Site Investigative Report

GEOPHYSICAL SURVEY RESULTS AND FIGURES

Sympson Lake Dam Evaluation

For the Kentucky Transportation Cabinet (KYTC)

Nelson County, Kentucky

June 16, 2025

Seismic Refraction Geophysical Survey
Sympson Lake Dam Evaluation

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Survey Scope

HDR's scope of work is to perform geophysical services as a prime contractor to the Kentucky Transportation Cabinet (KYTC) for work at Sympson Lake Dam in Nelson County, Kentucky. This geophysical scope included steps for data acquisition, data processing, and data interpretation to aid in the general understanding of the subsurface conditions under/within the Sympson Lake Dam. The information collected will be used to help supplement data collected from previous investigations and exploratory borings. The goal of the geophysical surveys was to collect seismic lines within areas not easily accessible for drilling to help determine the top of rock surface and to correlate velocities to rock properties from nearby borings. The geophysical method HDR proposed to conduct at this site was seismic surface wave tomography using Refraction Microtremmor (ReMi). This method was originally chosen due to the anticipated highway noise and possible plant noise near the toe of the dam. However, with the help of KYTC's traffic control and further discussions internally, HDR determined a more high-resolution seismic refraction tomography (SRT), compressional wave source would provide better results. Mostly this was due to the anticipated resolution and the option to close down traffic to one lane over the dam during data collection for short periods of time. Both ReMi and SRT data collection methods use similar equipment; the main difference is in the record lengths and final data processing. ReMi uses surface wave energy and passive noise to model shear-wave tomograms versus the SRT, which is an active source only using compressional wave energy to produce P-wave tomograms. Seismic refraction lines were collected along the proposed lines shown in the work plan, including a long continuous line along the road at the crest of the dam and two shorter lines near the spillway both mid-slope and near the toe of the dam.

A Ground Penetrating Radar (GPR) survey was completed within the concrete weir and spillway. The GPR was utilized to search for large anomalous areas that could represent shallow voids below the concrete. The GPR system HDR used was a dual frequency antenna setup to help image both shallow concrete and voids immediately below the slab, as well as a lower frequency to help increase the depth of penetration to help search for larger voids deeper below the concrete surfaces. More information on the methods and survey results can be found in the following sections.

Seismic Refraction Results

Summary

For the identification and delineation of bedrock and bedrock-like materials and possible weak/low velocity zones above and within the bedrock, HDR utilized a seismic refraction geophysical survey method to collect 3 seismic lines between August 20th and the 22nd, 2024. The survey consisted of approximately 2,830 linear feet of seismic refraction data collection. HDR utilized Bird Seismic Services (Bird) to provide a larger source and a larger seismic collection system, capable of layout and recording the 1,710 foot long Line 3 along the crest of the dam. The seismic survey was designed by HDR, and HDR personnel worked with Bird during collection. Data were reviewed in the field for quality, and final processing and interpretation was performed by an HDR geophysicist. The seismic collection system included up to 180 channels of 14 hertz geophones, cables, and a distributed seismograph system (Seistronix EX6). Line locations were marked out and recorded by HDR utilizing a virtual reference station (VRS) corrected GPS with sub-foot accuracies. Geophone spacings of 10 feet and source (shot) locations were taken approximately every 30 feet. A Betsey Seisgun was used as the seismic source. This source uses 10 gage shotgun shell blanks, and directs energy into the ground with the shell/end inserted approximately 10–12 inches below the surface. The seismic line locations are show in the Figure 1. The final data plots were processed with Intelligent Resources, Inc., Rayfract refraction tomography software.

Seismic Refraction Methodology

The seismic refraction method involves generating seismic waves at the ground surface. The seismic waves travel from the source through subsurface materials along a variety of paths including refracting along interfaces between soil or bedrock layers of differing seismic velocities. The returning seismic waves are recorded at various distances from the seismic source/shot through geophones placed along the surface. Seismic wave arrivals at the geophones are transmitted through cables to the seismograph for digital recording. Data are then processed by specialized refraction tomography inversion software, including analyzing the differences in elapsed time from the shot to detection of the seismic waves at various distances from the induced seismic source. A reconstruction of subsurface velocities can be made based upon the arrival times of the seismic energy. Refraction tomography is a relatively new processing method that produces two-dimensional (2D) velocity profiles, allowing for a more detailed analysis.

Seismic Refraction Summary

The seismic surveys were conducted along 3 designated lines, shown in Figure 1. The compressional wave (P-wave) velocity profile data were collected both along the shoulder of Highway 62 and the downstream side and toe of the dam. During data collection, VRS (corrected GPS) locations and elevations were collected along each line with a Trimble DA2 GPS unit. GPS location data was processed using a digital elevation model (DEM) from previous site surveys to extract elevations along the seismic lines. The seismic profiles are plotted as distance in feet along the lines and were processed using the elevations from the DEM. Subsequent geotechnical borings were conducted by the client and those locations are also shown in Figure 1 based on provided coordinates for each borehole.

Line 1 was near the toe of the dam and has a length of approximately 520 feet. This line is the shortest of the collected lines due to limited open space with adjacent wooded areas. Line 1 is nearly centered on the concrete spillway apron/bottom pool. Although 520 feet of geophones were deployed for Line 1, the total depth of the line was approximately 60 feet. We feel the shorter than anticipated profile depth is due, in part, to the relatively consistent and higher velocity interpreted rock surface being the shallowest along this line. Velocities of 4,500 feet per second (fps) to 6,500 fps that are consistent with typical top of limestone bedrock were observed at approximately 22–30 feet below the surface near the spillway and 18–24 feet below ground surface near the eastern flank. Borings 1009 and 1011 were located on the west and east sides of the spillway and 13 to 28 feet south of the seismic line (based on provided coordinates). These borings encountered limestone and started coring at a depth of approximately 14.5 feet. The corresponding velocities near these locations are lower than expected for limestone and could be related to a dipping rock surface (i.e., change in elevation along the rock surface), shallowing of the rock south of the seismic line location, or the amount of fracturing/weathering of the limestone and/or shale layers within the rock as a volume is decreasing the overall velocities of the rock, see Figure 2. Historic borings from a 1976 Dames and Moore investigation report were also added for comparison. These borings were performed prior to the overflow structure being added to the dam. B-6 was located in present day footprint of the overflow structure and approximately 4' south of Line 1, and B-7 was located west of the overflow and approximately 11' north of the line. Both borings show a similar depth to limestone as observed in the recent borings 1009 and 1011, and no anomalous zones or areas of significantly different materials noted above rock.

Line 2 was collected upslope from the dam toe and Line 1, see Figures 1 and 3. Line 2 was approximately 600 feet long and centered on the spillway. The depth achieved across this line was approximately 90 feet and it also exhibited a consistent and strong rock-like interface. Using similar velocities as mentioned above, the depth to interpreted rock is approximately 45-55 feet near the spillway and shallowest to the east at about 12–20 feet below the ground surface. Two anomalies were observed within the velocity zone above the rock surface, one under the spillway and a second apparent thicker zone, in the velocity range of 3,500–4,500 fps, a distance along the line of approximately 300-325 feet. This second anomaly was east of the spillway and included a lower than expected velocity that may be an indication of the presences of a wet or saturated zone or possibly the grout from former sinkhole repairs discussed in historic report reviews. The anomaly under the spillway had a higher velocity zone while the second anomaly east of the spillway exhibited a slightly lower velocity zone near the expected top of rock. Although the closest borings to this line were over 45 feet to the north along the roadway, the simplified logs for Boring 1008, 1010, and 1012 are shown on the seismic data plot, Figure 3. Borings 1008 and 1010 are located adjacent, west and east, of the spillway and limestone with shale was found at 68 and 50 feet, respectively. This 18 feet of elevation change in the rock surface occurred over a distance of approximately 100 feet and does generally follow a similar trend in the velocity zone mentioned above. However, when projected onto the data, Boring 1012 shows the limestone to fall above the ground surface at the seismic line location. This is expected to be due to a steeply dipping rock surface near the edges of the dam abutments. The steeply dipping rock surface near this abutment is anticipated to be trending more NW-SE based on the existing topography, and therefore, the near surface rock seen in Boring 1012 would better project to near the end of Line 2 or even just off-end of the line. Again, similar to Line 1, the 1976 Dames and Moore boring data were included in the interpretation. B-5 and B-8 were added to Figure 3 and locations shown on Figure 1. A similar trend in depth to top of the limestone was observed in these historic borings and the current ones. One noteworthy observation is that, based on the 1976 report best fitting of the boring layout figure to the current project's GIS map, B-5 appears to be located within the current day position of the spillway and one of the anomalous areas mentioned above. Nothing on the log for B-5 indicates a change in the dam fill materials. Further, the existing intake structure's pipe/duct system that would be crossing in this area is anticipated to be lower in elevation than the higher velocity anomalies observed. Note, this boring is also more than a 30+ foot offset (South) of both Line 2 and the anomalies, but falls within the footprint of the spillway.

Image 1: Seismic refraction equipment being deployed onsite.

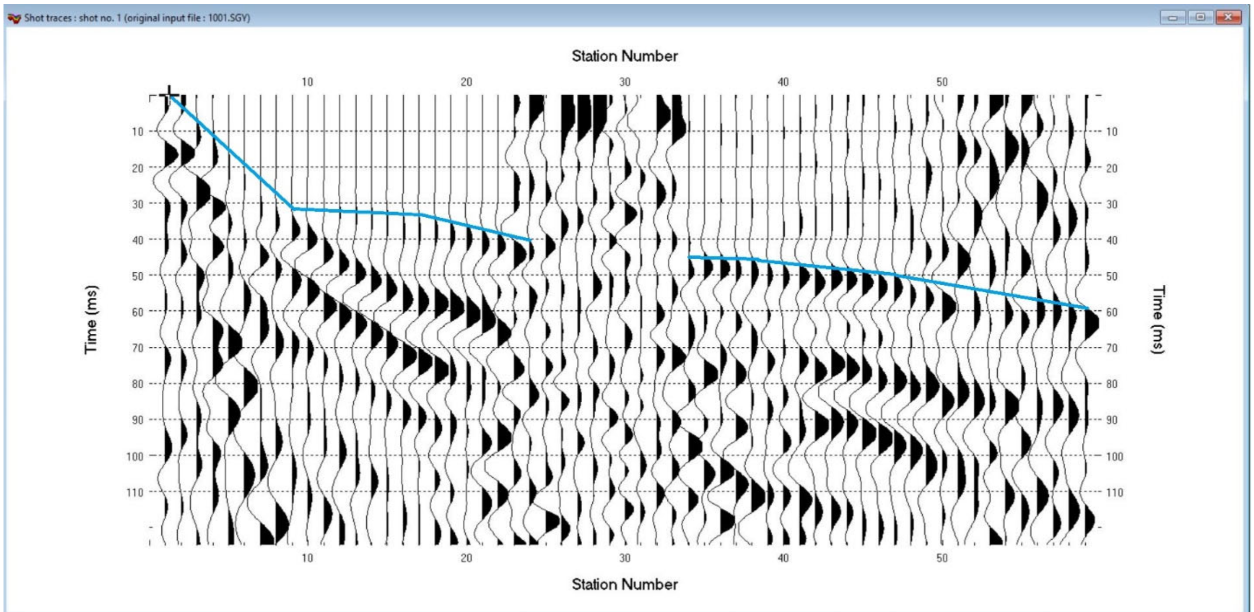
Line 3 was collected over a total distance of approximately 1,710 linear feet (geophone sensor length). Velocities consistent with typical top of rock were observed at approximately 50–70 feet below the surface near the spillway and shallowing to just below the surface on both the east and west flanks. Line 3 was collected just off the road shoulder so the geophone and shots were in soils for better coupling. Figure 4 is the processed refraction tomogram. The entire line was deployed and "live" during recording. As a result, the over 1,700-foot line produced data down to over 200 feet below the road surface. Again, simplified boring logs were overlayed on the seismic data and were used to help refine the interpreted top of rock. The boring logs near the center of the dam and near the spillway show top of rock falling within a smaller velocity range of approximately 5,500–6,000 fps. Two borings (1006 and 1012) that are near the dam's eastern flank show shallower than expected rock surface based on mapped velocities. However, this could again be related to steeply dipping rock that is trending more NW-SE to the line and would project the shallower depths closer to the eastern end of the line.

The only anomalies observed near the interpreted rock surface along the seismic lines were near/under the concrete spillway and weir structure. Figures 2 through 4 present the processed data for the three seismic lines. These lines crossed the spillway; however, this area was not accessible to install geophones. Therefore, small data gaps were observed and are represented based on ray-path mapping as diagonal checked/hatched areas on the data plots. These areas of lower data coverage are shown on the figures to aid in the data interpretations. Although the anomalies are outside the lower data coverage areas, it is not certain that these could be at least partially influenced by the data gaps. All three lines have a slight velocity increase near/under the spillway, and Line 2 has a slight velocity inversion as well. Another notable item in this same area is that the original outlet pipe/duct structure crosses the seismic lines within the vicinity of the spill way structure. Historic records show the buried water intake conduit and duct structure connects from the intake tower (west of the spillway) to a small ditch east of the spillway pool near the toe of the dam. However, these historic records show the conduit/pipe intake structure to be near the base of the dam and aligned towards the current treatment plant at about elevation 459-ft. The Dames and Moore 1976 report boring logs/locations were also overlaid on Line 3. B-1, B-2 and B-3 from this report were spaced along the shoulder of highway along the dam crest. The boring locations are shown on Figure 1 and the simplified logs were added to the seismic Line 3 on Figure 4. The depth to the top of the limestone is similar to the current studies borings, and no anomalous zones were noted within the dam cross-section/fill.

Seismic Refraction Data Interpretation

The refraction tomography processing was completed using Rayfract software by Intelligent Resources, Inc. Processing included loading the data, updating geometry files with elevations, filtering/gaining data, picking first breaks (example processed record shown as Image 2, from Line 1) and then running both an initial starting model and final model runs of compressional wave velocity measurements. The compressional wave (P-wave) velocities, presented on Figures 2 through 4, have been compared with typical or expected velocity ranges for bedrock. Figure 5 shows the three seismic lines at the same scales and aligned as they were collected, looking north. Note, these plots do not have any vertical exaggeration applied. The set of dashed lines represent the interpreted top of rock zone, following the velocity contours of 4,500 fps and 6,500 fps. Furthermore, observations from the test borings show these velocities tie with boring results for the central portion of the dam; however, the velocities that appear to correlate with the boring rock elevations tend to be at lower than anticipated velocities near the toe of the dam and the eastern abutment of the dam (assuming this would hold true for both abutments). At the time of this report, the boring logs used were based on draft field logs.

Image 2: Seismic refraction data picking example from Line 1.



Typically, a good correlation to rock-like velocities between the seismic refraction data and boring logs is the depth where rock coring was started during drilling. A general correlation of a velocity range of 10,000 to 12,000 fps is considered competent rock. However, in sedimentary bedrock, especially limestone and dolomite, auger refusal and coring tend to tie to the velocity zone mentioned above and within the dashed zone (4,500 fps and 6,500 fps) shown on Figure 5. There are some variations in this correlation and lower than expected velocities may also tie to boring depths for top of rock. Generally, in the color scales presented for the seismic data, the transition from green to yellow and yellow to orange is the expected top of rock.

Ground Penetrating Radar Results

Summary

GPR survey lines were collected within the weir and along the length of the concrete section of the spillway, see Figure 1. These GPR profiles were spaced approximately 10 to 12 feet apart and were approximately 120 feet in length along the spillway and conducted both N-S and E-W within the weir. The GSSI SIR-4000 GPR system consisted of a portable wheeled cart, 300/800 MHz dual-frequency antenna, and a control head unit. The GPR cart was light and maneuverable so that it could be lowered down the spillway using a combination of ropes to guide it along the survey transects. Within the weir, the cart was pushed along both N-S and E-W lines. The goal of the GPR survey was to look for voids and or pathways that would allow water movement under the weir and spillway concrete slabs. In general, no large or seemingly problematic anomalies were observed. See the interpretation section below for more details on the GPR survey results.

GPR Methodology

GPR is a geophysical method that uses electromagnetic pulses to image the subsurface. This method detects reflected signals from subsurface interfaces and structures including changes in materials and conditions. GPR can be used in a variety of media, including rock, soil, ice, fresh water, pavements, and structures, and under the right conditions can be used to identify subtle changes within the subsurface, including locating utilities. GPR surveys are commonly used for shallow investigations, usually less than 10 feet. The depth range of GPR is limited by the electrical conductivity of the ground, the transmitted center frequency, and the radiated power. As conductivity increases, the penetration depth decreases. Higher frequencies do not penetrate as far as lower frequencies, but typically provide better resolution. Good penetration is also achieved in dry sandy soils, or massive and dry materials, such as granite, limestone, and concrete. The depth of penetration for this survey varied between 2 and 6 feet. In moist and/or clay-laden soils and soils with high electrical conductivity, the penetration was less.

GPR Data Interpretation

The GPR files were processed using GSSI's Radan software. Generally, processing included surface normalization, signal filtering/gaining, and stacking the signal between the two antenna frequencies. Data was then analyzed, looking for anomalous zones. Anomalies were broken into two categories, shallow and deep. Typically, voids and wet zones will exhibit higher amplitude signal returns, either from the air space in the case of voids and the signal reverberation within the space, or higher dielectric contrast between very wet soils and dryer soils. Figure 6 presents the GPR interpretations. The survey positions over a simplified grid representing the weir and spillway are shown, as well as color-coded anomalies (both deep and shallow). General observations indicate the rebar appeared to vary in spacing between approximately 6 inches, especially near the walls and most of the weir slab, and approximately 12 inches in the main areas surveyed along the spillway. The thickness of the concrete was not easily interpreted, which could be due to the concrete and the base layer/soils being at a similar dielectric; however, in some areas it appeared to be between 8 and 10 inches thick.

The GPR depth of usable data is defined by the signal to noise, or basically the point where the signal is too noisy to see meaningful reflections of energy. In most areas of the weir and spillway, the GPR's usable signal was limited to 2 to 3 feet below the surface. The joints/seams in the concrete did appear to be very prominent in most cases within the data, suggesting moisture in the joints. Often an increase in the GPR signal amplitude was observed near the concrete joints, most likely indicating wet/moist soils in these areas. This is also evident by water seeping from the joints at several locations along the spillway. The anomalies observed did not seem to be widespread or continuous across the weir or across the spillway, nor very large. The approximate width of the anomalies is represented by the shaded areas on Figure 6. The thickness/depth of the GPR anomalies is difficult to estimate and is not reliable because the signal can reverberate (echo essentially) within the anomalous zone giving a false indication of thickness. The anomalies observed in the GPR data did not appear overly large or widespread to the point that they would be anticipated to impact the structural integrity of the floor of the weir/spillway in the areas surveyed. The GPR signal observed in the spillway did not exhibit characteristics typical of sub-slab voids seen in other similar situations, where large voids in the magnitude of a foot thick or more were present. However, signal response can vary between sites. Again, as previously noted, very large or extremely high amplitude anomalies were not observed across the weir and along the spillway. Example GPR profiles from the weir and spillway surveys are shown in Images 3 and 4, below. All GPR data files in a graphic format (.jpg) are included with this report as Appendix A. Processed files were displayed and saved prior to interpretation, with each antenna frequency stacked in each image. The 800 MHz on top and 300 MHz data on the bottom split screen. Images below are shown as merged data from the two frequencies into a single depth section plot.

Image 3: Example GPR profile from weir (GPR File 17).

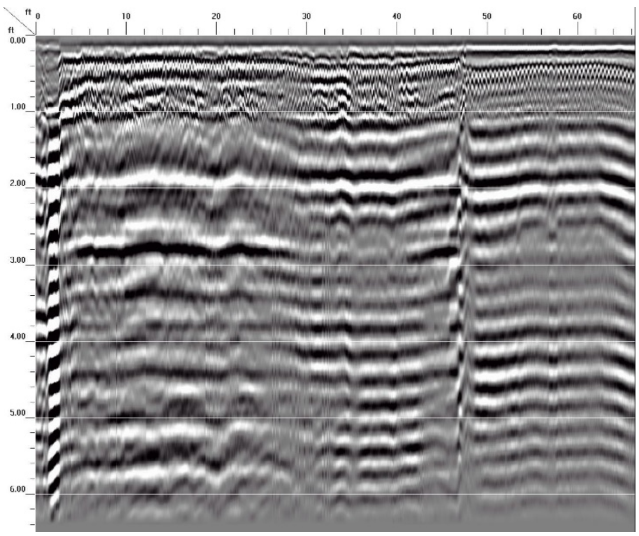
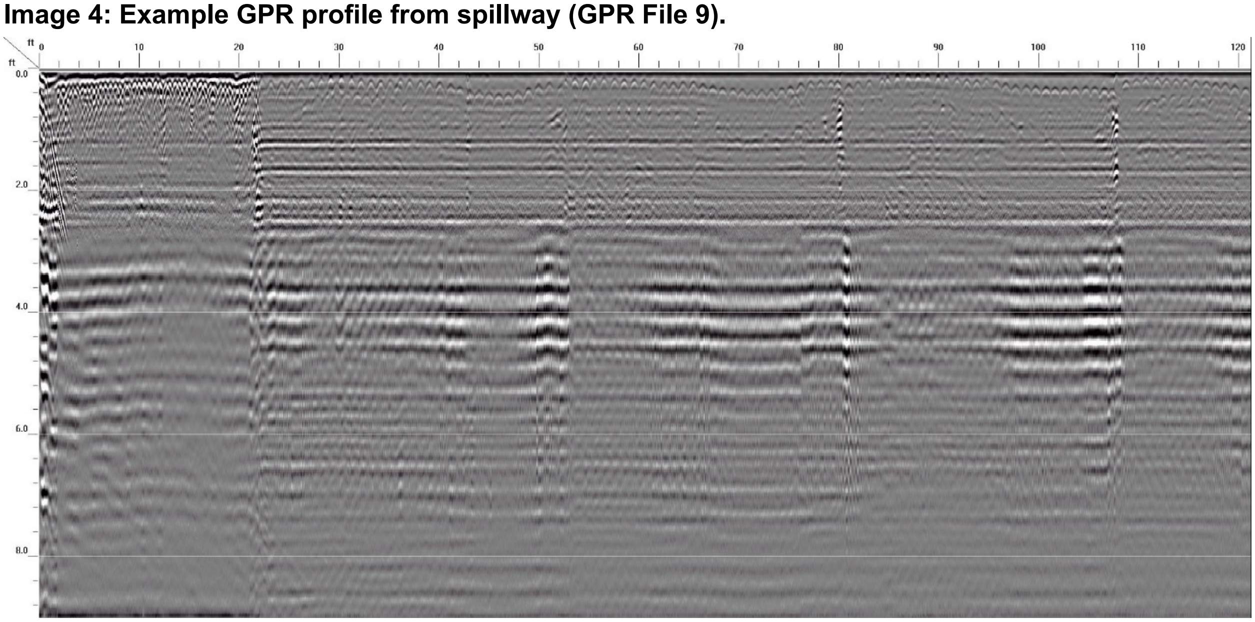


Image 4: Example GPR profile from spillway (GPR File 9).



Conclusions

The seismic refraction data discussed above did not show any interpreted deep anomalies within the rock, including lower velocity zones or large dips in the rock surface that are typically associated with karstic bedrock. Furthermore, large zones with irregular contour intervals and velocity inversions were not observed in the zone above rock, including the core of the dam. The only exception and area with anomalies in the data were near and directly below the concrete spillway. Two key points regarding these anomalous areas are: first, data gaps do exist in the shallow zone below the spillway due to not being able to place sensors across it; and second, historical records indicate the raw water supply pipeline(s) and duct system cross the seismic lines near the spillway.

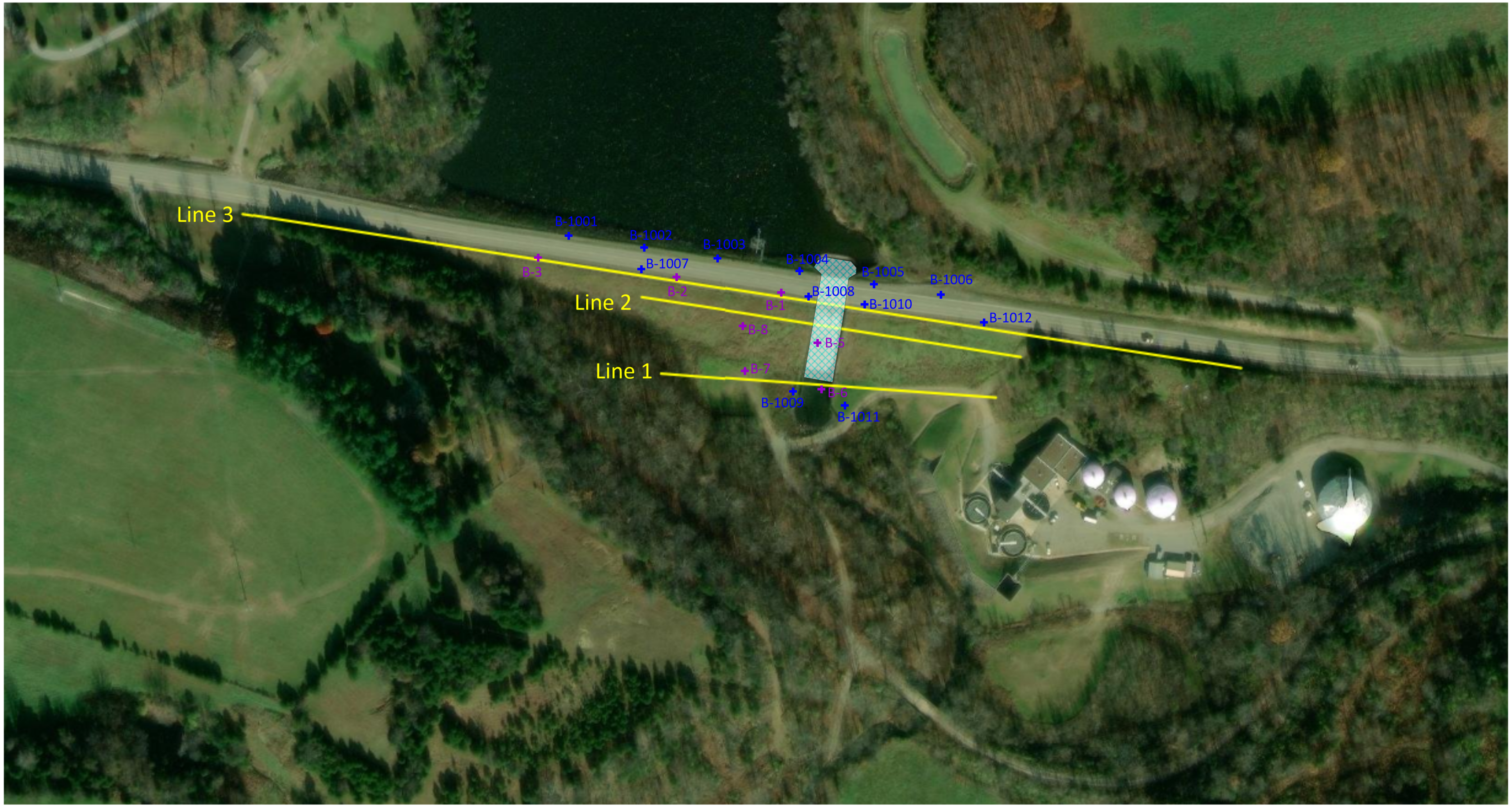
As for the GPR surveys within the weir and spillway, the joints/seams in the concrete appeared very prominent in most cases within the data, suggesting moisture in the joints. This is also evident by water seeping from the joints in several locations along the spillway. The anomalies observed did not seem to be widespread or continuous across the weir or across the spillway, or to be very large. Obvious conduits or channels were not identified within the GPR data.

Limitation and Disclaimer

All geophysical data analysis, interpretations, conclusions, and/or recommendations in this document have been prepared under the supervision of and reviewed by HDR senior geophysicists. This geophysical survey was conducted using sound scientific principles and state-of-the-art technology. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing, interpretation, and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review.

A geophysicist's interpretation of conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations, or ordinances.

Attachments



Scale 1"=200'

Refraction Seismic Survey Line

Weir and Spillway GPR Survey Area

Geotechnical Boring Locations

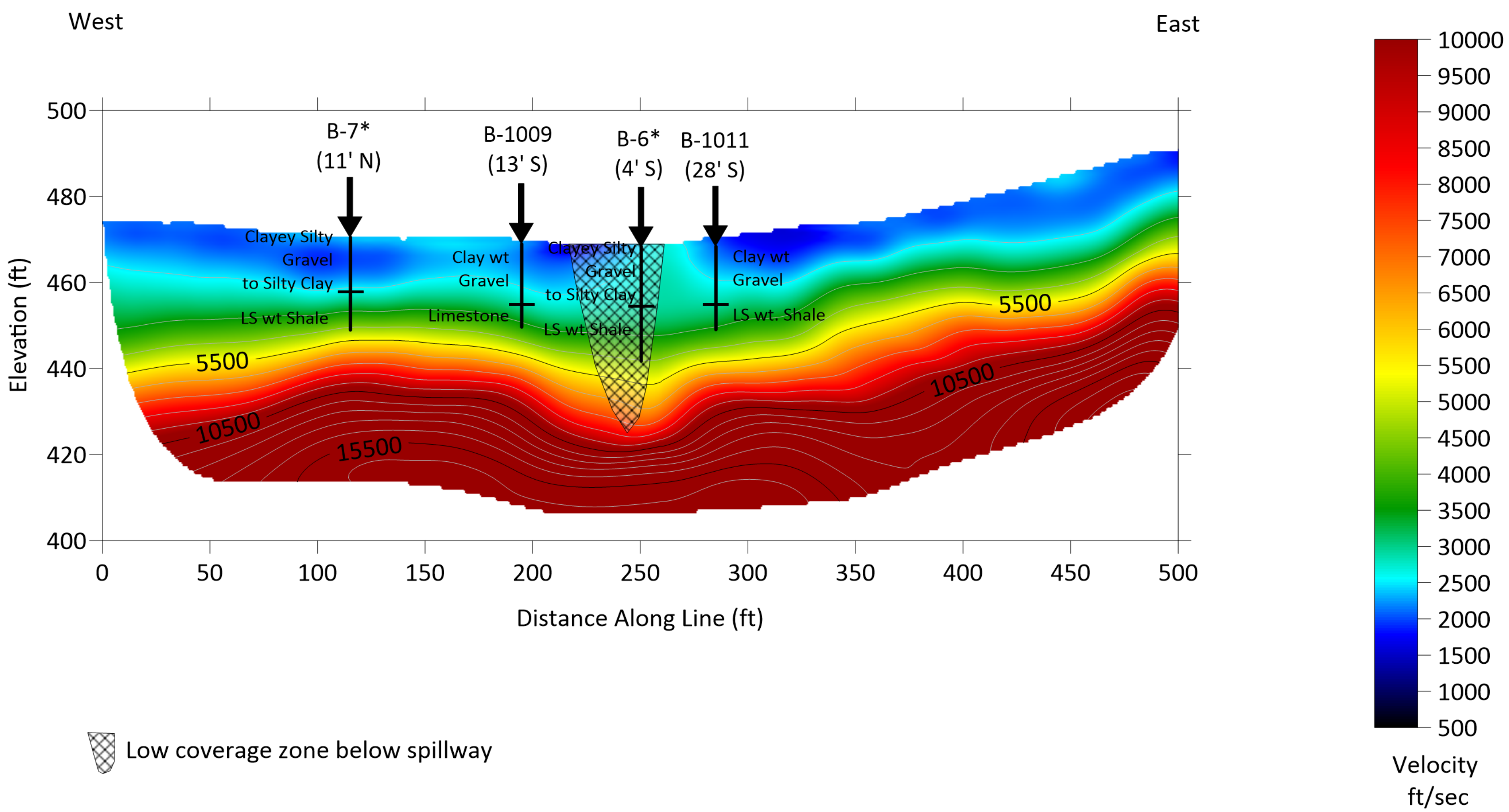
1976 Boring Locations (Dames & Moore)

REFRACTION SEISMIC and GPR SURVEY

Sympson Lake Dam Project

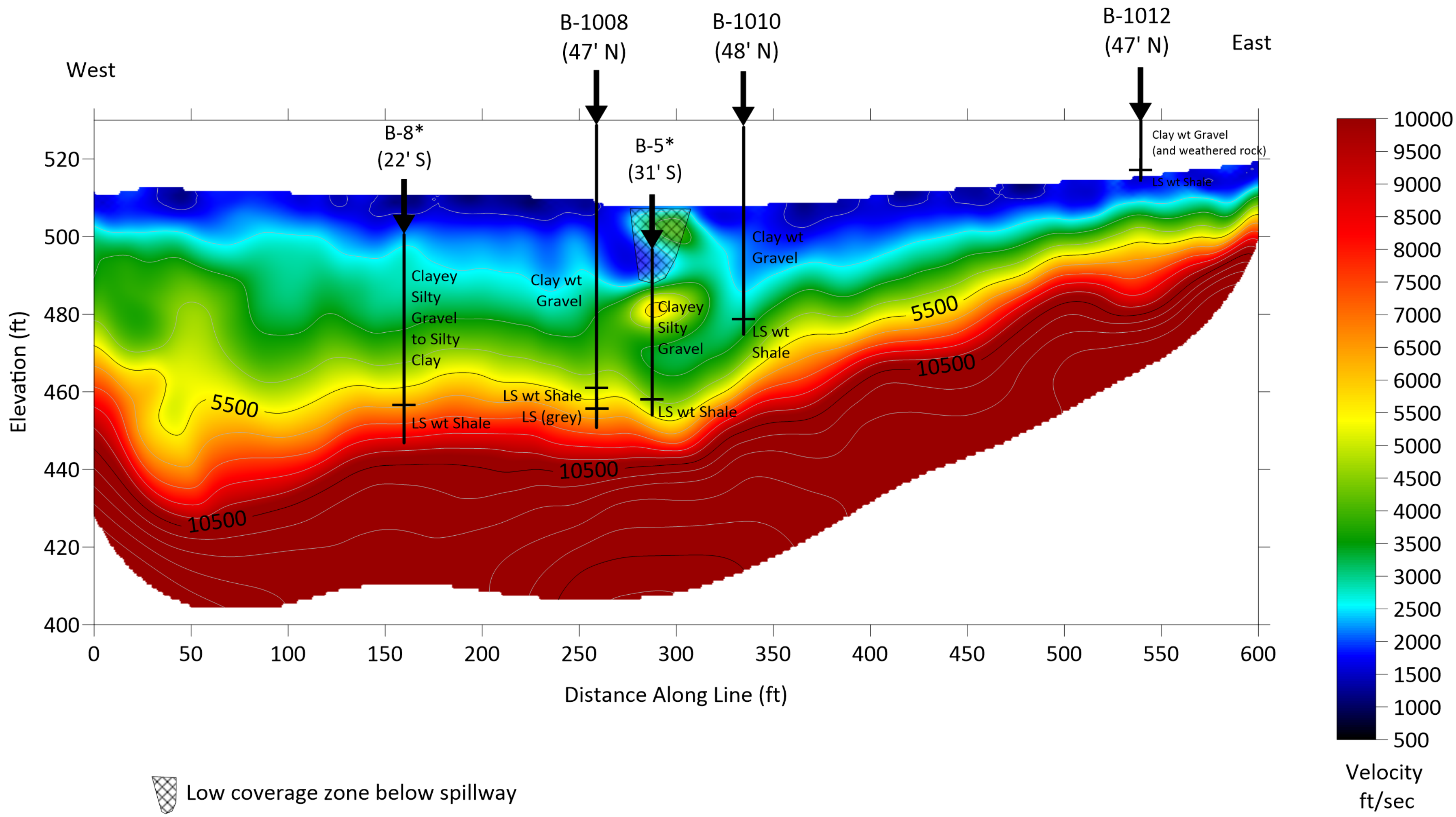
FIGURE 1

HDR



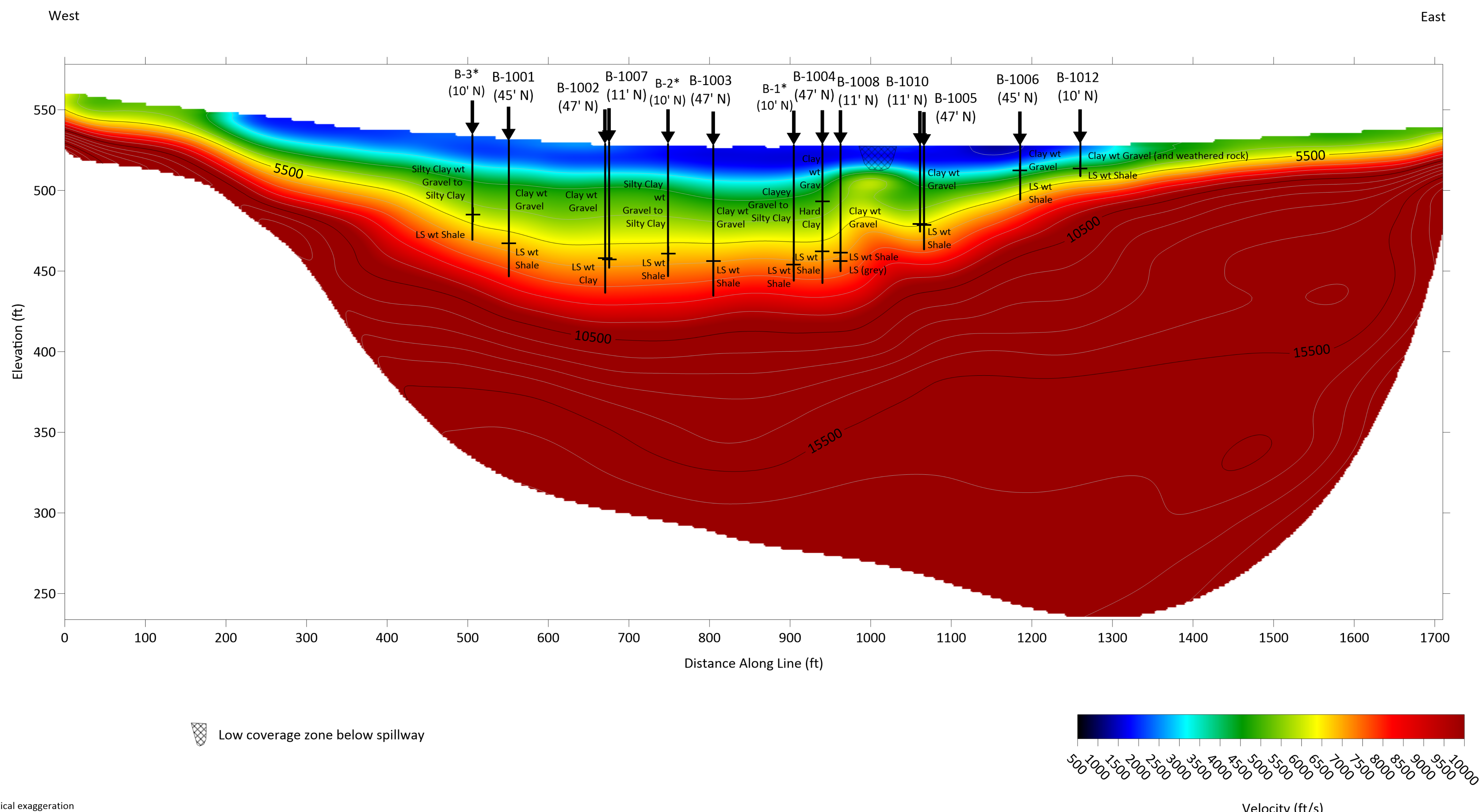
Notes:
2X vertical exaggeration
Distance is along ground surface
P-Wave/Compressional wave velocities
Boring "Name/number" (XX) denotes offset distance and direction from line
* Historic Boring information from Dames and Moore report 1976.

REFRACTION SEISMIC Line 1
Sympson Lake Dam Project
FIGURE 2



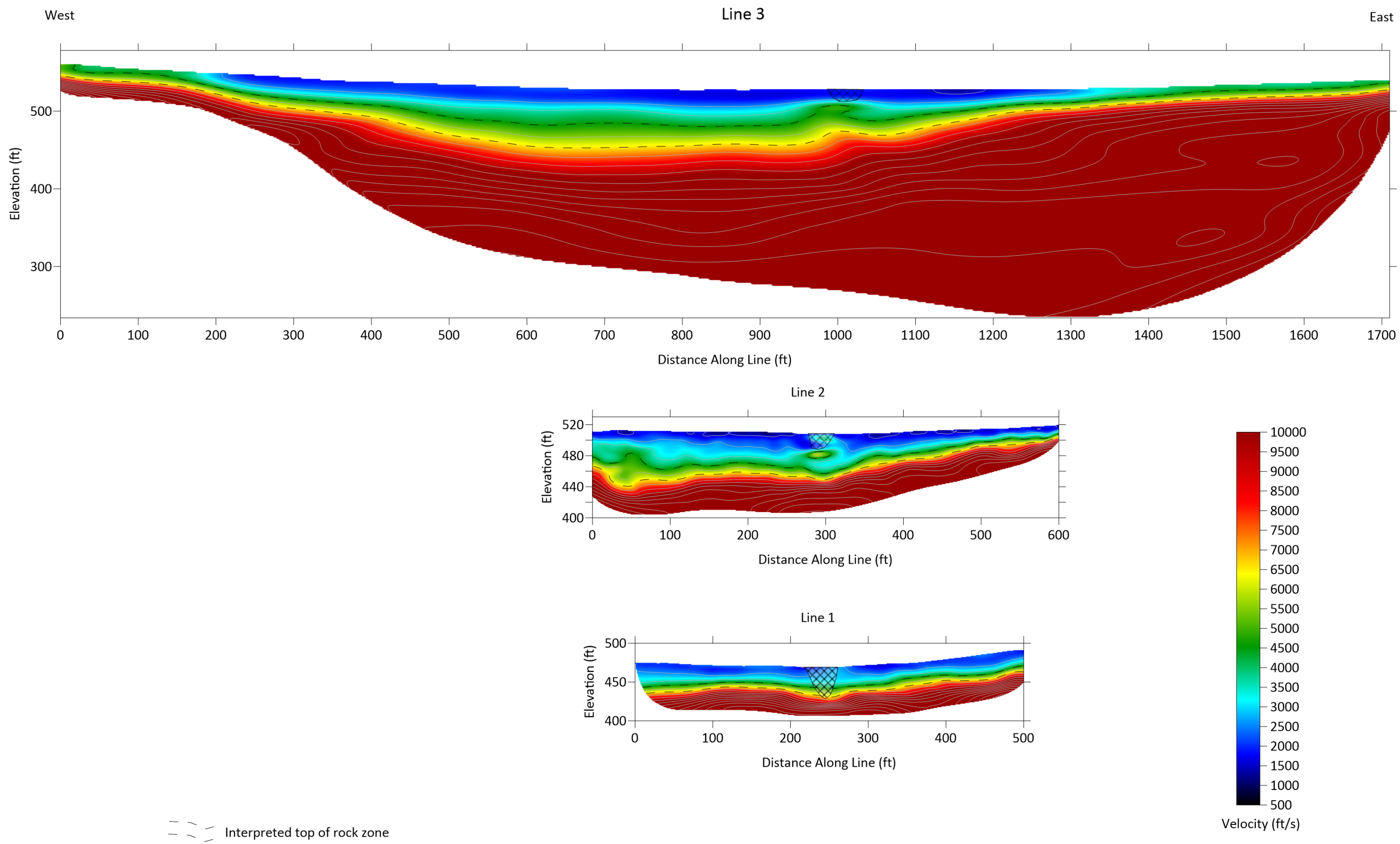
Notes:
2X vertical exaggeration
Distance is along ground surface
P-Wave/Compressional wave velocities
Boring "Name/number" (XX) denotes offset distance and direction from line
* Historic Boring information from Dames and Moore report 1976

REFRACTION SEISMIC Line 2
Sympson Lake Dam Project
FIGURE 3



REFRACTION SEISMIC Line 3
Sympson Lake Dam Project
FIGURE 4

Notes:
2X vertical exaggeration
Distance is along ground surface
P-Wave/Compressional wave velocities
Boring "Name/number" (XX) denotes offset distance and direction from line
* Historic Boring information from Dames and Moore report 1976



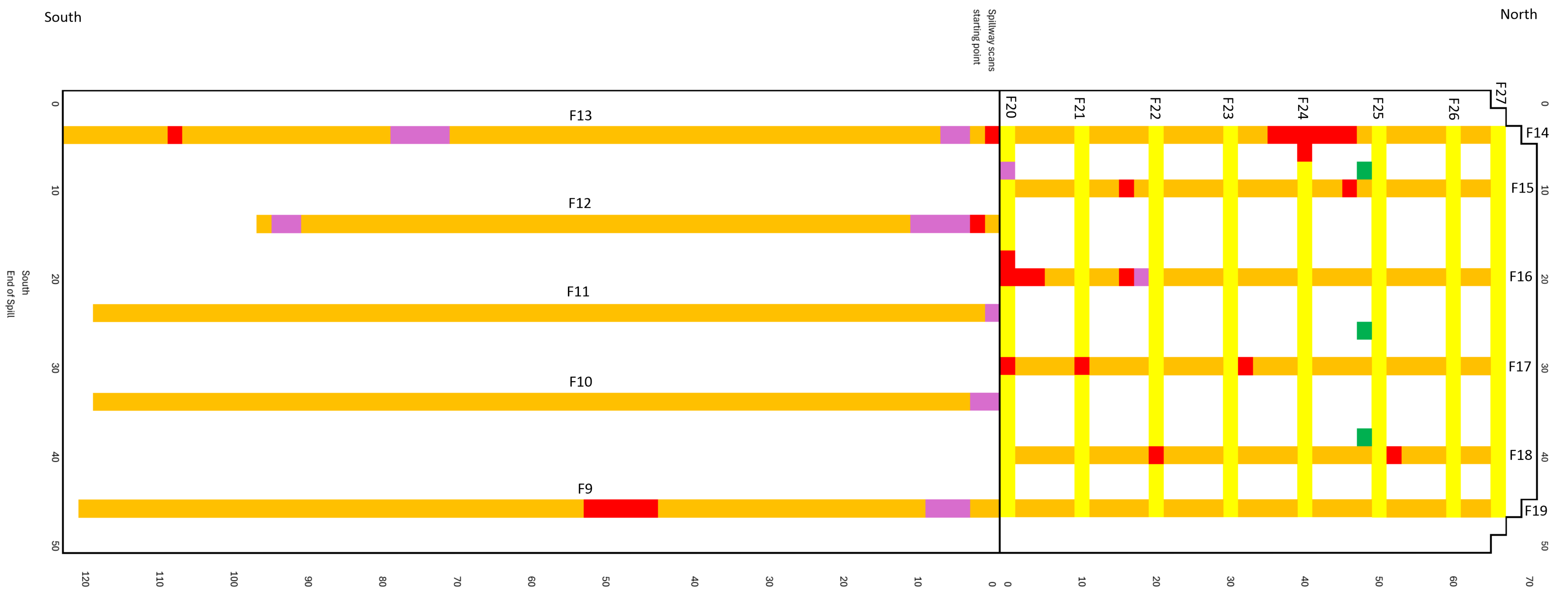
Interpreted top of rock zone

Low coverage zone below spillway

Notes:
No vertical exaggeration
Distance is along ground surface
P-Wave/Compressional wave velocities

REFRACTION SEISMIC Lines 1-3
Sympson Lake Dam Project
FIGURE 5

GPR Interpretations
Sympson Lake Dam Project
FIGURE 6



E-W GPR profiles
N-S GPR profiles
Increased refection near bottom of slab, possible void
Deeper anomalous areas, wet zone or change in fill
Approximate Corehole locations, visible in the field
F# GPR File Name

Notes:
GPR survey lines are show graphically as related to the walls of the Weir and Spillway
Distance is along the concrete surface as measured by the GPR instument

Appendix A

Electronic GPR Data graphic files (.jpg), spreadsheet of file notes (.xls)