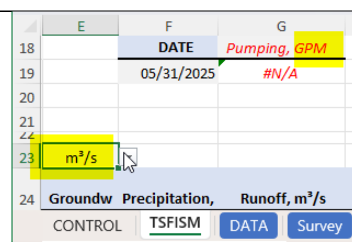


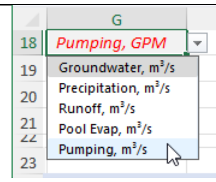

Flow component specified, cell G18.

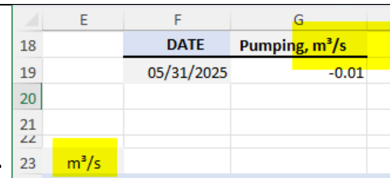
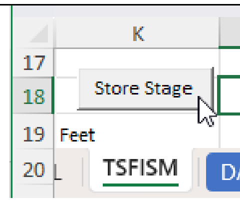
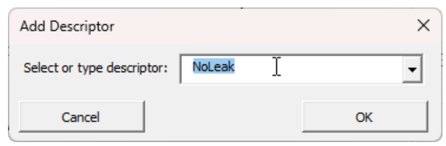
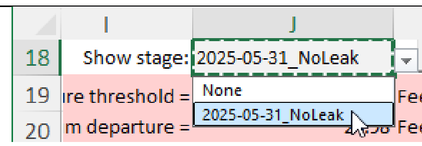
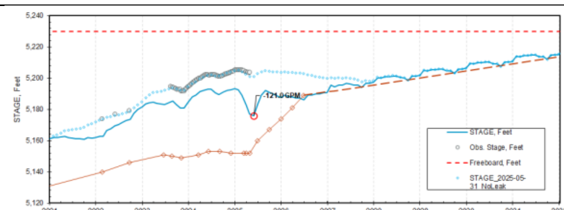
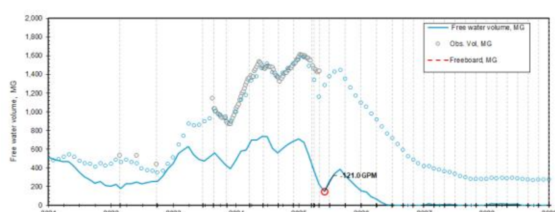
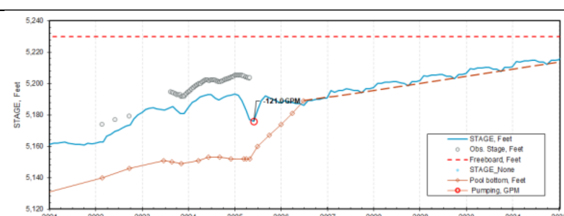



Changing flow units (E23) will create an error with specified flow component (G18).

G18 selection will turn red and error is reported for flow rate (G19).



<table>
<tr><td>Revising G18 selection to consistent units will restore reported flow rate in consistent units (G19).</td><td>

>>

</td></tr>
<tr><td>Press “Store Stage” button, cell K18 to store current simulated stage and free-water volume series for comparison to alternative TSF pool models.</td><td>
</td></tr>
<tr><td>A user-form will appear so label can be added to the stored time series.<br><br>Name is stored as current date with label appended, 2025-05-31_NoLeak.</td><td>
</td></tr>
<tr><td>Display series by selecting name in cell J18.</td><td>
</td></tr>
<tr><td>Stored series, 2025-05-31_NoLeak, can be compared to new model results, where<br><br>Vertical leakance = 0.001 1/d<br><br>Groundwater leakage was 0 in stored series.</td><td>
</td></tr>
<tr><td>Select “None” in cell J18 to not display alternative series.</td><td></td></tr>
</table>