Dynamically Representing Tailings Pool Geometry

GoldSim Webinar
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Introduction

- Tailings Impoundments have been getting a lot of attention lately.
- The overarching theme seems to be water.
- Water balance models of tailings impoundments have become critical components.
- The tailings impoundment is typically the most complex piece of the water balance model.
- One component is the pool geometry simulator.

The Issues

- Simulating a dynamic water pool typically requires a stage-storage-area table.
- In a conventional Tailings Storage Facility (TSF) water is ponded on the deposited tailings.
- The tailings cause the surface to constantly rise, and often changes shape.
- Simulating this behavior can be challenging.

Some Definitions to make sure we are all on the same page

- Impoundment – The component of a TSF designed to contain the tailings.

- Embankment – A constructed berm that forms part or all of the impoundment perimeter.

- Tailings – Finely ground rock remaining after the mineral extraction process. Mixed with water to form a slurry and discharged into the impoundment for permanent disposal. It typically settles out to a firm mud consistency.

- Beach Slope – The tailings will typically settle out at a very mild slope – 1% is typical. The beach slopes away from the point of deposition.

- Tailings Surface – The top of the tailings surface including under the pool.

- Tailings Beach – The exposed top of the tailings surface NOT including the pool.

Types of Tailings Impoundments

- It is important to understand how the tailings are being deposited, and how this will impact the geometry of the pool.
- There are many kinds of ways that tailings are deposited.
- Here are some typical methods:

Natural Valley

- The impoundment is formed by blocking a natural valley with one or more embankments.

- A cross valley impoundment will only need a single impoundment to dam up the valley.

- A valley bottom impoundment will use a second embankment to limit the extent of the impoundment on the uphill side.

- Both kinds may have minor side embankments to keep the impoundment out of an adjacent valley.

- Deposition is typically from one embankment so that the low point (for the pool) forms at the other end.

Cross Valley Impoundment

Bruno Creek Tailings Impoundment, Thompson Creek Mine, Custer County, Idaho

Valley Bottom Impoundment

Ahafo Tailings Impoundment, Ahafo Mine, Ghana

Ring Dike

- The impoundment is formed by an embankment that entirely circles the facility.

- Deposition can be from all sides so a depression forms in the middle, or from all but one side so a depression will form against one side of the impoundment.

Fimiston I TSF, Kalgoorlie Mine, Western Australia

Where are we going anyway?

So what are we trying to calculate for our model? The model typically calculates the volume of water in the pool, but we typically also need:

- The area of the pool for evaporation and precipitation calculations.
- The area of the exposed tailings beach for calculating runoff and evaporative losses.
- The elevation of the pool for reporting remaining freeboard.
- The depth of the pool to maintain a minimum depth of water for the pumps.

Issues with Calculating the Stage-Storage-Area Table

- The stage-storage-area table for the impoundment represents a level surface in the depression, this cannot be used with the tailings solids, as the surface is sloped.

Volume with Level Surface

Volume with Sloped Surface

- Developing a stage-storage table to account for the slope would require a new table every time the geometry changes.

- For many impoundments, the shape of the pool is not constant, so we cannot use one stage-area-storage table for the life of the facility

- Elevation of the base of the pool (zero depth) increases steadily, but typically not uniformly.
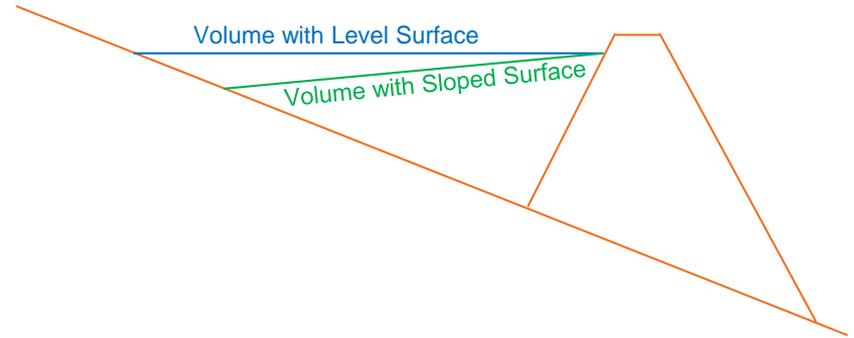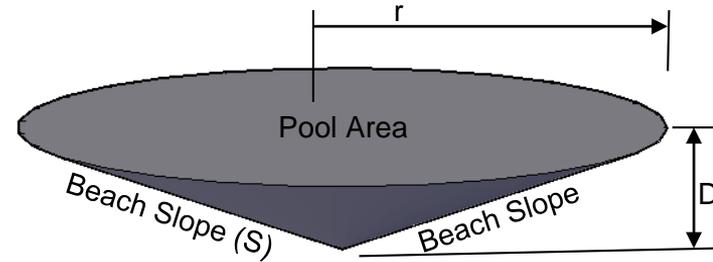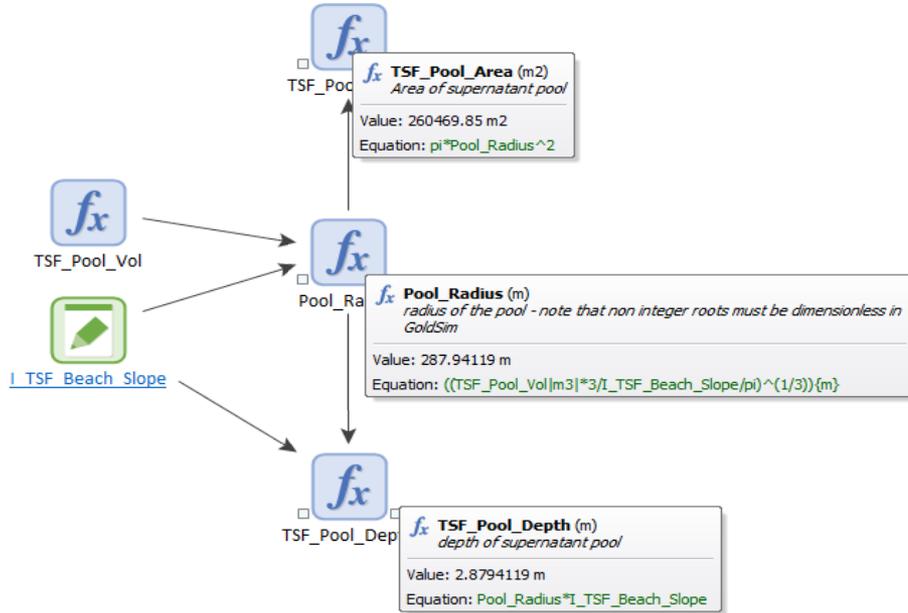
Method 1 – Inverted Cone

- In many impoundments, we can approximate the pool as a shallow inverted cone, especially Ring Dike impoundments.

- The equation for the volume of a cone is:

$$V = \frac{D \pi r^2}{3}$$
But realize that $D = S\,r$ so $$V = \frac{S \pi r^3}{3}$$ Rearrange the equation: $r = \sqrt[3]{\frac{3\,V}{S\,\pi}}$

- So assuming your water balance calculates the volume of water, you can use this equation to estimate the radius (r) of the pool.

- From the radius, you can calculate the area ($A = \pi r^2$) and the depth (D).

Inverted Cone – Depth and Area Model

TSF_Poo...

TSF_Pool_Area (m2)
Area of supernatant pool

Value: 260469.85 m2
Equation: pi*Pool_Radius^2

TSF_Pool_Vol

Pool_Ra...

Pool_Radius (m)
radius of the pool - note that non integer roots must be dimensionless in GoldSim

Value: 287.94119 m
Equation: ((TSF_Pool_Vol|m3|*3/I_TSF_Beach_Slope/pi)^(1/3)){m}

I_TSF_Beach_Slope

TSF_Pool_Dep...

TSF_Pool_Depth (m)
depth of supernatant pool

Value: 2.8794119 m
Equation: Pool_Radius*I_TSF_Beach_Slope

Note that we had to strip the units off the volume in order to let GoldSim take the 3rd root, then we put them back.

But, we still don't know the elevation of the pool and the area of the beach.

Inverted Cone – Elevation and Beach Area

Elevation (m)	Surface Area (m²)	Volume (m³)
24.5	0.0	0.0
25	63,907.5	10,651.3
35	893,717.9	6,318,232.0
40	933,942.0	10,892,953.3
40.5	945,607.2	11,362,837.6

- We should have available to us a stage-area-storage lookup table for the whole Impoundment, hopefully developed by the TSF designers as part of the impoundment design.

- The model should calculate the volume of tailings in the impoundment and we assume we can also approximate the whole depression on top of the tailings surface as a shallow cone...

Depression Volume

Tailings Volume

- The sum of the two volumes can be used to find the area and elevation of the top of the tailings surface from the stage-area-volume lookup table

Inverted Cone – Depression Volume

Start by assuming the area of the depression is the area of the tailings beach at the last time step.

- Assume the top surface approximates a circle, so we can determine the equivalent radius of a circle with the same area:
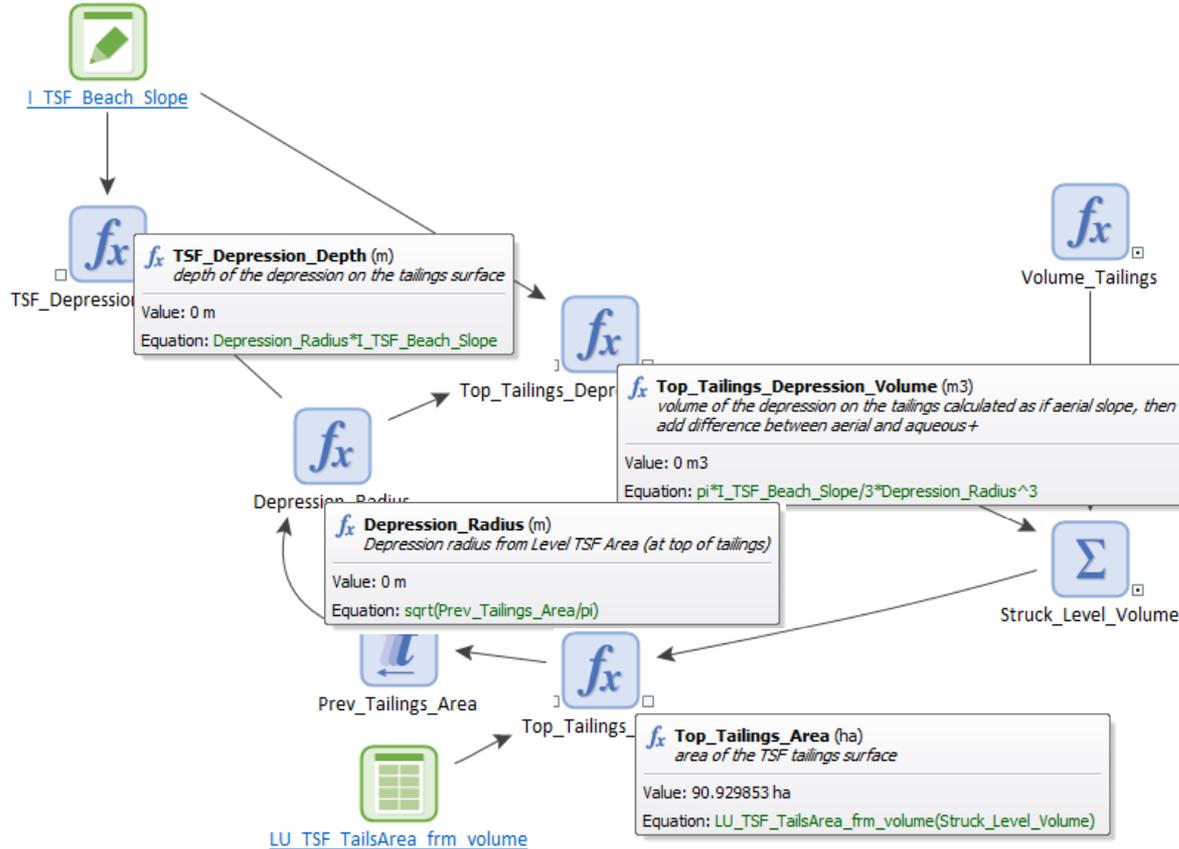
$$A = \pi r^2$$ Rearranged: $r = \sqrt{A/\pi}$

- Then calculate the volume of the depression using the equation of a cone:

$$V = \frac{S\,\pi\,r^3}{3}$$

- The volume of the depression and the volume of the tailings will give us the elevation and area of the top of the whole tailings surface from the table.

- With the depth of the depression, we can determine the elevation of the base of the pool.

Inverted Cone – Depression Model

I_TSF_Beach_Slope

TSF_Depression

TSF_Depression_Depth (m)
depth of the depression on the tailings surface

Value: 0 m

Equation: Depression_Radius*I_TSF_Beach_Slope

Volume_Tailings

Top_Tailings_Depr

Top_Tailings_Depression_Volume (m3)
volume of the depression on the tailings calculated as if aerial slope, then add difference between aerial and aqueous +

Value: 0 m3

Equation: pi*I_TSF_Beach_Slope/3*Depression_Radius^3

Depression_Radius

Depression_Radius (m)
Depression radius from Level TSF Area (at top of tailings)

Value: 0 m

Equation: sqrt(Prev_Tailings_Area/pi)

Struck_Level_Volume

Prev_Tailings_Area

Top_Tailings_

Top_Tailings_Area (ha)
area of the TSF tailings surface

Value: 90.929853 ha

Equation: LU_TSF_TailsArea_frm_volume(Struck_Level_Volume)

LU_TSF_TailsArea_frm_volume

Inverted Cone - Refinements

You can further refine this method if needed, for instance:

- If the Pool is up against the embankment, you can define that you only have a wedge of the cone, defined by the included angle. This wedge could change in time as the deposition matures.
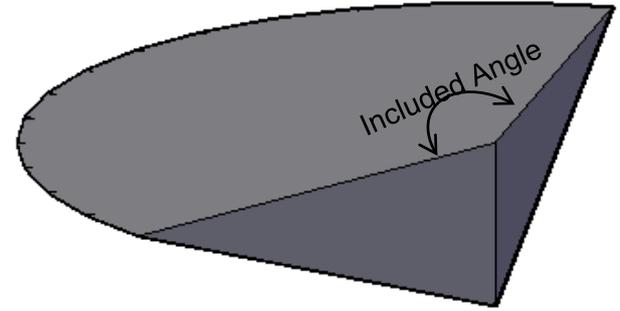

Included Angle

- The volume equation then includes a "Wedge Factor" to reduce the volume:

$$V = \frac{S \, \pi \, r^3}{3} \, x \, \frac{Inc. \, Angle}{360 \, deg}$$

Inverted Cone – Inundated Beach

You may need to check to see if the pool volume exceeds the capacity of the depression on top of the tailings.

- If this is the case, then the area and elevation can be determined for the stage-area-storage curve for the entire impoundment, using the combined volume of the pool and the tailings like you did for the depression volume.

- The model checks each time step if it should use the conical method to determine the aerial depth and area, or the inundated depth and area from the lookup table.
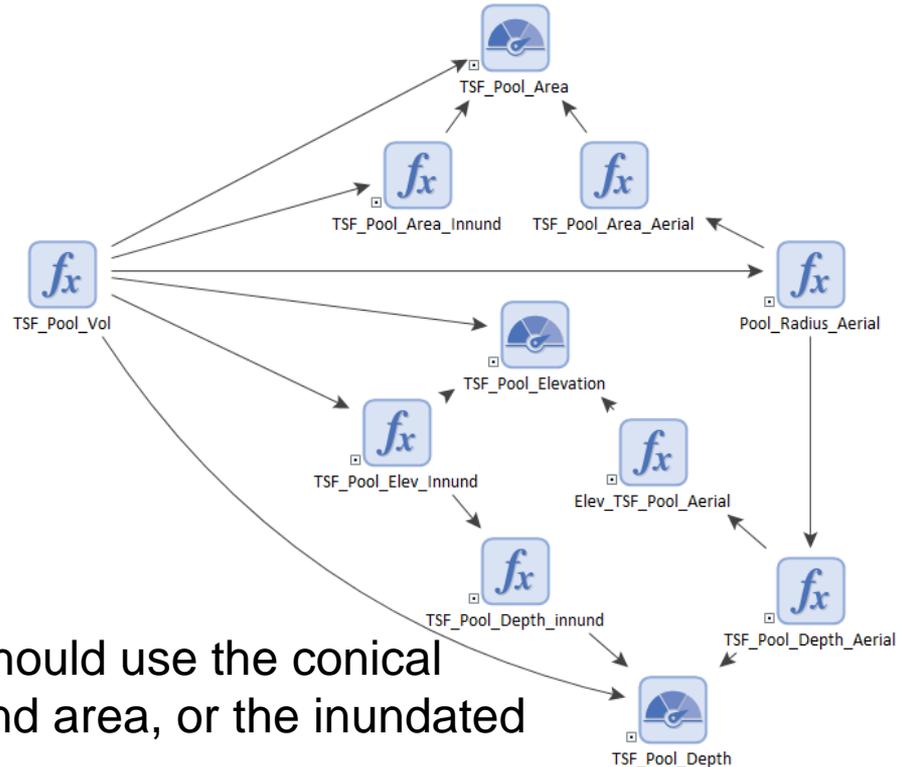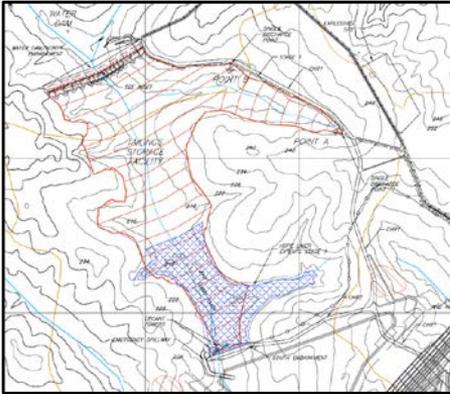
Method 2 – Tabular Method

So what do we do if we are not comfortable with the assumption that the top of the tailings is not a cone?

- Many tailings impoundments are in natural drainages and have very irregular shapes, especially in the early period of operations.

- We need a more robust method that accounts for the changing shape of the pool.

- We can use design drawings of the tailings impoundment to develop stage-area-storage lookup tables, but these will only apply at one point in time.

- We need a method allows the model to transition the stage-area-storage curve from one point to another in time.
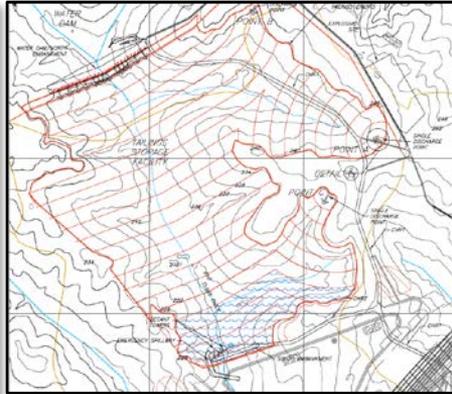
Tabular Method – Design Drawings

- For complex impoundment geometry, the TSF designers will often develop several snapshots showing the top surface of the tailings at various points in the life of the impoundment. The Tabular Method interpolates between each snapshot to find the area or the depth from the pool volume.
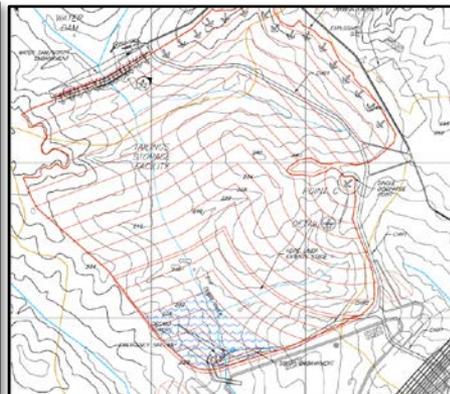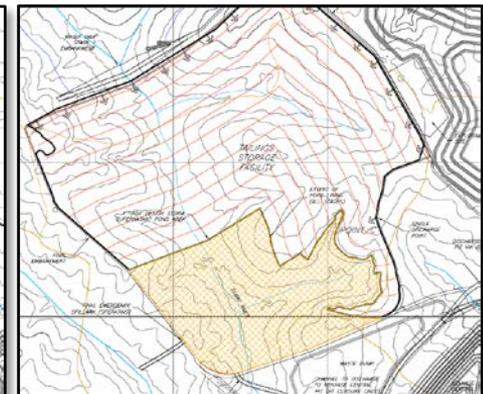
Phase 1   Phase 2   Phase 3   Phase 4

Tabular Method – 2D Tables

Edit 2-D Table: LU_Vol_frm_Depth_n_Tails

Result Value Dimensions: m3

The table can be referenced in the model as:
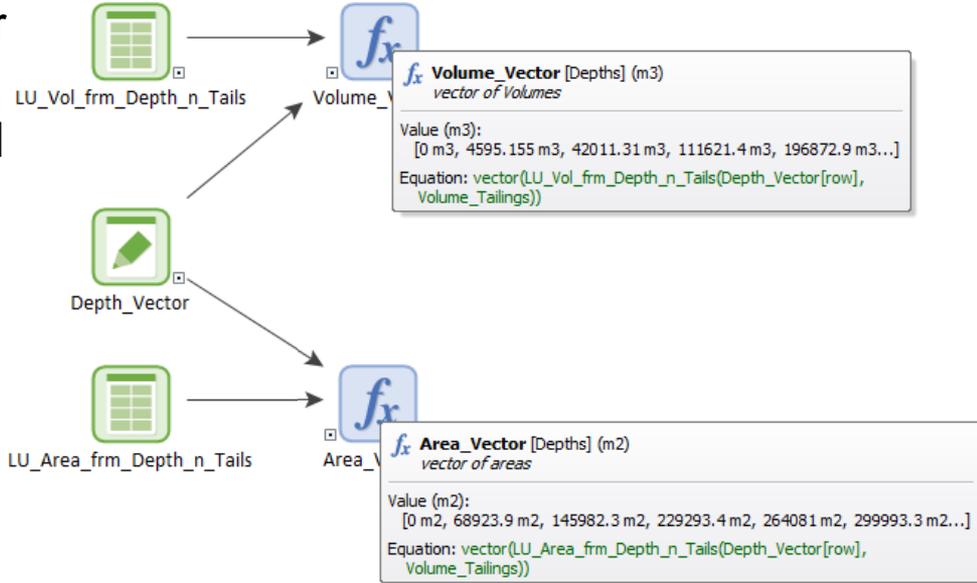
LU_Vol_frm_Depth_n_Tails(Row Variable, Column Variable)

Volume of Tailings in Impoundment (Mil!-m3)

Pool Depth (m)	0	2.317	7.542	19.027	29.027	45.107
0	0	0	0	0	0	0
0.2	0	7363.6	1972.2	2401.3	3197.4	4127.2
0.4	0	65008.7	20222.5	24430	30704.8	37944.8
0.6	0	164564.3	61460.8	73724.8	87480.9	103258.4
0.8	0	265088.2	132242.5	156321.4	181122.7	207977.2
1	0	331360.2	234435.2	273151.4	311551.2	354153.6
1.2	0	397632.2	365690.8	423613.7	477376.4	539569.1
1.4	0	463904.3	527571.4	607274.8	680027.7	762967.3
1.6	0	530176.3	725111.2	825820.6	917067.9	1026378.
1.8	0	596448.4	887795.5	1083481.	1192707.	1328649.
2	0	662720.4	986439.4	1386770.	1515307.	1675146.
2.2	0	728992.4	1085083.	1630929.	1887554.	2074039.
2.4	0	795264.5	1183727.	1779196	2183002	2525111.

- We can develop a 2D lookup table for depth and volume of tailings vs. area/volume.

- I prefer to use tailings volume as my second variable instead of time as it can accommodate changes in mine throughput.

- Unfortunately, we can't use the 'TBL_Inverse" option in 2D lookup tables to invert the table and use pond volume to determine depth.

- Rearranging the 2D lookup table to index on volume instead of depth is very time consuming and tedious.
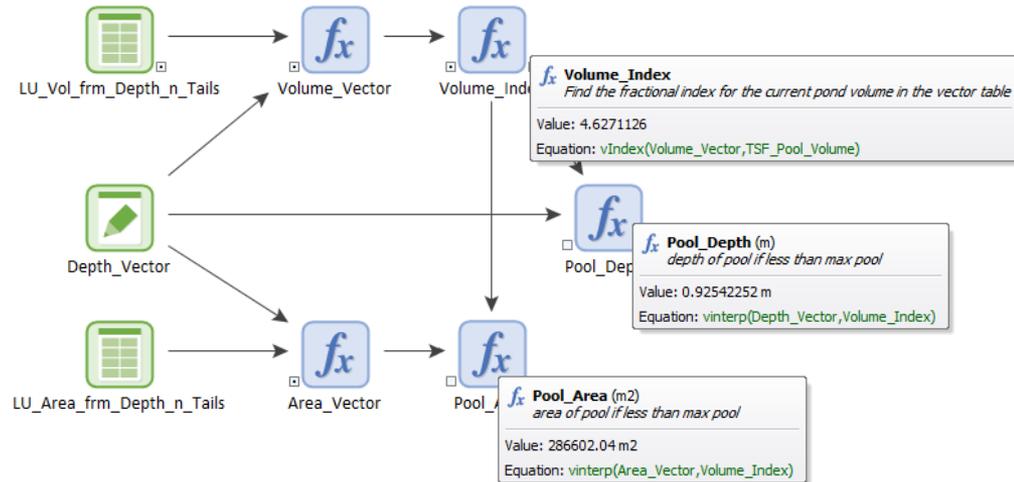
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Tabular Method – Vector Tables

But! We can use the vector function to build 1D lookup tables that we can use:

- Make a vector of depths that cover the range of the 2D table, at about the same frequency as the original tables

- Build a vector of areas and volumes from the tables for the current tailings volume.

- In effect, this method builds a new lookup table every time step.

LU_Vol_frm_Depth_n_Tails

Volume_V

f_x **Volume_Vector** [Depths] (m3)
vector of Volumes

Value (m3):
[0 m3, 4595.155 m3, 42011.31 m3, 111621.4 m3, 196872.9 m3...]

Equation: vector(LU_Vol_frm_Depth_n_Tails(Depth_Vector[row], Volume_Tailings))

Depth_Vector

LU_Area_frm_Depth_n_Tails

Area_V

f_x **Area_Vector** [Depths] (m2)
vector of areas

Value (m2):
[0 m2, 68923.9 m2, 145982.3 m2, 229293.4 m2, 264081 m2, 299993.3 m2...]

Equation: vector(LU_Area_frm_Depth_n_Tails(Depth_Vector[row], Volume_Tailings))

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Tabular Method – Vector Lookups

- Use the Vindex and Vinterp functions in GoldSim to find the index of the volume in the Volume Vector, and the corresponding depth and area in the other two vectors.

- The Vindex function returns a fraction index that is the interpolation between the values in the vector.

- The Vinterp function uses that index to go into the other tables to interpolate the values from them.

Volume_Index
Find the fractional index for the current pond volume in the vector table
Value: 4.6271126
Equation: vIndex(Volume_Vector,TSF_Pool_Volume)

Pool_Depth (m)
depth of pool if less than max pool
Value: 0.92542252 m
Equation: vinterp(Depth_Vector,Volume_Index)

Pool_Area (m2)
area of pool if less than max pool
Value: 286602.04 m2
Equation: vinterp(Area_Vector,Volume_Index)

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Tabular Method – Other Components

To complete the method, we need to determine pool elevation

- Develop two new 1D lookup tables from the original data set, for elevation of top of tailings and elevation of bottom of tailings at each snapshot, with the independent variable the volume of tailings.

- These tables provide you the elevation of the bottom of the pool to add to the depth

- It also lets you calculate the volume of the depression on top of the tailings, which lets you make the same inundated tailings calculation as we did in the conical method.

The table can be referenced in the model as:
LU_Min_Elev_frm_Tails(Row Variable)

	Row Variable [mill-m3]	Result [m]
1	0	90
2	2.32	100
3	7.54	106
4	19.03	123.15
5	29.03	135.2
6	45.11	151.2

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Tabular Method – Wrap Up

The tabular method is quite robust, but does require a lot of input data to be developed. You will also find you need to include a lot of error trapping to prevent out-of-bound table errors.
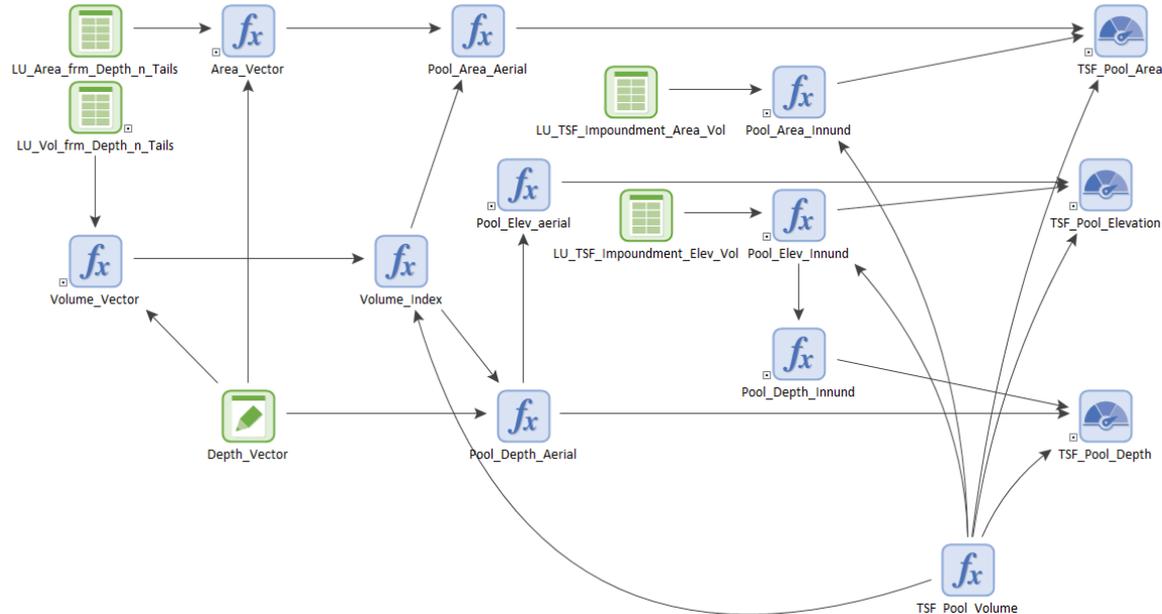
Conclusions

- By understanding the geometry of the tailings surface, we can approximate it in GoldSim.

- You need to extract a lot of data from the TSF design to be able to faithfully represent the surface.

- GoldSim has the tools to do these complex calculations, if you know where to look.

- We will put a sampler of these methods in the GoldSim library.

Highland Valley Copper, BC, Canada
(Courtesy of Teck)

The End – Questions?