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May 10, 2022

Mr. Dennis Todd
City of Lake Waukomis
1147 NW South Shore Drive
Lake Waukomis, MO 64151

Re: Lake Waukomis Dam/Abutment Seepage Project
Affinis Job No. 21-0909-01
DRAFT Seepage Assessment Report

Dear Mr. Todd,

Affinis Corp team has been retained by the City of Lake Waukomis to assess the current seepage of Lake Waukomis, document findings in a report, and provide recommendations for the City to select a preferred alternative. The preferred alternative will then be taken to a final design. The purpose of this report is to summarize the findings of the Affinis team's assessment and provide recommendations to the City for the selection of the preferred alternative.

A document search was performed of the stored documents located at City Hall. Documents determined pertinent to the seepage study were copied, scanned, and file names assigned based on the document date and description. Using the documents obtained from the document search history of the dam was summarized concerning seepage. Pertinent documents were used within the report as overlays for determining site-specific seepage.

Figure 1 is an aerial view of the dam.

Figure 1-Aerial View of Dam

Dam History

The original dam was constructed in 1945. To help orientate the reader, where the abutment location is stated as West it refers to the “right” abutment. Where the abutment is stated as East it refers to the “left” abutment. The following is a chronological order of historical modifications or issues that relate to seepage

- 1955: A seepage study was conducted that identified seepage coming out of the Plattsburg Limestone near the West Road Ditch of Highway AA.
- 1963: Seepage was identified in the NorthEast abutment ridge
- 1964-1965: The left abutment was grouted by P.J. Judy Company, Kansas City, Missouri.
- 1966-1968: Plans and specifications were prepared to raise the dam, widen the spillway, and construct a two-lane road across the dam. Modifications were constructed from 1967 to 1968.
- 1976-1979: A slide was identified in the NorthEast portion of the embankment in 1976. Plans, specifications, and slide repairs were all completed in 1979.
- 1982: The Judy Company was hired to grout the NorthEast abutment ridge. This work was not safety-related and not required by the State Dam and Reservoir Safety Program.
- 1987: Plans and specifications were submitted to grout the SouthWest abutment and raise the dam. Grouting and dam raise construction began in October 1987. Grouting effort reduced the measured seepage at a v-notch weir from 300 gpm to 2 gpm (December 1987 Judy Company grouting report).
- 1993: Annual dam inspection noted West abutment seepage greater than in previous years (estimated 150 gpm).
- 1995: Annual dam inspection noted 150 gpm seepage.
- 1996-2000: Annual dam inspection noted West abutment consistent seepage ranging from 150 gpm to 180 gpm.
- 2002: Annual dam inspection noted West abutment seepage ranging from 820 to 1,100 gpm.
- 2003: West abutment grouting performed by Judy Company.
- 2005: Annual dam inspection estimated West abutment seepage less than 200 gpm.
- 2008: Annual Dam inspection noted seepage near road ditch of NW Waukomis Drive adjacent to the East abutment (no flow rate noted in the report). No West abutment seepage was noted.
- 2010, 2012, 2014, 2015, 2017: Annual Dam inspection noted seepage near road ditch of NW Waukomis Drive adjacent to the East abutment (no flow rate noted in the report). No West abutment seepage was noted.
- 2012: During construction of the 36-in water pipe water seepage from an exposed rock face was encountered. Construction of the 36-in waterline required placing fill. To allow drainage of the seepage a 24-in HDPE pipeline was constructed to drain the seepage to the West ditch of NW Waukomis Drive.
- 2019: The dam seepage report stated that when the lake was 5.5-ft below normal pool the West abutment seepage was measured to be 249 gpm and when the lake was at normal pool seepage was measured to be 355 gpm. The East abutment seepage pipe was noted to be less than the West seepage flow (no weir at the East abutment pipe).
- 2020: The dam inspection report by MoDNR noted “major” seepage in the West abutment groin and “minor” seepage in the East abutment groin.

Since the original construction, there have been several occasions where seepage was determined excessive and grouting operations were necessary. Grouting has been performed typically in or near the abutments. The West Abutment has typically been the location for high seepage rates. See Appendix A for key historical documents related to dam seepage and past grouting programs.

Description and Technical Assessment of Field Activities

Introduction

Following a review of available, historical documentation, coupled with the visual observation and documentation of the locations and estimated flow rates for active areas of abutment seepage, a two-phase approach was implemented to spatially identify and quantify the subsurface locations/zones of abutment seepage. The approach was comprised of two (2) components:

1. A boots-on-the-ground visual inspection for seepage was performed on November 16, 2022, to determine any visual signs of seepage occurring at the ground surface.
2. A topographic survey was performed to locate the visual seepage locations found and to supplement the 1987 Record Drawings.
3. A geophysical/resistivity survey to identify and estimate the vertical and horizontal locations of active pathways of subsurface abutment seepage. The survey focused on the West and East abutment areas.
4. A drilling and sampling program of the subsurface/bedrock strata that corresponded to active seepage paths identified by the geophysical/resistivity survey. This drilling/sampling effort can essentially be defined as a "ground truthing" process.

Visual Inspection

A boots-on-the-ground inspection was performed on November 16, 2022. The West and East abutments and dam toe were inspected for possible visible seepage. The approximated lake water surface elevation was estimated 1.5-ft below the spillway crest at an elevation of 938.5-ft.

The West abutment seepage locations were numbered (SP-0 to SP-8), staked, and flagged to be surveyed for vertical and horizontal locations (see Figure 2). The West seepage elevations ranged from elevation 910-ft to 904-ft. The seepage flow was estimated at each identified seepage location. In general, the seepage decreased from SP-0 to SP-8 (decreasing moving East to West). The West abutment weir was measured, and discharge flows were calculated for the V-notch weir. See Figure 7 for a summary of the estimated seepage and weir flows.

Figure 2 shows the West abutment seepage locations found during the boots-on-the-ground inspection.

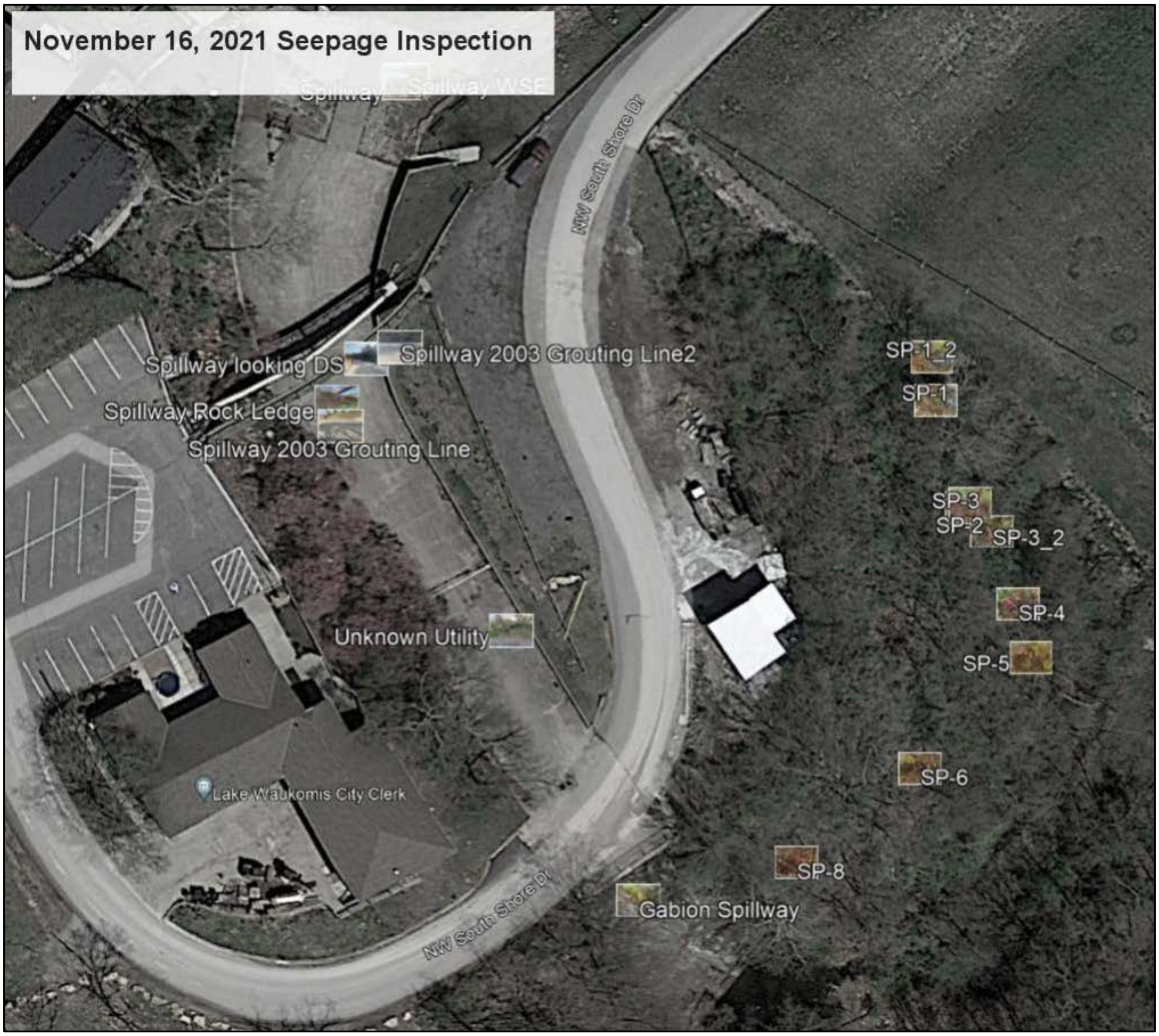


Figure 2-West Abutment Seepage Locations

Figure 3 is a photo Seepage Point #1 where the highest seepage flows were estimated.

Figure 3- Seepage Point #1

Figure 4 is a photo of the West abutment seepage weir.

Figure 4- West Abutment Seepage Weir

The East abutment inspection found only a single location for visual seepage coming from the 24-in HDPE (see Figure 5). The East abutment looked dry and free from indicators of seepage. A 48-in RCP had some discharge that was coming from inside the pipe as well as from what appeared the granular bedding material below the pipe. Flow from the 48-in RCP is likely from upstream drainage. The approximate seepage discharge elevation from the upstream end of the HDPE pipe is 917-ft based on as-built drawings from the 2012 bulkhead construction.

Figure 6 shows the East abutment seepage location found during the boots-on-the-ground inspection. The East abutment inspection only found one seepage location to be discharged from the left abutment bulkhead drain (24-in HDPE pipe). The HDPE does not have a weir for measuring discharge flows. However, the depth of the pipe was measured, and an estimated flow was calculated. See Figure 7 for the estimated pipe flow.

Figure 5- East Abutment Seepage Location

Figure 6 is a photo of the East abutment seepage from a 24-in HDPE pipe.

Figure 6- East Abutment Seepage Discharge from 24-in HDPE

Figure 7 is a summary of the estimated seepage found during the visual seepage inspection.

Seepage No.	Location	Picture No.	Est. Seepage (gpm)*	Notes
Right Abutment				
SP-1	Right Abutment	SP-1	200	3 seepage points in area
SP-2	Right Abutment	SP-2	10	
SP-3	Right Abutment	SP-3	50	
SP-4	Right Abutment	SP-4	10	
SP-5	Right Abutment	SP-5	1	
SP-6	Right Abutment	SP-6	75	
SP-7	Right Abutment	SP-7	25	Seepage extends from SP-6, outside weir flow
SP-8	Right Abutment	SP-8	25	Seepage extends from SP-7, outside weir flow
Spillway	Gabion	Spillway	50	Outside weir flow
		Total	**446**	Weir Reading = 7"; Q= 294 gpm or 422,794 gpd
Left Abutment				
HDPE	Left Abutment		171	24" HDPE pipe discharging to ditch, 2" flow

* gallons per minute (gpm); gallons per day (gpd)

Figure 7-Field Summary of Visual Seepage Inspection

Figure 8 is the summary of City provided West weir measurements and field measured water depth at the discharge of the East abutment 24-in HDPE.

Date	East Side Depth Measurement (inches	West Side Weir Measurement (inches)	Water Level at Dam (feet)	East Side Flow (gpd)	West Side Flow (gpd)	East and West Combined Flow (gpd)
5/6/2021	2	6.5	4	246,345	351,804	598,148
08/04/21	2	6.5	4	246,345	351,804	598,148
08/10/21	2	6.5	4.25	246,345	351,804	598,148
08/18/21	2	6.5	4.25	246,345	351,804	598,148
08/24/21	2	6.5	0	246,345	351,804	598,148
09/16/21	2	6.5	0.25	246,345	351,804	598,148
10/09/21	2	6.5	0.5	246,345	351,804	598,148
11/12//21	2	7	1	246,345	422,784	669,129
12/12/21	2	7	1.08	246,345	422,784	669,129

* gallons per day (gpd); convert to gpm: gpm = gpd/1,440

Figure 8- Summary of City Provided Weir Measurements and Calculated Flows

Geophysical/Resistivity Survey

Electrical Resistivity Tomography (ERT) Spontaneous Potential (SP) area mapping tools are typically used for the investigation of earth structures (such as dam abutments) to identify and assess potential areas related to seepage. ERT and SP methods are particularly suitable types of geophysical investigation methodology for mapping dam seepage, given the overall sensitivity of these methods to moisture content and saturation of subsurface materials.

As reservoir water infiltrates and saturates areas of an earth structure, particularly spillway and abutment areas, electrical conductivity will increase, thereby providing high contrast between dry and saturated material. This contrast provides an excellent “target” for subsurface electrical resistivity mapping. Using small, steel electrodes arrayed on the surface, a small electrical current is introduced to the soil/bedrock at a given location and the voltage is measured along the remainder of the array. Results are typically provided as two-dimensional (2D) cross-sections which results in a straight-forward identification of low resistivity (high conductivity) that generally indicates conditions/pathways of seepage.

ERT and SP are cost-effective and non-invasive investigative techniques that can identify areas associated with seepage in, around, and beneath earthen dams and spillways, thereby providing information related to subsurface zones that require mitigation, such as grouting, to minimize/reduce flow and improve the long-term performance of the earth structure.

A geophysical survey using resistivity mapping was undertaken by Geotechnology, LLC at the Lake Waukomis Dam during the week of December 6, 2021. The results and summarization of this mapping effort are presented in the report contained in Appendix B

The ERT and SP effort generally identified eight (8) anomalous areas of suspected seepage. The locations of these suspected areas of seepage are depicted in Figures 9, 10, 11 and 12. Of these eight (8) anomalies and following a review of the resistivity results and the general conditions in these areas, Anomalies 1, 6, and 7 were not deemed to be of any significant concern with regard to abutment seepage. These anomalies were eliminated from consideration with regard to drilling and sampling, primarily due to possible “false indicators” due to electrical interferences caused by metal guard rails and other similar features.

Figure 9- Aerial View Geophysical Survey Lines

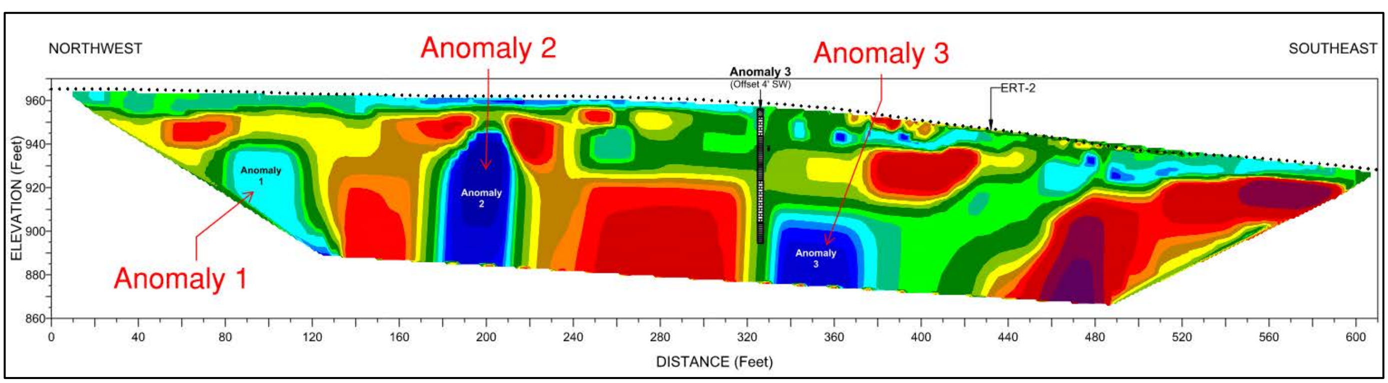


Figure 10- Geophysical Survey - ERT Line 1

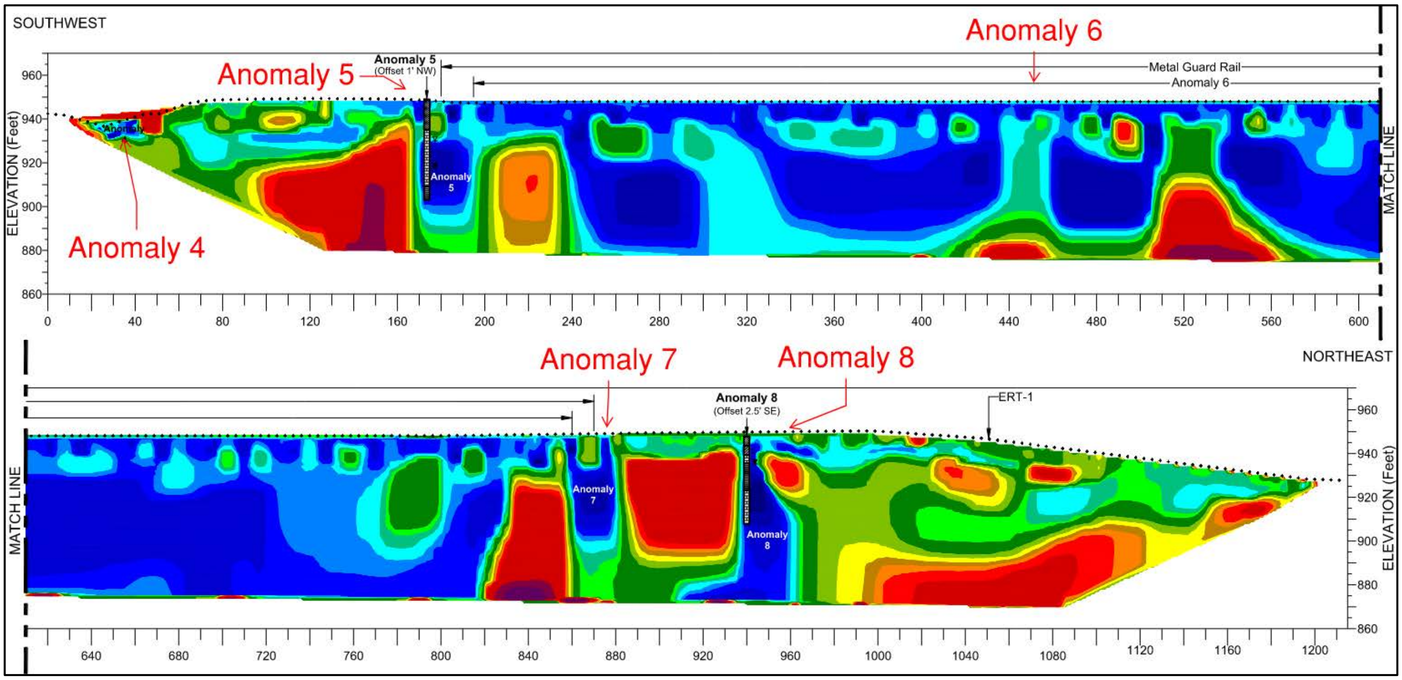
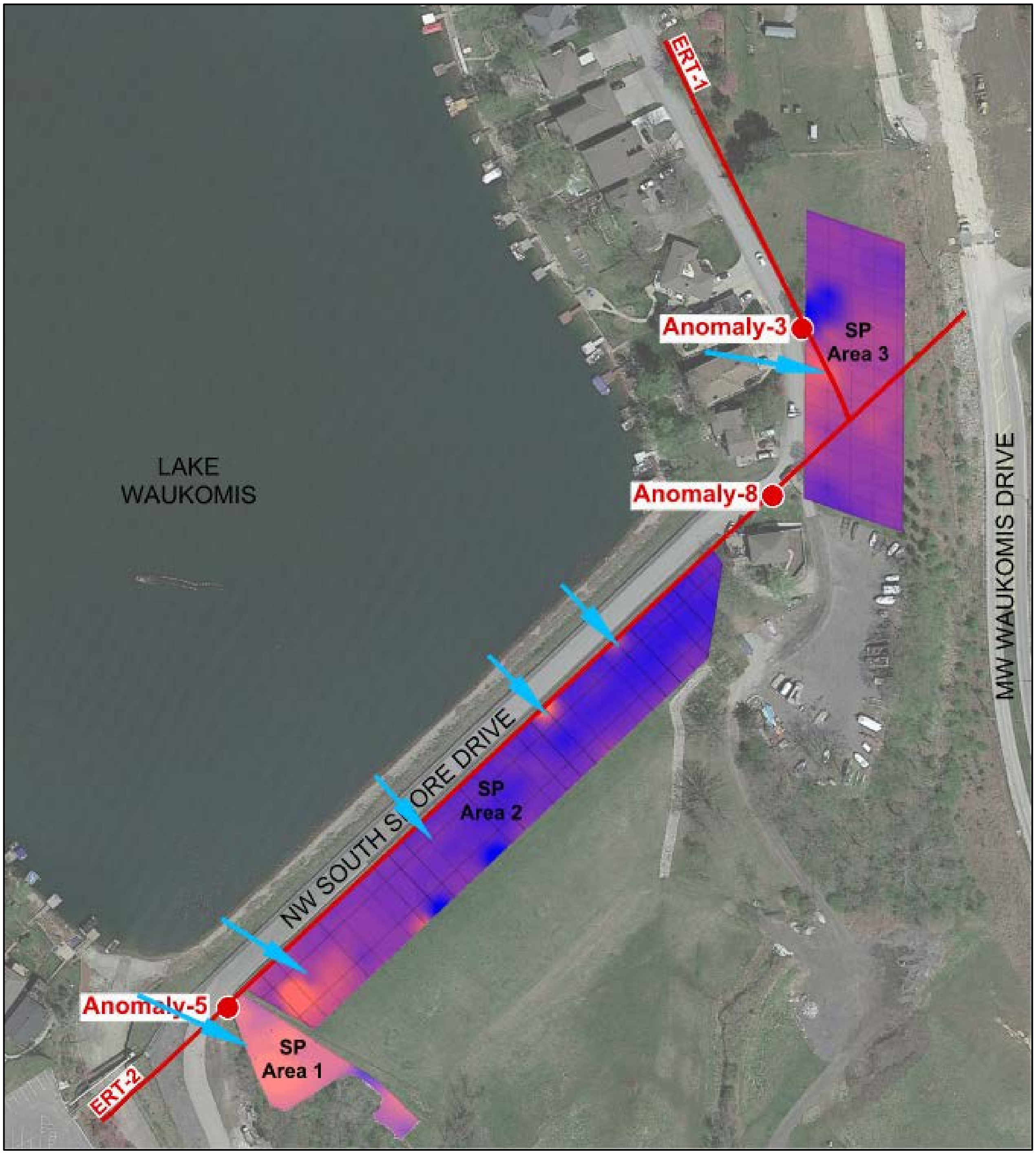


Figure 11- Geophysical Survey - ERT Line 2



<u>Figure 12- Spontaneous Potential Areas with Interpreted Seepage Path</u>

Of particular interest were Anomalies 4 and 5, which were located in areas of the West abutment that had been the focus of previous/historical grouting programs. Both of these areas were grouted using inclined grout holes (spaced at 5-10 feet), likely to intercept vertical joints or features in the lower bedrock units – the Captain Creek Limestone below the spillway (Anomaly 4) and the Spring Hill Limestone in the West abutment (Anomaly 5). A review of the orientation and spacing of the grout holes at both locations (see Figure 13) indicates possible "windows" in the grout curtain at both locations, thereby indicating the need to possibly implement a grouting program with more closely-spaced grout holes.

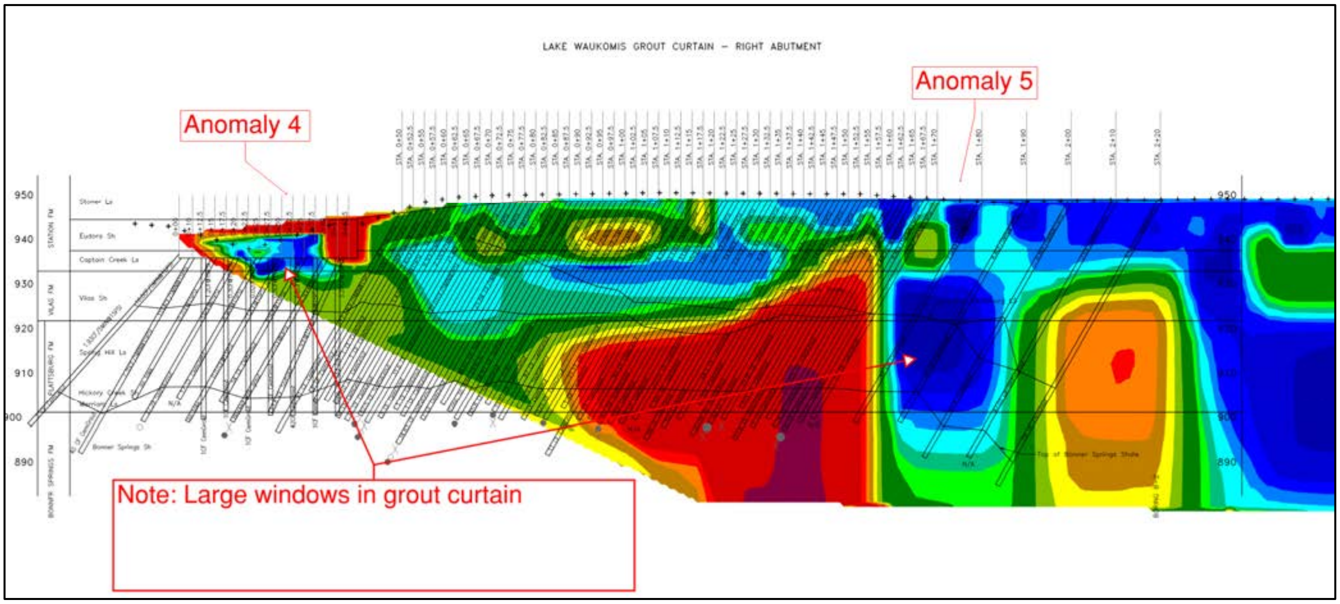
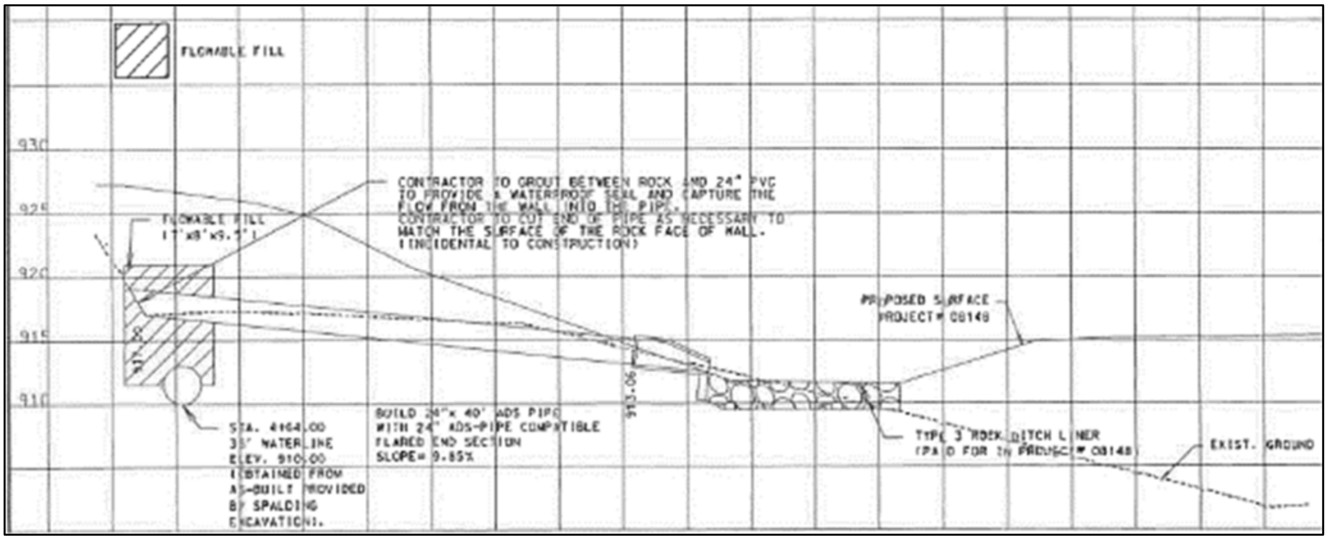


Figure 13- 2003 Grout Profile Overlay on Geophysical Survey (ERT-2)

With regard to the East abutment, an evaluation of Anomaly 2 would indicate that an existing buried utility of unknown origin may have been identified by the ERT. Anomaly 3 appears to be related to a West-to-East reservoir seepage path through bedrock that is ultimately being intercepted by a buried bulkhead located between the dam and NW Waukomis Drive (see Figure 14). This buried bulkhead was constructed in 2012 by a contractor to control excessive seepage water emanating from a vertical trench wall in a bedrock excavation for a storm sewer pipe placed along the West side of NW Waukomis Road. Anomaly 8 suggested a very discrete, vertically-oriented seepage path that is likely related to a vertical feature/seam within the subsurface bedrock profile.



<u>Figure 14- East Abutment Seepage Buried Bulkhead</u>

It should be noted that historic grouting had not been previously conducted in the East abutment since 1965.

Drilling/Sampling of Bedrock Strata

Following a review and evaluation of these areas of perceived/significant seepage, the following areas were selected for the supplemental drilling of "ground truthing" borings to confirm the geologic stratum present and to attempt to identify the vertical locations of possible seepage paths, as well as to possibly quantify seepage conditions via the use of packer permeability testing.

East Abutment Area

- Anomaly 3 – NE of Dam, between NW Shore Drive and NW Waukomis Drive
- Anomaly 8 – Approximate Dam Station 9+40

West Abutment Area

- Anomaly 5 – West Abutment at Approximate Dam Stations 1+50 to 2+00

The results of the field drilling/sampling activity are presented in Appendix B. Additionally, the results of packer permeability testing are also presented in the drilling/sampling summary report.

A summary of key observations developed from a review of the data provided by the boring logs, bedrock core sampling, and packer permeability tests for each of the three (3) boring locations are discussed below. For the purpose of these discussions, please note that the reservoir water elevation can typically range from Elevation 939-ft to 936-ft. The water surface elevation of 937.98-ft was surveyed on December 9, 2021.

Boring at Anomaly 3

- The boring generally penetrated the Captain Creek Limestone, the Vilas Shale, and the Spring Hill Limestone. The boring terminated in the lower Bonner Springs Shale.
- Significant core loss (and possibly related poor rock quality) was noted at approximate elevations of 951-ft (Core Run 1), 945-ft (Core Run 2), and 938-934-ft (Core Runs 3& 4).
- Staining in the core in Core Run 8 (approximate elevation of 918-ft) and most of Core Run 9 indicated the presence of water.

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- Packer permeability testing indicated significant water infiltration under pressure for the interval of elevation 948-915-ft (Vilas Shale and upper Spring Hill Limestone).
- The static water level in the boring was noted at an elevation of 937-ft at a time 17.5 hours after completion of drilling activities, indicating some level of hydraulic communication with the lake.
- Significant grout loss when backfilling the boring was noted at an approximate grout elevation of 937-ft, indicating grout loss was occurring in the bedrock below this level.
- It appears that the upper portions of the Vilas Shale, along with the lower Vilas shale and upper Spring Hill Limestone, would be candidate locations for lateral subsurface seepage.

Boring at Anomaly 5

- The boring generally penetrated the Spring Hill Limestone and terminated in the lower Bonner Springs Shale.
- Significant core loss (and possibly related to poor rock quality) was noted at approximate elevations of 935-928-ft (Core Runs 1 & 2), 927-918-ft (Core Runs 3 & 4), and 915-916-ft (Core Run 5).
- Staining in the core above elevation 922-ft in Core Runs 3 & 4 and below elevation, 918-ft in Core Runs 5 & 6 indicated the presence of water.
- Packer permeability testing indicated significant water infiltration under pressure for the interval of elevation 920.5-910.5-ft (lower Spring Hill Limestone).
- The static water level in the boring (via temporary piezometer) was noted at elevation 918-ft at a time 43 hours after completion of drilling activities, indicating some possible level of hydraulic communication with the lake.
- It appears that the entirety of the Spring Hill Limestone would be a candidate location for lateral subsurface seepage.

Boring at Anomaly 8 (Boring 8)

- The boring generally penetrated the Captain Creek Limestone, the Vilas Shale, and terminated in the Spring Hill Limestone.
- Significant core loss (and possibly related poor rock quality) was noted at approximate elevations of 937-ft (Core Run 1) and 924-ft (Core Run 4).
- Minor staining in the core for Core Runs 1 and 2 (elevation 940-936-ft), as well as Core Runs 6 and 7 (approximate elevation of 918-908-ft), indicated the presence of water.
- Some minor vertical seams/fractures were noted in the bottom of Core Run 5 at an approximate elevation of 918-ft.
- Packer permeability testing did not indicate significant water infiltration under pressure for any of the intervals tested within the Spring Hill Limestone. The fact that the packer testing did not identify any high permeability zones may indicate that discreet, vertically-oriented joints may be the source of water movement.
- The static water level in the boring was noted at an Elevation of 935-ft at a time 24 hours after completion of drilling activities, indicating some level of hydraulic communication with the lake.
- It appears that the lower portion of the Spring Hill Limestone (elevation 919-ft to 909-ft) would be a candidate location for lateral subsurface seepage.

Ace Pipe Cleaning Video Inspection

[Pending Pipe Cleaning video inspection of existing gravity sewer lines at the West and East abutments.]

Conclusions - Key Areas of Seepage

Based on a technical review and assessment of the available historical information, the data related to current areas of observed seepage, a review of the ERT and SP survey data, and the results of the "ground truthing" borings/field testing conducted at key anomalous areas, it is concluded that the following areas should be considered as primary locations for supplemental formation grouting to minimize/reduce lateral reservoir seepage. The formation grouting should use both vertical and inclined grout holes, as well as horizontally/vertically staged grouting processes. A variety of grout types, ranging from standard grout mixes to specialized chemical grout mixtures, may need to be considered for the abutments of the Waukomis Dam. An important component of any of these grouting programs would include both qualitative and quantitative observation and monitoring of both existing seepage areas and seepage weirs. This monitoring component, conducted during grouting operations, will directly indicate the relative effectiveness of the grouting program in reducing the magnitude of the current abutment seepage.

1. For Anomalies 3, 5, and 8, the formation grouting effort would be focused on the entirety of the Spring Hill Limestone, with the exception of the Anomaly 3 where upper and lower portions of the Vilas Shale may also require treatment.
2. For Anomaly 4 encountered below the spillway, the formation grouting effort would be focused on the Captain Creek Limestone and the upper portion of the Vilas Shale.

Alternatives Summary

The proposed alternatives have been split between the West Abutment and East Abutment for proposed grouting locations. See Appendix D for the proposed alternatives exhibit and Appendix E for the opinion of construction cost for each alternative.

West Abutment

The West Abutment has two alternatives identified for grouting. See Figure 15 for Alternative 1W and Alternative 2W for location and limits.

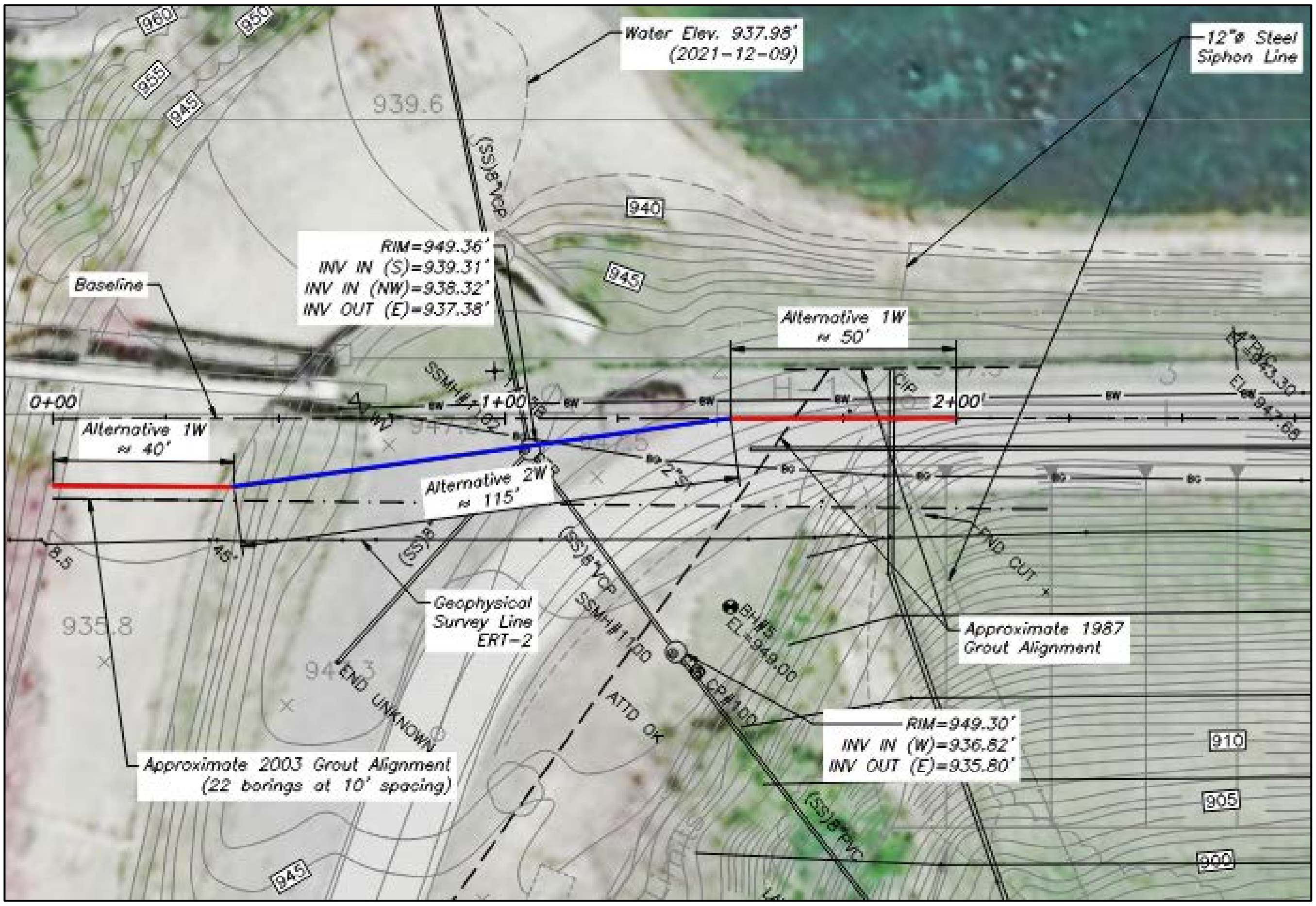

Figure 15- Alternative 1W and 2W

Alternative 1W: Install two Discreet grout lines.

- Grout lines would intersect the seepage locations identified as Anomaly 4 and Anomaly 5. The proposed grout hole spacing would be less than the 2003 grout curtain (10-ft primary spacing). A single grout line using the split-spacing technique.
- Anomaly 4 Area: grout curtain minimum 5-ft in front of the previous grout line. Provide a primary grout spacing of 8-ft, secondary at 4-ft spacing, and tertiary at 2-ft spacing. Grout approximate depth of 25-ft below the spillway (elevation 915-ft). The length of the grout line is approximately 40-ft. Use cement and chemical grout.
- Anomaly 5 Area: Grout near the center of the road with a proposed grouting length of 72 feet. The proposed approximate grout depth is 55-ft. Provide a primary grout spacing of 8-ft, secondary at 4-ft spacing, and tertiary at 2-ft spacing. Use cement and chemical grout.

Alternative 2W: Connect the two discreet grout lines

- The grout line would connect the ends of the two discreet grout lines proposed in Alternative 1W.
- A single grout line using the split-spacing technique.
- Alternative 2W would intersect any possible seepage paths that exist between Anomaly 4 and 5.
- The approximate proposed grouting length is 85 feet.
- The approximate grout depth of 55-ft (elevation 892-ft). The primary (vertical) spacing is 8-ft, secondary (vertical) at 4-ft, and 2-ft tertiary (vertical) spacing.
- Use cement and chemical grout.

East Abutment

The East Abutment has two alternatives identified for grouting. See Figure 16 for Alternative 1E and Alternative 2E location and limits.

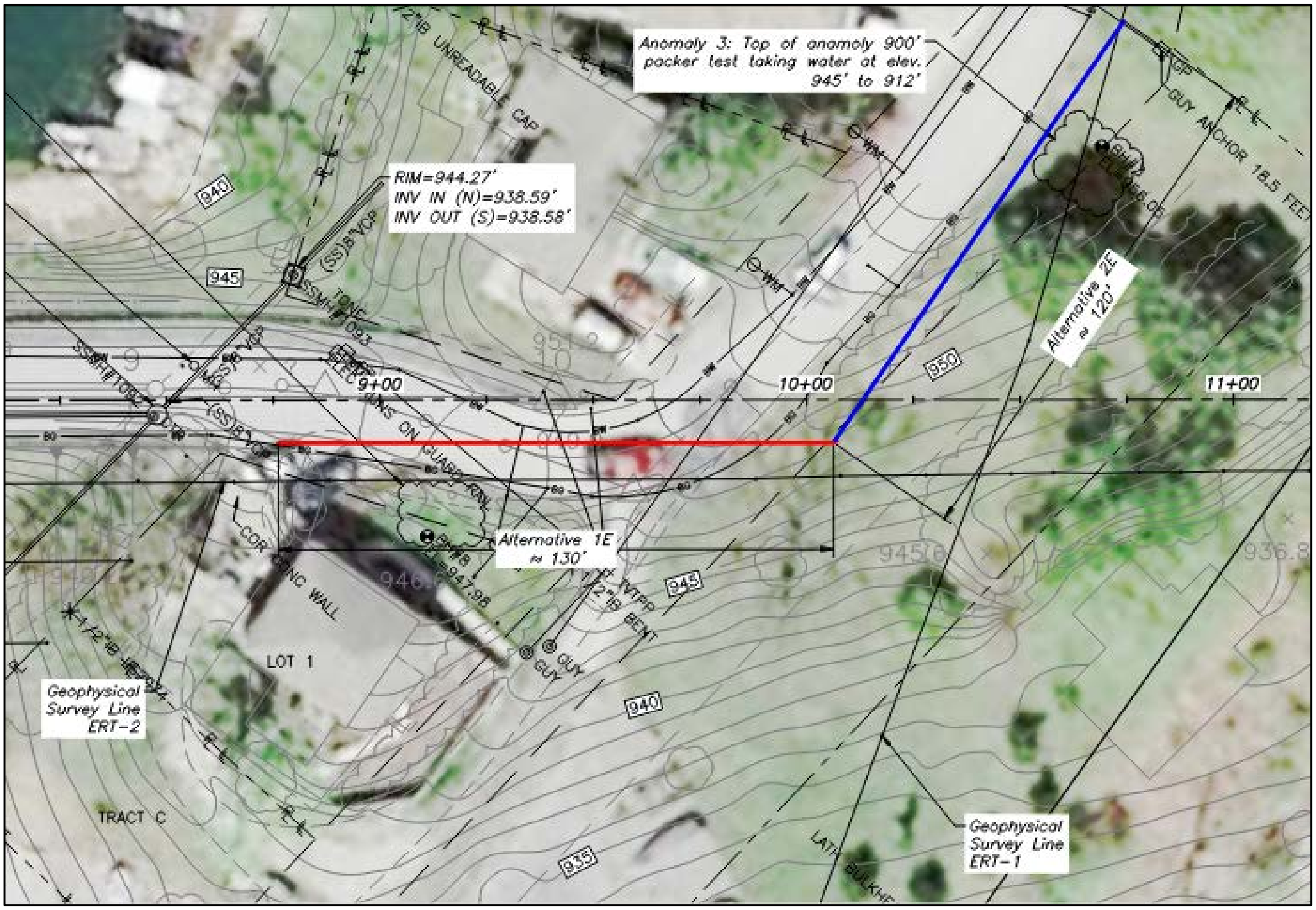

Figure 16- Alternative 1E and 2E

Alternative 1E: Install Primary Line

- Grout line would intersect Anomaly 8.
- A single grout line using the split-spacing technique.
- Anomaly 8 geophysical survey indicated a "bulge" at an approximate elevation of 920-ft. The proposed grout line would intersect the bottom of limestone at elevation 937-ft and a vertical feature located at elevation 916-ft. The proposed grout depth would extend to an elevation of 900-ft.
- The grout line length is 135-ft.
- The approximate grout depth of 55-ft. The primary (vertical) spacing is 8-ft, secondary (vertical) at 4-ft, and 2-ft tertiary (vertical) spacing.
- Use cement and chemical grout.

Alternative 2E: Install Secondary Line.

- Grout line would intersect Anomaly 3.
- A single grout line using the split-spacing technique.
- Anomaly 3: The top of the anomaly is located at an elevation of 900-ft. The boring indicated augur refusal at elevation 895-ft. The packer test-taking water elevations 945-ft to 912-ft. The proposed grout line would extend to an elevation of 885-ft.
- The approximate grout depth of 70-ft. The primary (vertical) spacing is 8-ft, secondary (vertical) at 4-ft and 4-ft tertiary (inclined) spacing.
- Use cement and chemical grout.

Recommendations

The recommendations have been split based on the either the West or East Abutment. The majority of measured seepage is currently located within the West Abutment. Therefore, the West Abutment is considered the main effort for reductions in overall seepage flows.

West Abutment

The recommended alternative for the West Abutment includes Alternative 1W. Alternative 1W is considered the minimum grout line based on geophysical survey results. Alternative 1W would provide a grout curtain to cutoff the seepage shown within the geophysical survey and based on previous mapping of geology from past grouting operations. Based on how grouting of Alternative 1W performs during field grouting conditions will dictate the need for Alternative 2W. If at the completion of grouting Alternative 1W a significant reduction in seepage is realized, then the decision can be made to complete Alternative 2W. The construction contract could be structured as Alternative 1W is the base contract with Alternative 2W as an alternate bid item.

East Abutment

The recommended construction contract structure would be to have Alternative 1E and 2E as bid alternatives. The East Abutment Alternative would be exercised as bid alternates based on the West Abutment grouting success. As stated above, the West Abutment currently is experiencing the majority of measured seepage. Therefore, the East Abutment should be viewed as the secondary for reduction of seepage flows. Order of completion for the East Abutment would be Alternative 2E first with Alternative 1E as second.

Recommended Order of Priority Completion:

1. Alternative 1W.
2. Alternative 2W.
3. Alternative 2E.
4. Alternative 1E.

Appendix A – Key Historical Documents
Appendix B – Geophysical Survey and Boring Logs
Appendix C – Ace Pipe Cleaning Video [to be added upon completion]
Appendix D – Alternatives Exhibit
Appendix E – Engineer's Opinion of Construction Cost

We appreciate the opportunity to be of assistance to the City of Lake Waukomis. Please contact the undersigned with any questions.

Sincerely,

Jason D. Davis, PE
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Gary J. Van Riessen, PE
Gary Van Riessen, P.C
Missouri: PE-019058

Cc: Project File