New Tank Mapping Method Improves Waste Removal Process

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ABSTRACT

Savannah River Mission Completion is the Liquid Waste (LW) contractor at the Savannah River Site (SRS). The LW mission is tasked with treating and disposing of legacy nuclear waste. There are multiple facilities involved in this work, including the Concentration, Storage, and Transfer Facilities (CSTF), the Defense Waste Processing Facility (DWPF), the Salt Waste Processing Facility (SWPF), and the Saltstone Production Facility (SPF). The CSTF includes 43 underground waste tanks used to store and support processing of radioactive liquid waste. Waste removal activities, such as salt dissolution campaigns and sludge agitation, are conducted within the CSTF waste tanks to convert the waste into a form that allows for downstream processing at other LW facilities.

While performing these waste removal campaigns, camera inspections are performed to assess the quantity and distribution of the remaining waste within the waste tank (i.e. saltcake or sludge). Understanding the quantity and distribution of the salt/sludge within the waste tanks allows for improved waste removal strategies (e.g. mixing pump operation) and refined safety controls. Typically, several camera inspections are performed during a waste removal transfer to verify the elevation of the visible salt/sludge mounds against the known elevation of the liquid surface. The camera inspection footage must then be interpreted by a trained engineer who will develop a 2-D map that depicts the waste distribution at various elevations within the waste tank. This tank mapping is then used in conjunction with conservative assumptions to evaluate the volume of saltcake or sludge that is present within the waste tank.

Despite the simplicity of the completed tank maps, the process of creating the tank maps can prove very challenging. Often, there are limited tank top risers available by which to perform the camera inspections, which limits the available viewpoints. Also, maintaining awareness of the camera orientation while reviewing the camera inspection footage can prove difficult as the camera operators will often rotate the viewing angle and change the magnification to provide a variety of perspectives.

To combat these issues, a new tank mapping method has been developed. This new mapping process considers the positioning of tank landmarks (e.g. pumps) as well as the visible arc of the tank walls and uses that information to create a directional map that is overlayed onto a single, wide-view camera inspection image. This directional map provides a "full view" of the inside of the tank despite the viewing limitations of the single camera inspection image. The directional map shows the full arc of the tank walls and creates axes based on the known positions of the tank landmarks relative to each other. In this way, the location of tank landmarks that are not in view within the initial camera inspection image can still be determined. Having this full view of the tank allows us to overcome the perspective distortion of the camera inspection image by considering the salt/sludge mounds in terms of relative distance to each of the tank landmarks. To accomplish this, an equal number of relative spacing markers are added on each directional axis of the overlayed map. The "actual distances" of these spacings within the tank are determined by comparing the spacing distribution to the known distances of the tank landmarks from the tank center. Once this information is known, the visible salt/sludge mounds can be analyzed from various angles despite only utilizing one reference image. The shapes of the visible mounds are defined in terms of notable mound boundary points and their respective distances from the tank midpoint. The mound boundary point distances are then used to create the 2-D tank mapping.

This new mapping method creates a standardized approach for accurately defining the waste distribution within a waste tank while minimizing the required camera inspection footage. The process is most useful

in Type 4 waste tanks in which a wide, unobstructed view of the inside of the tank is possible. Most recently, this mapping process was utilized during the 2023 Tank 22 Sludge Removal Campaign. Using this mapping method, this campaign was able to credit a sludge volume reduction of 73%, which was an improvement of 31% above the previous Tank 22 sludge removal campaign.

INTRODUCTION

SRS has 51 underground waste storage tanks located in the H and F Tank Farms (HTF and FTF). These Tank Farms, along with other equipment, make up the CSTF. The mission of the CSTF is the storage and processing of legacy radioactive waste in a manner that prevents releases to the environment and minimizes exposure to both on-site and off-site personnel [1]. There are currently 43 waste tanks remaining in the CSTF, as eight of the 51 tanks have been operationally closed and filled with grout. The waste tanks at SRS store three major types of waste: saltcake or salt, sludge, and supernate. Waste removal activities, such as salt dissolution campaigns and sludge agitation, are conducted within the CSTF waste tanks to convert the remaining waste into a form that allows for downstream processing at other LW facilities.

Waste tanks in the CSTF were built in the early 1950s to support the reactor and separations processes. Additional waste tanks were constructed in the decades that followed with different styles of construction being utilized to produce more secure structures for waste storage. These tanks are cylindrical in structure and can house up to 1.3 million gallons (4921 m^3) of waste. A total of five different tank types were constructed, and are referred to as Type I, II, III, IIIA, and IV tanks [1]. As seen in Figure 1, the Type IV waste tanks present the best visibility within the tank as this tank type lacks the support columns and cooling coils seen within the other tank types.

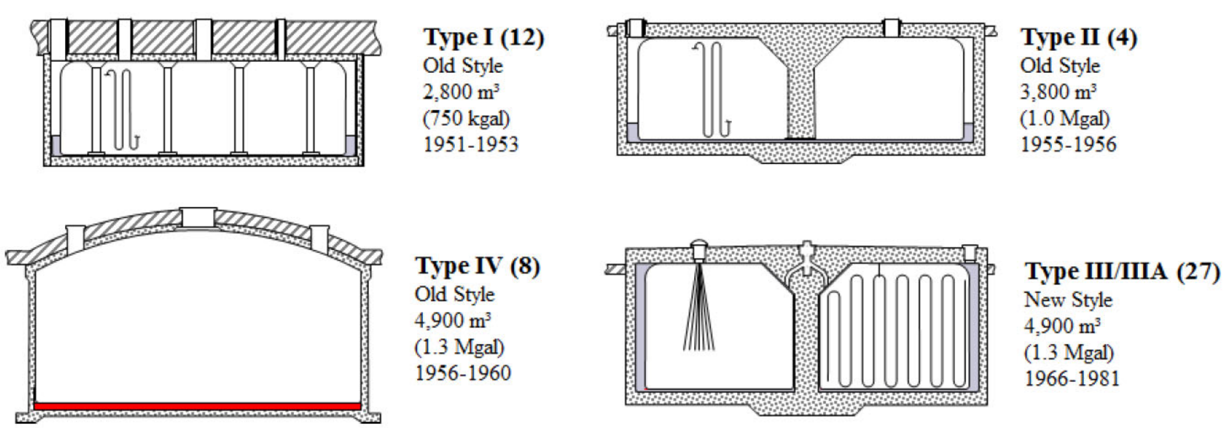


Figure 1. SRS Waste Tanks. Number of each tank type, tank capacities, and years of construction are shown. Type III tanks have insertable or deployable cooling coils while Type IIIA tanks have permanently installed coils [2].

Access into the waste tanks is limited by available waste tank openings called tank top risers. Equipment and instrumentation, such as mixing devices and reel tapes, are installed within tank top risers to support operational activities. Mixing devices are installed, on an as needed basis, to slurry the waste within the tanks, while reel tapes are standard instrumentation installed to measure the tank liquid level. Each waste tank has detailed documentation that outlines specific riser locations, riser sizes, and relative distances from one riser to another reference point within the waste tank. Tank top diagrams are created to reflect the general location of risers and key operating equipment that is installed within a waste tank [Figure 2].

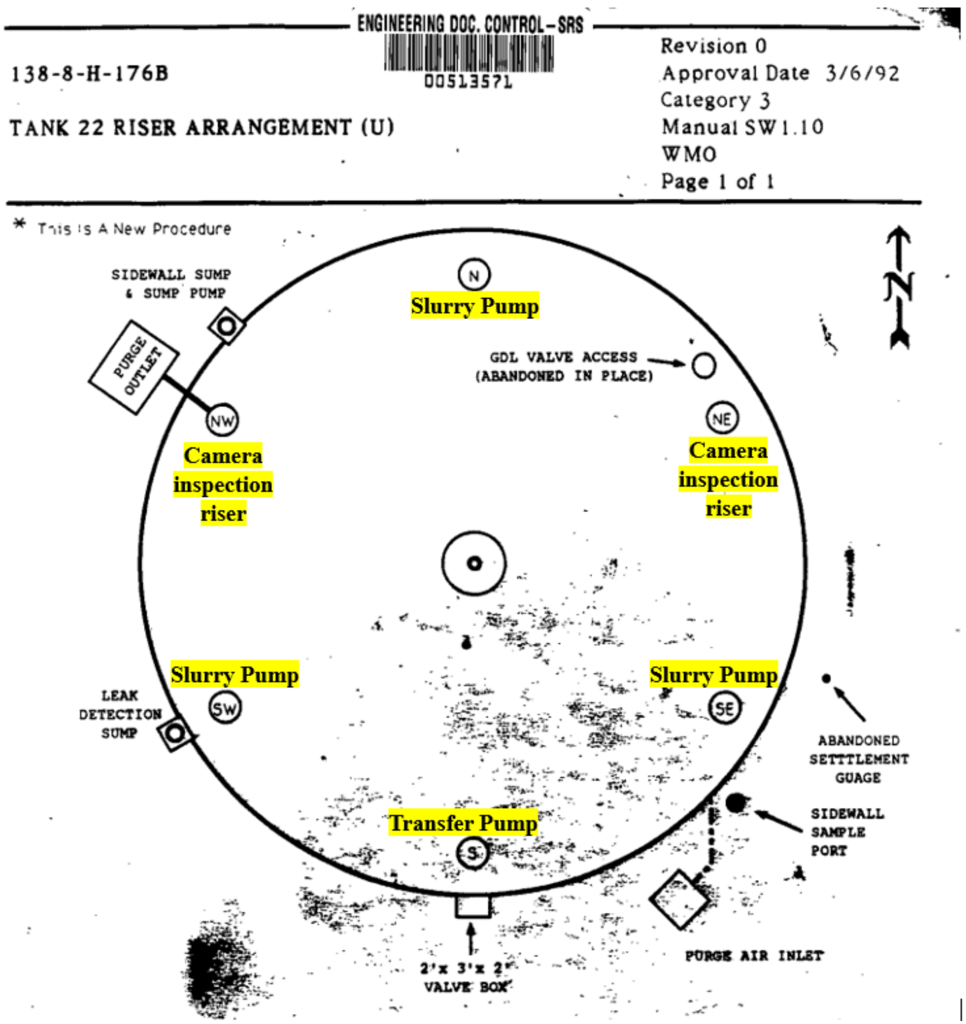


Figure 2. Tank top diagram: Tank 22. These tank top diagrams showcase the tank risers and notable tank equipment. Typically, there is also a summary of equipment installed in each riser below the diagram (not included). The highlighted text featured was added for additional clarity on the installed equipment in this example case [4].

Most tank top risers cannot be readily accessed due to installed equipment. However, tanks will maintain accessibility to at least one riser that can be used to insert instrumentation into a waste tank on an as needed basis. Camera inspections within our waste tanks are performed, on an as needed basis, by lowering a camera into an available riser. Camera inspections allow for visual confirmation of waste tank conditions and are often performed while conducting waste removal campaigns to assess the quantity and distribution of the remaining waste within the waste tank (i.e. saltcake or sludge waste). The cameras utilized within CSTF can digitally zoom and allow for a 360 degree pan to provide a variety of viewing angles during the inspection. Operators will control the cameras once in a waste tank and will focus in on various areas within a tank, typically with guidance from the tank Design Authority Engineer. The camera inspection footage is then reviewed by a qualified engineer to develop a 2-D tank mapping, which defines the topography of the salt or sludge waste at various elevations. The elevations of the visible waste mounds during each camera inspection are determined by noting the tank liquid level at the time the camera inspection was performed. Several camera inspections at various times during a waste removal transfer are needed to create an accurate tank mapping. This tank mapping is then used in conjunction with conservative assumptions to evaluate the volume of saltcake or sludge that is present within the waste tank, and to refine operating strategies for continued waste removal.

Traditionally, the location of visible salt or sludge mounds within a tank are determined by assessing where the mounds are positioned relative to other known and distinguishable tank landmarks such as mixing devices, thermocouples, reel tapes, cooling coils, etc. However, in tanks where there are limited tank landmarks to reference, it can be difficult to accurately define the location and distribution of exposed mounds, especially when these mounds are in a different tank quadrant from where the camera is installed. This is often true of Type IV tanks which do not have a lot of equipment, or structural components present that can be used to distinguish the positioning of waste mounds, especially around the middle of the tank. The difficulty in accurately defining the position of exposed waste mounds is amplified by the perspective distortion that is experienced based on the position of the camera relative to the location of the waste mounds. The further away the mounds are from the camera, the smaller they will appear in the camera inspection image despite their true size and scale.

This paper discusses a new tank mapping method which overcomes the effect of perspective distortion and improves the waste removal process by creating a standardized approach for accurately defining waste distribution within a waste tank while minimizing the required camera inspection footage.

BACKGROUND

The variation in the camera inspection image geometry compared to the expected tank geometry is known as perspective distortion [3]. This effect happens when the image of an object is captured at either a wider or more narrow viewing angle than what is traditionally expected. In the case of creating a tank mapping, the tank geometry is most accurately viewed from a top-down perspective in which the tank is depicted as a perfect circle. However, there is rarely an opportunity to perform a camera inspection in which a perfect top-down perspective is achievable. The position of the camera within the available tank risers will create a wider viewing angle for objects that are closer to the camera and a narrower viewing angle for objects that are further away from the camera [Figure 3]. Because of this, objects that are closer to the camera, or at a wider viewing angle, will appear much larger and more accurately spaced out than objects that are further away from the camera lens.

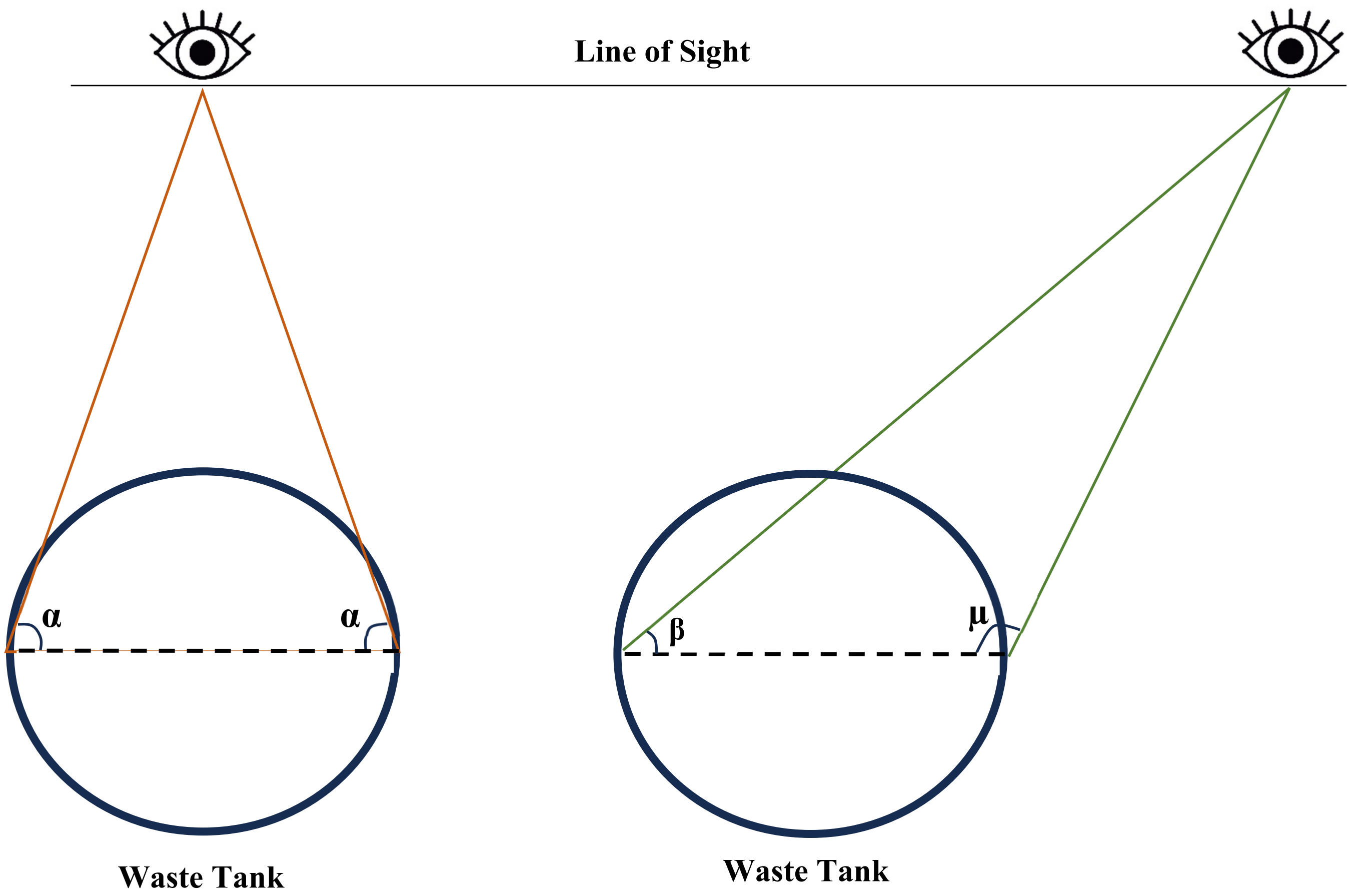


Figure 3. Example of the Viewing Angles Created by Perspective Distortion. From a perfect top-down perspective, angle Alpha (α) is witnessed by the viewer on both sides of the tank. However, if the viewers perspective is shifted from the tank center as shown, the tank side that is closest to the viewer creates a larger angle Mu (μ), while the tank side that is farther from the viewer creates a narrower angle Beta (β) when compared to the α angles.

The perspective distortion associated with camera inspections adds complexity when attempting to determine an object's true location and sizing within a tank. This effect is amplified the further away the object is from the camera's lens. Because of this, camera inspections will often be performed from two or more risers if the option is available. However, this option is not always available depending on the tank, and ultimately this approach will decrease camera service life by increasing camera wear due to the additional operating time and radiation exposure within the tanks. Also, additional camera inspection footage will equate to additional personnel-hours spent reviewing the footage and deciphering how to translate what was observed to create a 2-D tank map. This process of deciphering the camera inspection footage can prove tedious not only due to the length of the footage that must be reviewed, but also due to the challenge of maintaining awareness of the camera orientation while watching the inspections, especially as the camera rotates and changes magnification to provide a variety of viewpoints within the tank. These aspects of the current tank mapping process increase the overall cost associated with producing these tank maps.

In addition, since there is no standard approach applied to reviewing the footage and creating the tank maps, there is room for subjectivity which can negatively influence the accuracy of the tank maps and limit their effectiveness as a tool for aiding in future operating decisions. For example, a tank map may be reviewed to help develop the operating strategy for a waste removal campaign that employs mixing pump indexing. Mixing pump indexing is a process in which a mixing pump is operated at a fixed position to target a specific area within a tank. This approach can prove effective when targeting known waste mounds, but it has a limited zone of influence compared to the traditional operation of mixing pumps in oscillation mode. Therefore, for this operating strategy to work effectively, it is important to have an accurate understanding of the location of the waste mounds that are being targeted. If the indexed position of the pumps is selected based on a tank mapping that does not accurately reflect the location of waste mounds within a tank, then this type of pump operation may not disturb the targeted mounds and would prove ineffective.

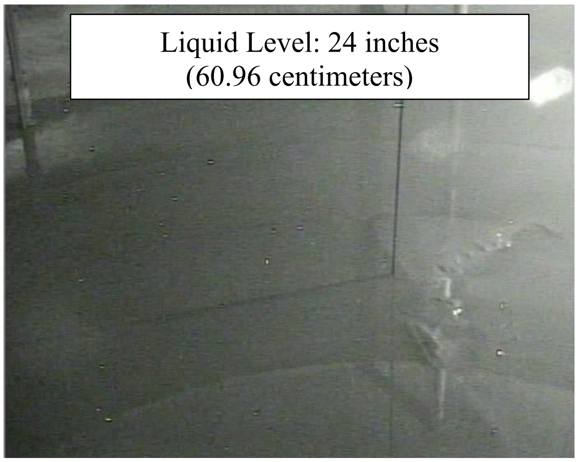
Having a more accurate map to reference also allows for a more accurate assessment of the remaining sludge or salt volume within a tank, which can have major impacts on the required flammability controls for that tank. Typically, a larger volume of slurried sludge within a tank will increase the credited hydrogen generation rate which may require additional restrictions to protect a larger vapor space volume [1]. These additional flammability controls would limit the available tank operating space which may impact system plans and overall limits operational flexibility. In these ways, there is both a cost and operational benefit to a standardized mapping approach that can minimize the camera inspection footage required and maximize the accuracy of the resulting map.

NEW TANK MAPPING METHOD

The new tank mapping method discussed below was first utilized during the 2023 Tank 22 Sludge Removal Campaign, which occurred from January to March 2023. Tank 22 serves as the receipt tank for transfers from the DWPF Recycle Collection Tank (RCT). The sludge volume in Tank 22 will increase over time due to these recycle transfers. Tank 22 has six total risers with three installed slurry pumps in the North (N), Southeast (SE), and Southwest (SW) risers. Tank 22 also has one telescoping transfer pump (TTP) installed in the South (S) riser. Camera inspections during this campaign were performed from the NE and NW risers. Figure 2 is a tank top diagram depicting the risers in Tank 22. This figure represents a perfect top-down viewpoint of the tank from the tank midpoint (i.e. no perspective distortion). As you can see from Figure 2, the risers in Tank 22 are evenly positioned at 60-degree angles from the tank midpoint. Understanding this symmetry between the risers will be utilized in the tank mapping process.

To effectively employ this new mapping strategy, first a series of wide-view camera inspections must be performed during a waste removal transfer. Typically, these inspections are performed every two to four inches (approximately 5 to 10 centimeters) of tank level change. The timing of these inspections will depend on the transfer flowrate. For these inspections, the camera should be fully zoomed out and positioned to capture any waste mounds visible within the tank. Ideally, the camera positioning for each inspection will align such that the images from each inspection could be superimposed with minimal changes to the camera perspective. Keeping the camera orientation consistent between inspections will allow for more efficient analysis of the mound changes. As the transfer progresses, it is likely that not all of the exposed waste mounds will be able to be captured in one image. In this case, the camera should remain zoomed out, and pan to view the additional mounds that have been exposed. Ideally the panned view will still include some portion of the pervious camera inspection image so that the location of the newly exposed mounds relative to the higher elevation mounds can be more easily interpreted. If desired, multiple camera inspection angles can be pursued (i.e. camera inspections from two or more risers) and the camera operator can zoom in on specific mounds, but these additional shots are not required to complete the tank mapping, as long as a full, unobstructed view of the exposed mounds is available from one camera position. Additional camera inspections should be pursued if there are obstructions within the tank that limit a full tank view. This is why this mapping approach is most effective when utilized for

Type IV tanks [Figure 1]. Figure 4 shows examples of exposed waste mounds from camera inspections performed at two liquid levels, 24 inches and 19 inches (60.96 and 48.26 centimeters). The wide-view camera inspection images at the various tank levels will then be reviewed to create the tank map.



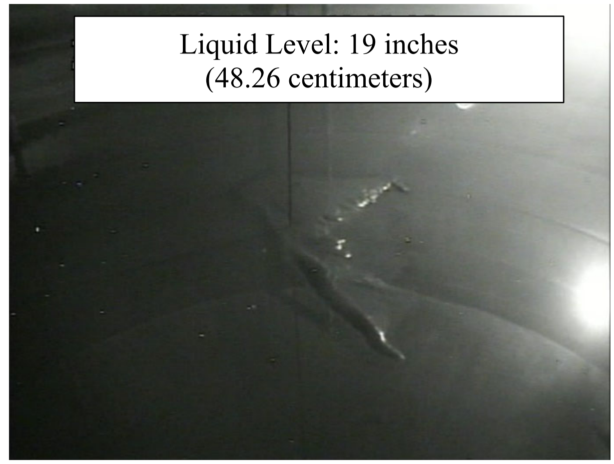


Figure 4. Example of Camera Inspection Images at Various Liquid Levels. It is clear from reviewing these images that more of the sludge mound is exposed at the lower tank elevation of 19 inches than is seen at a liquid level of 24 inches. The differences between the exposed mounds at various liquid levels allows for a more refined understanding of the waste distribution. It is of note that neither of these images is fully zoomed out as is recommended for best results.

Once the camera inspection footage has been acquired, the tank mapping process can begin by first creating a directional map that is overlayed on each camera inspection image to provide a “full view” of the inside of the tank despite the viewing limitations of the single image. This directional map was created in Microsoft PowerPoint. The directional map shows the full arc of the tank walls and creates axes based on the known positions of tank landmarks relative to one another. In Figure 5, the tank landmarks utilized to start the directional map are the S and SW riser mixing pumps, which are both pictured. Ideally, the camera inspection images for the various liquid levels will align in perspective (fully zoomed out and showing the same tank landmarks) so that the directional map that is created can be reused for all images that are analyzed.

First create the map axes by relating the tank landmarks pictured with the relative location of the tank risers that are not pictured. For example, it is known that the camera inspection image in Figure 5 was captured from the NE riser and that the pump pictured at the center of the image, which is furthest away from the NE riser, is within the SW riser [Figure 2]. Based on the riser relationship identified from the tank diagram, we can create our first axis as a straight line from the SW riser down to the NE riser. This first axis will help to locate the tank mid-point. The next axis created was from the S riser, which is also pictured on the far left of the image, to the N riser, which is not pictured. To help identify the positioning of the N riser, a second wide-view image that pictures both the SW riser pump and the N riser pump could be utilized and overlayed to fit together with the original image such that the second image serves as a continuation of the original image [Figure 9]. This approach will give more accurate results. In this example however, that approach was not utilized and instead, the exact position of the N riser was estimated based on the relative angles of the S pump compared to the SW pump as well as knowledge that the black pipe pictured is a thermowell that is 2-ft (0.6-m) from the tank mid-point and at a 22.5 degree angle from the SE riser [5]. Now that two axes have been created from the SW riser to the NE riser and from the S riser to the N riser, the last axis needed for this example is from the SE riser to the SW riser.

This axis was estimated based on the understanding that the distance between the SW riser and the S riser (both pictured) should be similar to the distance between the SW riser and the NW riser [Figure 2]. Also, the NW riser to SE riser axis line needs to run through the same mid-point that was previously established.

Now that the axis lines have been established, re-create the tank wall arc using an oval shape from the 'Shapes' dropdown menu in Microsoft PowerPoint. Adjust the sizing of the oval until the oval arc matches the tank wall arc pictured, and the sides of the oval align with what has been identified as the locations of the SE and N risers. These two risers are utilized to define the widest points of the oval because they are known to be at the widest angle away from the NE riser [Figure 2]. Again, having enough camera inspection images available from the same wide-angle perspective which can be overlayed to create one continuous image of the entire tank would be preferred to minimize any error associated with estimating the tank wall arc and tank landmarks [Figure 9].

It is known that the tank geometry from a top-down perspective is that of a perfect circle as depicted on the tank diagram [Figure 2]. However, the oval shape created accounts for the effect of perspective distortion on the camera inspection image. The same proportional distortion effect will exist at all points on a given axis line. In this way, the oval created provides a template by which to define the effects of perspective distortion at various points in the tank. To accomplish this, the aspect ratio of the oval is locked within the size options, and multiple ovals are created with this same aspect ratio and at various sizes to relate equivalent positions on each of the axis lines. Specifically, these intersections of an oval with each of the axis lines represent equivalent distances from the midpoint at all points along that oval. Given that understanding, a series of concentric ovals are created over the axis lines to define various relative points within the tank. To assist with placement of the ovals, markers are added to each axis at equivalent positions. For example, the halfway point on each axis line is identified and used as the starting marker. Additional markers are added by identifying the halfway point on the line segments created. The ovals are then sized to intersect the equivalent markers on each axis line. Adding more positioning ovals to the map will provide more reference points by which to define the size of the visible waste mounds.

Understanding the distance of the tank landmarks from the tank center provides context to determine the distances of the various positioning ovals that are created. In this example case, it was known that the pumps and tank walls are 37-ft (11.3-m) and 42.5-ft (12.9-m) away from the tank center respectively [6, 7]. Therefore, a positioning oval that is half the distance from the tank center to the pumps would be approximately 18.5-ft (5.6-m) away from the tank center. Applying this same concept to all of the positioning ovals created allows for the ovals to be used to define the lengths of the visible waste mounds. Specifically, the extremities and distinct features of the visible waste mounds are labelled with their respective distances. Using these values, the mound geometry will then be translated into a separate Microsoft PowerPoint slide to create the 2-D tank mapping.

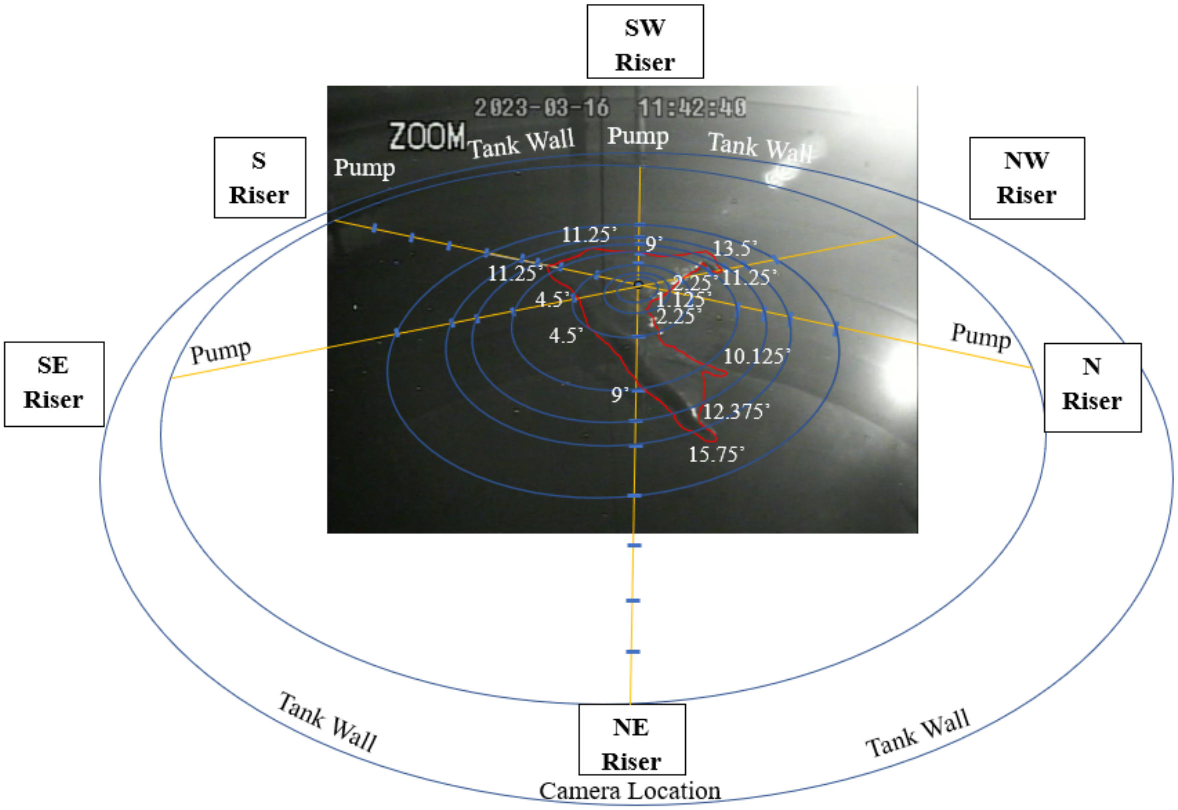


Figure 5. Camera Inspection Image with Directional Map. This example image demonstrates the various directional map features discussed above including the tank axis lines shown in yellow, the small blue axis markers, the positioning ovals shown in blue, and the white distance indicators at notable mound boundary points.

Creating the 2-D tank map starts with a recreation of the tank diagram to identify the tank risers. Reference lines, similar to the axis lines described above, are also added to identify the tank quadrants and to connect the various risers. The reference lines represent the digital equivalent to the tank diameter. Because of this, the reference lines can be used to calculate a sizing ratio, which relates the actual tank distances to an equivalent digital tank distance. In this example, a sizing ratio of 0.08565 digital in/actual ft (0.0071 digital m/ actual m) is calculated by determining the digital length of the tank radius, 3.64-in (0.0925-m), and dividing that value by the known actual length of the tank radius, 42.5-ft (12.95-m) [7]. Additional reference lines may be added as necessary to assist in defining the waste mound extremities. The tank diagram image and added quadrant lines are then grouped in PowerPoint so that they may be easily rotated as one image.

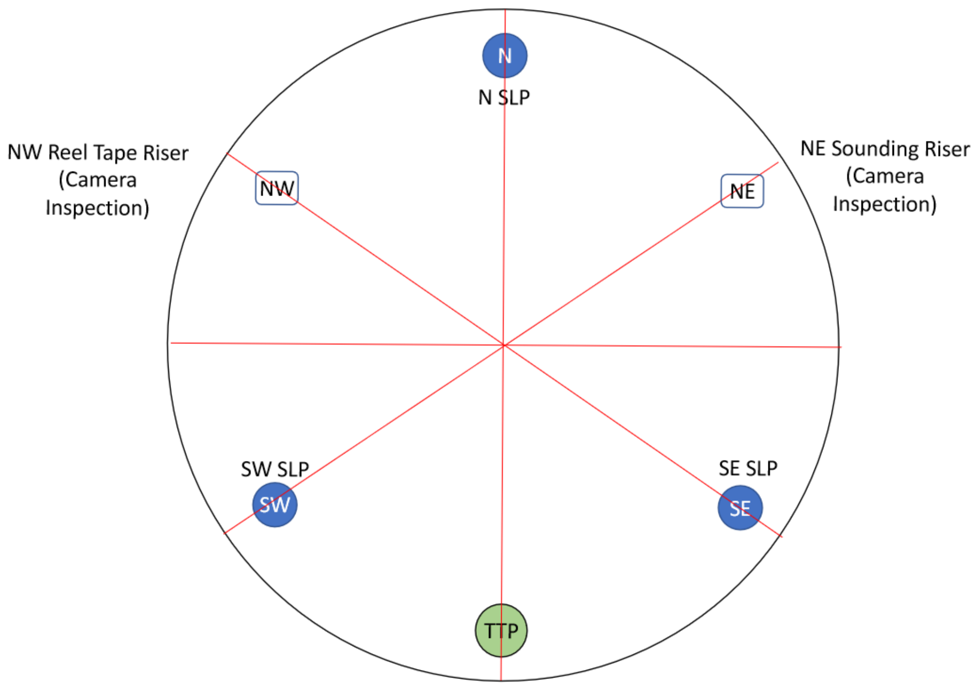


Figure 6. Tank Map Base. This will be the base onto which the camera inspection results will be translated. The reference lines are shown in red.

After the base of the map has been created, the sludge mounds from each of the camera inspections can be added onto the map starting with the highest peaks. In this example, the highest peaks were witnessed at 19 and 24 inches (48.26 and 60.96 centimeters). The distances identified on the camera inspection directional map [Figure 5] will be added as line shapes onto the 2-D tank map starting from the tank mid-point [Figure 6]. These distance lines will be scaled to the correct lengths, as identified in Figure 5, by applying the calculated sizing ratio. Note that the orientation of the camera inspection directional map does not align with the orientation of the 2-D map as presented in Figures 5 and 6. The corresponding reference/axis lines between the two maps are used to determine where to place the distance lines that are created for the 2-D map. When adding the scaled distance lines onto the 2-D map, the 2-D map should be rotated so that the line shapes can be added as a vertical line (0- inch/centimeter width) onto their correct tank location. This approach will avoid the need for additional scaling of the line width. Be sure to group the newly added distance lines to the rest of the 2-D map image so that the entire image can be rotated as necessary to continue development of the tank map. Once all sludge mound lines are created for a given tank liquid level, the 'Freeform: Scribble' shape tool is used to connect the edges of the lines which creates the sludge mound shape [Figure 7]. This same approach is used for all camera inspection tank levels that are considered in the mapping. Once all camera inspection images were translated, the reference lines were removed from the final tank map [Figure 8].

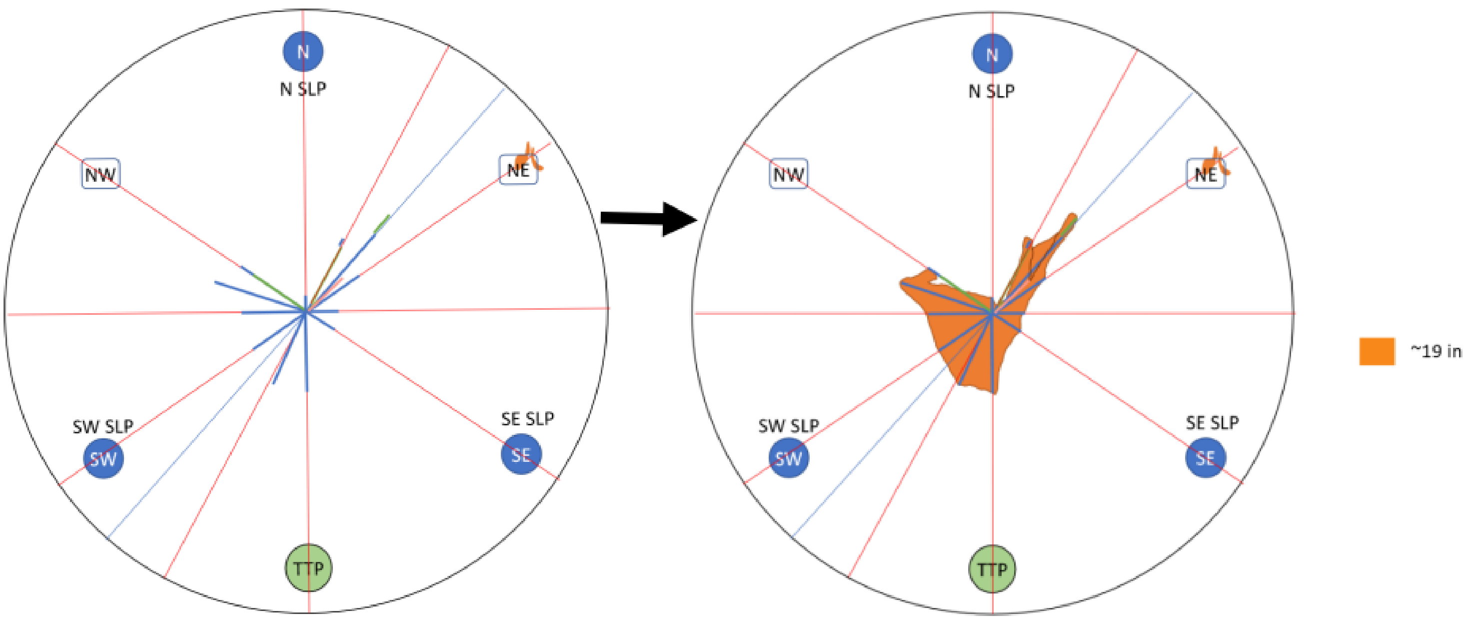


Figure 7. Sludge Mound Creation on the Tank Map. This example shows the scaled distance lines on the left tank map and on the right tank map shows how these distance lines are connected to create the sludge mound shape for a given liquid level.

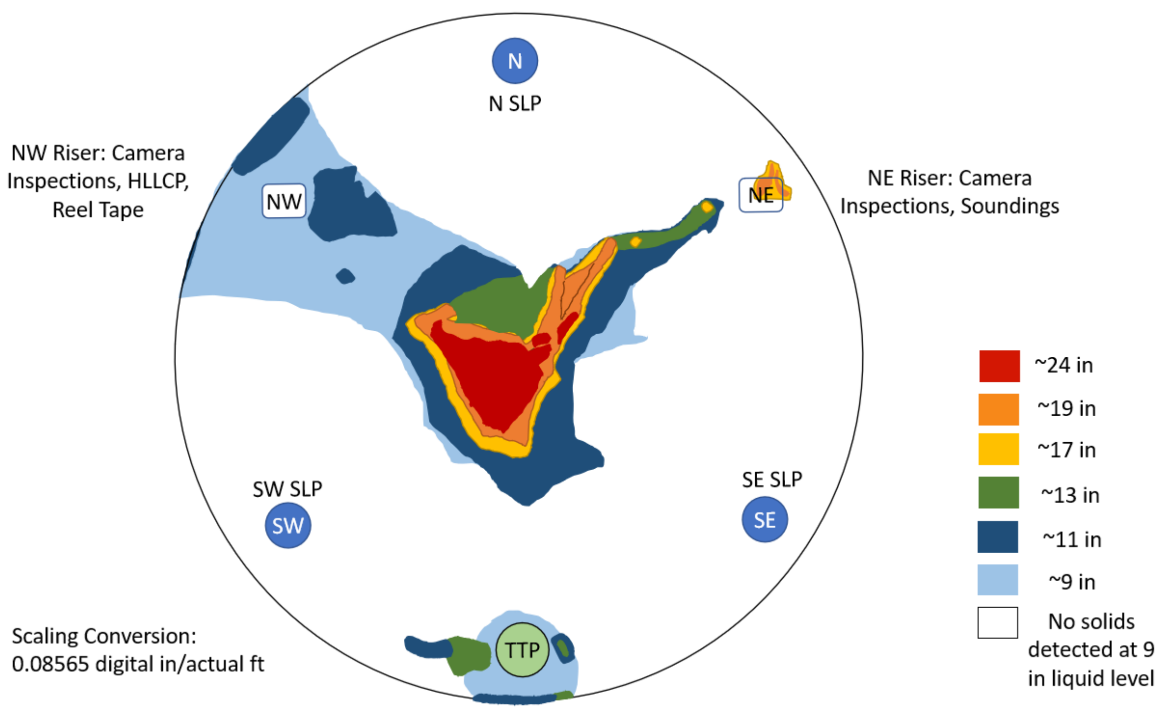


Figure 8. Tank 22 Final Tank Mapping. This is an example of a completed tank map which utilized the tank mapping methods described above. Each colored section represents new sludge mounds that became visible at that corresponding liquid level. The transfer was terminated at a liquid level of approximately 9 inches (23 centimeters).

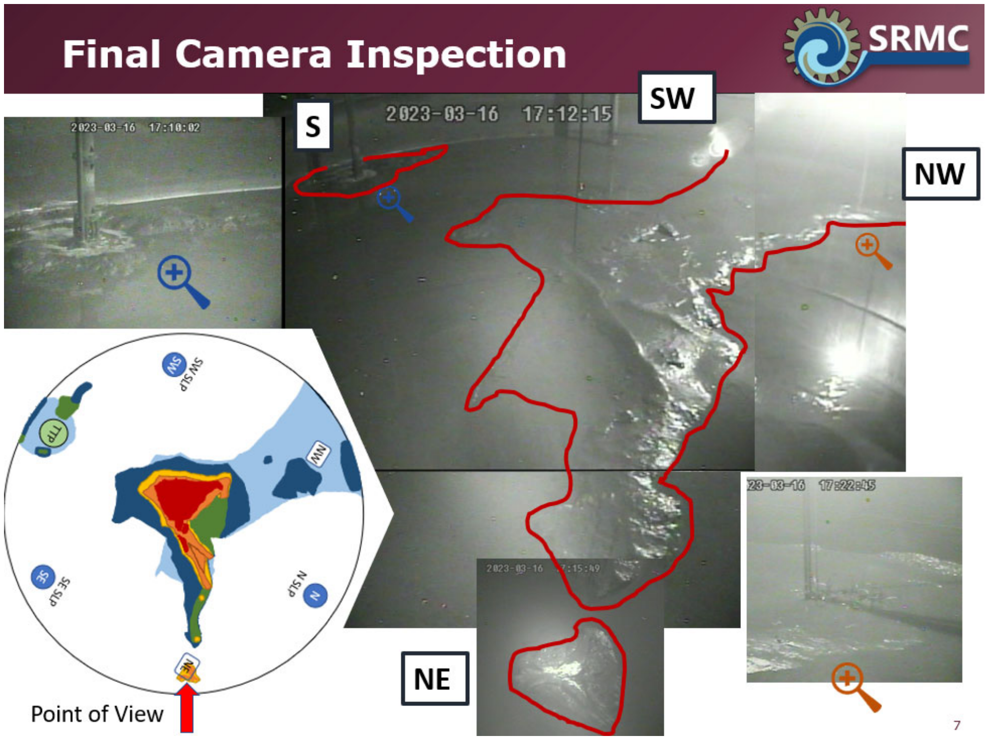


Figure 9. Comparison of Tank 22 Map and Camera Inspection Images. The camera inspection images are overlaid to produce one continuous view within the tank. The two magnifying glasses show zoomed in images of the S and NW risers.

SLUDGE VOLUME DETERMINATION

As discussed, the tank map created can be used as a tool to inform future operating strategies and to refine the credited tank sludge volume. To refine the tank sludge volume, a sludge volume determination is performed in Excel. Specifically, an excel tank map is created, which breaks up the surface area of the tank into 1-ft by 1-ft squares (or 1-m by 1-m squares). Each square will contain a sludge height input in inches (or meters) as shown on the tank map. To fill in the sludge volume map squares with the correct sludge levels, the final tank map [Figure 8] is overlain onto the Excel map such that the two tank diagrams align and the tank map can be used as a template. The sludge volume map conservatively applies the sludge level heights seen in Figure 8 to the corresponding square area [Figure 10]. If certain squares intersect at two or more sludge heights, the largest sludge height value is conservatively selected for that square to maximize the total sludge volume. The heights in each square foot (or square meter) box are then converted to feet (or left as meters) and added together to determine a tank volume in ft^3 (m^3) which can be converted to gallons (or left as m^3). The Excel map is color-coded to show the highest sludge levels in dark red and transitions to progressively lighter shades of blue for the lower sludge levels depicted. This sludge volume map assumes that the sloped edge coming off from the visible mounds starts at the post-transfer liquid level of 9 inches (approximately 0.23 meters) and decreases by 1-inch (1-meter) for each subsequent square coming off from the mound both vertically and horizontally. This progression continues until only 1-inch squares remain (0.03 meters). If a square has conflicting slope height requirements from the horizontal and vertical direction, the larger of the two slope values is selected and the decreasing slope progression continues from that selected value. This is a conservative assessment of the remaining sludge below the supernate surface [8].

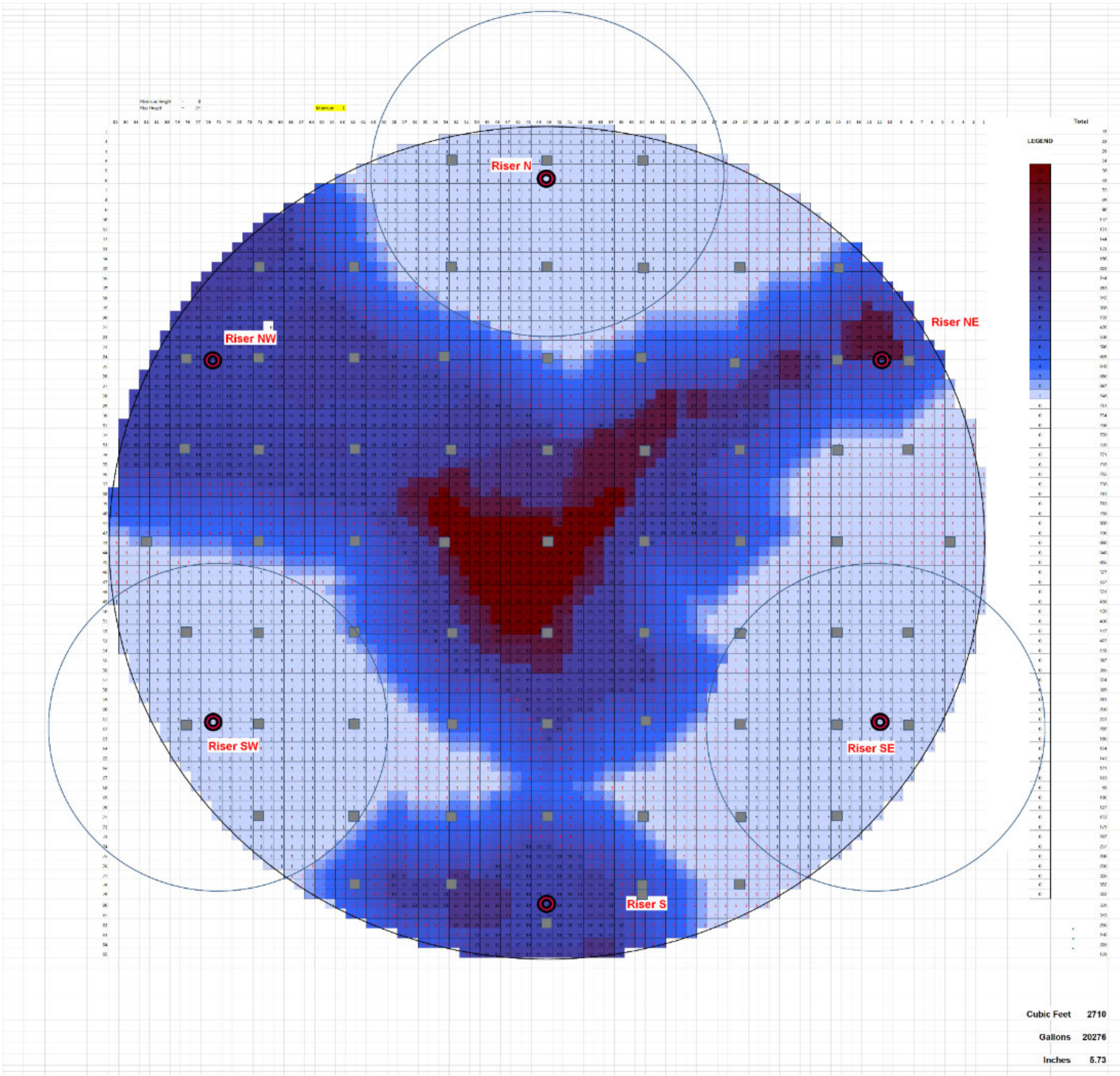


Figure 10. Sludge Volume Map. The more accurate your tank map is, the more refined your final sludge volume will be which will improve your required flammability controls.

CONCLUSION

The mapping method described in this paper creates a standardized approach for accurately defining the waste distribution within a waste tank while minimizing the required camera inspection footage. This mapping method can be used to improve operating decisions and refine flammability controls.

This tank mapping method is most useful in Type 4 waste tanks in which a wide, unobstructed view of the inside of the tank is possible. However, despite the potentially limited applications, this process resolves a unique challenge associated with Type 4 waste tanks in that it provides context to determine the positioning of waste mounds that are not near tank landmarks, notably the waste mounds near the tank center. Without any tank landmarks of known position to reference in the camera inspection, it is very difficult to determine an accurate tank mapping of the observed waste mounds, especially considering the effects of perspective distortion.

The mapping process described can be improved by creating a full view camera inspection image using various camera shots that are all fully zoomed out and can be overlayed to fit together as one image. An example of this can be seen in Figure 9. Utilizing this method to create a full view camera inspection image before creating the directional map will improve results in that the riser locations that are not pictured will not need to be estimated.

The mapping process presented was used during the 2023 Tank 22 Sludge Removal Campaign. This mapping process contributed to the success of the 2023 sludge removal campaign by allowing for a significant increase to the credited sludge volume reduction in Tank 22. Using this mapping method, Tank 22 was able to credit a sludge volume reduction of 73%, which was an improvement of 31% above the previous Tank 22 sludge removal campaign [8,9].

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