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Golder Associates

RESULTS OF THE DESCHUTES PARKWAY AND CAPITAL LAKE GEOPHYSICAL SURVEY

Prepared for:

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Submitted by:

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FIGURES

1. INTRODUCTION

Between March 12 and April 6, 2001, Golder Associates Inc. conducted a geophysical survey along the Deschutes Parkway and in Capital Lake in Olympia, Washington (Figure 1). The purpose of the investigation was to gather subsurface information to help identify failure zones along the roadway and submarine slope failures in the lake that occurred following the February 28, 2001 earthquake. This report describes the methodology and field procedures, and discusses the results and conclusions of the geophysical investigation.

Box

2. INSTRUMENTATION AND METHODOLOGY

The survey was conducted on the parkway, between the parkway and the lake, and in the lake. A number of geophysical instruments were used to achieve the project objective of defining subsurface failure surface and identifying offshore movement of material. The geophysical methods used included:

- Differential global positioning (lake)
- Precision echosounding (lake)
- Side scanning sonar (lake)
- Subbottom profiling (lake)
- Ground penetrating radar (lake and land)
- Electrical resistivity imaging (land)
- Electrical magnetic utility locating (land)

2.1 Horizontal Control

Horizontal control for the lake survey was obtained with a Trimble PRO-XRS differential global positioning system. The data were stored in the dGPS acquisition system or sent directly to a navigation computer. The accuracy of the position fix was +/- 1 meter before processing and +/- 0.2m following processing.

The horizontal control for the onshore geophysical surveys used a cloth survey tape. The positions were measured from the centerline of the roadway. Station marks painted on the road provided base points from which these measurements were made.

2.2 Echosounder System

Bathymetric data were acquired with an Odem Hydro Track echosounder using a 200 KHz transducer. The echosounder transducer emits and receives acoustic pulses. The time difference between the transmitted and received acoustic pulses is used to calculate the water depth. For this survey a sound wave velocity of 4800 feet per second was used to calculate the depth. The echosounder produced an annotated graphical record of the lakebed and output digital depth data to the navigation computer.

2.3 Side Scan Sonar

The lakebed features were imaged with an EdgeTech Model 260 side scan sonar system using a 500 kHz transducer.

Side scan sonar uses acoustic pulses to image the lakebed to the left and right of the towfish. The image produced is called a sonargram. Acoustic pressure waves are transmitted and the reflected echoes received by the towfish. The acoustic data is displayed in real-time on a thermal graphic recorder. The sonogram image also includes navigation event marks that are input by the navigation computer.

On the sonograms, high intensity reflections (dark areas) represent coarse-grained material usually rocks, boulders, and debris. Low intensity reflections (light areas) represent fine-grained sediment such as silt and fine sand. Features such sunken logs, debris, slumps, sand-waves and variations in lithology can be identified and mapped from the sonogram records and the dGPS position data.

2.4 Subbottom Profiler System (SBP)

Seismic reflection data were collected with a Datasonics Model SBT 2200 subbottom profiler system (SBP) using a 5 KHz transducer.

Seismic reflection profiling uses acoustic pulses, emitted at regular intervals by an acoustic energy source, to image subbottom conditions along the survey trackline. The acoustic pulses generated by the transducer are reflected from the lakebed and underlying geology. The transducer receives the acoustic pressure waves and converts them into electrical signals. The signals are sent to the topside unit where they are processed. The processed data displayed on a graphic recorder. This display, the seismic reflection record, is an acoustical profile of the lakebed and subbottom structure along the trackline.

2.5 Ground Penetrating Radar (GPR)

The ground penetrating radar survey was conducted with a GSSI SIR System-8 with 100, 120 and 400 MHz antennas. The data were displayed on an EPC Model 8700 thermal graphic recorder.

The GPR method uses electromagnetic pulses to map subsurface conditions along a survey transect. The radar antenna continuously transmits radar pulses into the ground as is it moved along the survey transect. Reflections are produced where there is a change in electrical properties. These changes can occur at the interface between soil layers, at the water table, where there is a discontinuity in the soil layers, such as failure surfaces, and where there are discrete objects such as pipes, cables or miscellaneous debris. Reflected signals received by the antenna are processed by the GPR console to produce a graphic cross-sectional record of the subsurface.

Depth is determined by calibration to an object at a known depth or by assigning a typical velocity for the type of subsurface materials present. Horizontal control is obtained by marking the record as the antenna passes station marks, or as events are recorded with the dGPS system.

The maximum depth of penetration of the GPR signal is a function the frequency of the antenna and the electrical properties of the soils. The presence of water and fine-grained sediments, such as silts and clays tends to reduce the depth of penetration. However, in coarse-grained sediment, such as sand and gravel, up to 50 feet of penetration can be obtained.

2.6 Electrical Resistivity Imaging (ERI)

An AGI Sting / Swift system was used to collect resistivity data of the subsurface soil.

ERI is used to map differences in electrical properties of geologic materials. These differences can result from variations in lithology, water content, pore-water chemistry, and the presence of buried debris. The method involves transmitting an electric current into the ground between two electrodes and measuring the voltage between two other electrodes. The voltage and current values are used to calculate the apparent resistivity of the area beneath the electrodes. The subsurface depth of measurement increases, as the electrode spacing is increase. Recent advances in technology permit rapid collection of multiple soundings, using up to 56 electrodes for each spread. The data are modeled to create a 2-D geo-electric cross-section that is useful for mapping both vertical and horizontal variations of the subsurface strata.

2.7 Electromagnetic Utility Location (EMUL)

EMUL uses a multi-function precision locator for detecting utilities and pipelines. The hand-held Radiodetection RD-400 instrument detects 60 Hz signals from power lines, re-radiated very low frequency (VLF) signals that have traveled through the earth from government communication transmitters, or signals that are coupled to the utility from a portable transmitter. Most conductive utilities, actively or passively energized, can be detected by this method. In areas of multiple utilities and power lines signals may bleed to adjacent conductors making it difficult to locate a particular cable.

3. FIELD PROCEDURES

3.1 Horizontal Positioning

An integrated and automated hydrographic system was used for on-line navigation and positioning of the survey vessel. This system consisted of a Trimble PRO XR dGPS receiver, HP Computer and CRA-NW navigation software.

The differential global positioning system (dGPS) was used to determine the vessel's location in real-time, and to plot the vessel's position along the survey lines. The pre-plotted survey lines, and the actual survey lines traversed by the vessel, were displayed in real-time on a video monitor. The navigation computer transmitted event marks to the geophysical recording instruments every 20-seconds in order to correlate the geophysical data with the survey vessel position.

The time-tagged soundings and the position of the survey vessel were merged in post-processing, corrected for water elevation. The trackline information was plotted on a large-scale map and used to assist in the interpretation of the geophysical data.

Along the Deschutes Parkway the survey transects were referenced to station marks painted along the roadway centerline. A tape measure was used to measure offsets from the station marks. Stations and line lengths were noted directly on the data printouts and/or in a field notebook.

The dGPS was used to obtain absolute positions of the painted stationing marks from Station 65+00 to 111+00 at 200-foot intervals. These values were used as control points for the marine survey base map and tracklines.

3.2 Bathymetery

Bathymetric data were collected in the north section of Capital Lake, from the west shore to the old river channel (Figure 2). The main portion of the lake was surveyed on lines spaced 100 feet apart. Additional lines were added parallel and perpendicular to the shoreline where rapid topography changes were noted.

The echo sounder transducer was mounted on the side of the survey vessel and suspended 15 inches below the waterline. The dGPS receiver antenna was mounted above the transducer for positioning. Bathymetric and positioning data were recorded on a laptop computer for further processing.

The data were corrected for elevation by direct measurement of the lake water level at a tide gauge placed along the shore. The tide gauge elevation, surveyed in by JWMA, is referenced to mean sea level (MSL), City of Olympia datum.

3.3 Side Scan Sonar

Side scan sonar data were collected in the north section of Capitol Lake, from the Deschutes Parkway shoreline to the old river channel (Figure 3). Side scan sonar data were acquired on lines spaced approximately 100 feet apart. In addition, data were collected on a survey line that followed the shoreline.

The side scan sonar towfish was suspended two feet below the water line from the bow of the survey vessel. The range on the side scan was set to 50 meters per side (~165 feet), or a swath, full width of the image, of 100 meters (~330 feet).

3.4 Subbottom Profiling

Two subbottom profile lines were collected in the north section Capital Lake (Figure 4). The profiles were run parallel to the shoreline approximately 10 and 50 feet offshore.

The subbottom profiler transducer was mounted on the side of the survey vessel, with the dGPS receiver antenna mounted above it. Incoming dGPS data were recorded with event marks that were added to the subbottom reflection records.

Probing of the sediments was conducted during the subbottom profiling using a pole to aid in classifying the sediment. Probing was also done as subbottom profile records suggested the presence of gas charged sediments.

3.5 Ground Penetrating Radar

The GPR was used in the lake to image subsurface features along the west shoreline of Capital Lake (Figure 5). Two profiles were run parallel to the shoreline approximately 10 and 50 feet offshore. GPR cross line profiles were collected in the north section of the lake at a nominal spacing of 200 feet.

The data were plotted on an EPC 8700 thermal graphic recorder. The dGPS receiver antenna, mounted above the echosounder transducer, was approximately 6 feet from the GPR antenna. Fiducial marks were made on the records for correlation to the dGPS navigation data.

On the Deschutes Parkway GPR profiles were run along the roadway centerline, and on the east and west parking strips where accessible. The profiles were collected from Station 42+00 to 52+00 and 65+00 to 113+00. In addition, a line was collected on the east parking strip from Station 26+00 to 65+00 using a 100 or 120 MHz frequency antenna. A time scale of 350 nanoseconds was used for the record length, which corresponds to a maximum depth of approximately 70 feet.

At selected location along Deschutes Parkway cross line profiles were run using a 400MHz antenna. Roadway stationing and line lengths in Table 1 below are used to identify the GPR cross line profiles:

TABLE 1

Deschutes Parkway GPR Cross Line Locations and Lengths.

Station	Line length (feet)	Station	Line length (feet)	Station	Line length (feet)	Station	Line length (feet)
42+00	70	43+00	70	44+00	70	45+00	70
45+27	70	45+58	75	46+00	70	47+00	65
48+00	70	48+35	75	48+63	75	49+00	70
49+32	70	49+48	70	50+00	70	51+00	65
52+00	70	67+00	85	68+80	35	77+00	90
78+00	90	79+00	85	81+35	85	84+82	105
87+90	80	90+00	75	92+00	75	93+00	90
94+00	85	95+00	85	96+00	85	97+00	85
98+00	80	99+00	80	99+90	85	100+82	45
100+88	45	100+93	45	101+00	80	101+50	80
102+00	85	103+00	80	104+00	85	104+57	80
104+90	80	105+15	80	108+04	75	108+20	75
108+79	80	111+55	80	112+00	75	112+55	50

3.6 Electrical resistivity Imaging

Electrical imaging data were collected using 42 electrodes spaced at 3-meter intervals for a total spread length of 123 meters or ~404 feet. The profile was collected along the east edge of the sidewalk from Station 104+00 to 108+04.

3.7 Electromagnetic Utility Location

The EMUL survey was conducted using the Radiodetection RD-400 in the radio and power modes of detection. A positive Radiodetection response is interpreted to indicate an active or energized utility. The locations of utilities detected were compared to the anomalies on the GPR records during the field interpretation of the geophysical data.

4. ANALYSIS AND RESULTS

The following summarizes the results of the various geophysical methods used on this project. This information is also presented on a series of figures included in the appendix.

4.1 Horizontal Positioning

All surveys conducted in the lake used dGPS for positioning. The data were converted to US State Plane 1983 HPGN coordinates, Zone Washington South 4602, in feet.

4.2 Bathymetery

The bathymetric data, referenced to the Olympia datum MSL are plotted on Figure 6. As can be seen the lake floor has very little relief and the maximum water depth is approximately 25 feet. Nearshore a depression or channel can be seen along the shoreline near the riprap sections (approximately from station 100+00 to 1300+00). This channel may be the result of scour by wave action, or may be the result of the construction excavations from building the road.

4.3 Side Scan Sonar Data

The lake floor appears to be predominantly silt and mud with occasional clumps of plants. Along the shoreline coarse-grained sediment and rocks are evident (Figure 7). Several features identified on the side scan sonar data are interpreted to be related to the earthquake (Figures 3 and 7). These features include slumps; small, cone-like structures that may be evidence of sand boils, and linear extension and ridge structures.

4.4 Subbottom Profiler Data

The subbottom profiler was not able to penetrate the lake floor sediment due to the presence of gas and organic material. The presence of gas was confirmed by probing the bottom with a pole and observing profuse gas bubbles coming to the surface. The stations probed and the interpreted sediment types (qualitative) are plotted in Table 2 below. The location of the probe sites and subbottom tracklines are plotted in Figure 4.

Table 2

INTERPRETED LAKEBED MATERIAL (FIGURE 4)

LOCATION NUMBER	LAKEBED DESCRIPTION
1	Rip rap
2	Silt and sand
3	Rip rap
4	Course sand to gravel
5	Sand
6	Soft silt to fine sand
7	Sand
8	Silt to fine sand
9	Sand, gravel and rip rap
10	Silt, sand, and gravel
11	Sand
12	Sand
13	Gravel and rip rap
14	Sand and rip rap
15	Sand, gravel and rip rap

4.5 Ground Penetrating Radar Data

In the lake, a two way travel time of 18 nanoseconds per foot was used for calculating the water depth, and 10 nanoseconds per foot for calculating the sediment thickness.

On the radar records the sediment in the area of cross line 9I to 9k appear to be disturbed by deformation of sedimentary layers. The area of disturbed sediments correlates to the area of linear extensions and ridges on the side scan sonar records. The sediments in the flat areas of the lakebed attenuated the GPR signals resulting in a lack of subsurface penetration. This is characteristic of electrically conductive sediments such as clay or marine sediments containing salt.

The radar wave velocity for the materials along Deschutes Parkway was calculated near Station 87+00 by direct measurement to an exposed utility located at a depth of 5.8 feet. This calibration produced a two-way travel time of 5 nanoseconds per foot. This value was used to calculate the depths of features on the radargrams. The maximum subsurface penetration with the 100/120 MHz antenna was 30 feet and approximately 12 feet with the 400 MHz antenna.

The interpreted GPR data along the roadway detected fill and in-place, natural stratigraphy, possible utilities, voids, and anomalies that may represent disturbed soil (Figures 8 and 9). Figure 8 (cross line at Station 100+90) is in the area of a roadway failure. Several subsurface concave reflectors are interpreted to possible slide planes. Figure 9 shows data from the two cross lines located at Stations 47+00 and 49+32 near the Interpretive Center. The data at Station 47+00 is interpreted to show fill and native material that is relatively undisturbed, while the data at Station 49+32 is interpreted to show disturbed soils where failure occurred.

The interpreted results of the GPR survey are plotted in Figures 10 and 11. The interpreted features are referenced to Station 26+00 to 113+00. Subsurface depths are referenced to the road surface, and are not corrected for topography or elevation.

Near the Interpretive Centers some voids were detected just below the concrete along the east edge of the road and adjacent to observed failures. The voids appear to extend approximately 5 to 10 feet eastwards from the road edge. Table 3 below lists the approximate location of these voids.

TABLE 3

Location Of Possible Voids Under Deschutes Parkway

CROSS LINE STATION	Distance east from the curb
45+27	5 feet
45+58	10 feet
46+00	7 feet
48+35	8 feet
49+58	6 feet
49+32	6 feet

4.6 Electrical Resistivity Imaging Data

An electrical imaging profile was collected to gain information about the deeper materials that underlie the roadbed (Figure 12). The materials detected in the upper 14 feet are interpreted to be fill and have a resistivity value of greater then 200 Ohm-meters. The material below the fill, with a resistivity value of less then 150 Ohm-meters are assumed to be clay, or marine sediment containing salt. Failures along the roadway where the soil is cracked show up as highly resistive areas (greater then 1000 Ohm-meters). The increase in resistivity may be related to the presence of air filled voids and lowered water content of the soil.

The shallow, low resistivity zones (red area), located where the road and sidewalk have collapsed, may indicate water saturated fill or poor fill material such as clay.

4.7 Electromagnetic Utility Locator Data

The RD400 electromagnetic utility locator was used for reconnaissance purpose only and to determine if anomalies on the GPR data might be utilities. No data are recorded with this unit. The unit detected the power, lighting and AT&T utilities along the roadway during the survey. These features were not mapped.

5. CONCLUSIONS

A comprehensive offshore and onshore geophysical survey was conducted in Capital Lake and along the Deschutes Parkway on the eastern shore of the lake. The purpose of the study was to assist in identifying surface and subsurface geologic features associated with the recent earthquake. The geophysical investigation used a combination of echosounding, side scanning sonar, subbottom profiling, ground penetrating radar, electrical resistivity imaging, and utility locating.

Several features identified on the geophysical data are interpreted to be a result of the earthquake. Furthermore, some of these features are possible evidence of where additional failures may occur.

There was evidence of slope failure and movement of riprap into the lake along the shoreline near the northern end and mid section of the lake.

Possible hummocks and tension cracks detected by the side scan sonar and disturbed soil detected by GPR may indicate the deformation of the lakebed.

Possible scour areas along the rip rap sections, observed on the side scan sonar, GPR and bathymetric data, may be an area of future slope failure.

Dipping interfaces in the fill were noted along the southern end of Deschutes Parkway to the Causeway (Figure 9). These interfaces may become conduits for ground water and act as slip surface.

Many of the surface failure cracks were noted to be associated with buried utilities, suggesting that trenching and back filling for the utilities has weakened the soil.

Anomalies on the GPR data may indicate loose soil, voids, and or buried debris. Some of the voids are possible due to piping of sediment from areas that have undergone liquefaction following the earthquake.

Sediment with low resistivity values at depth below the roadway suggests the presence of fine-grained material such as clay. The upper surface of the clay unit, that is impermeable to water, may act as a slip surface.

6. RECOMMENDATIONS

The following activities are recommended to provide additional information on subsurface conditions.

Inspect the lakebed features with underwater video or divers to confirm the side scan sonar interpretations.

Conduct a detailed GPR inspection over the drain culverts to check for void created by sediment piping. Voids from piping may not be large enough to detect by GPR for some time depending on the rate of sediment transport. A video pipe inspection of the culverts may reveal broken culvert pipes or gaps in the pipe sections.

Conduct a seismic refraction and/or reflection survey and a shear wave reflection survey to obtain geologic information on the deeper stratigraphy.

Conduct a electrical resistivity imaging survey to obtain a high-resolution subsurface image of variations in resistivity. This image would show contacts between different lithologic units such as clay, silt-sand, and tills.

FIGURES

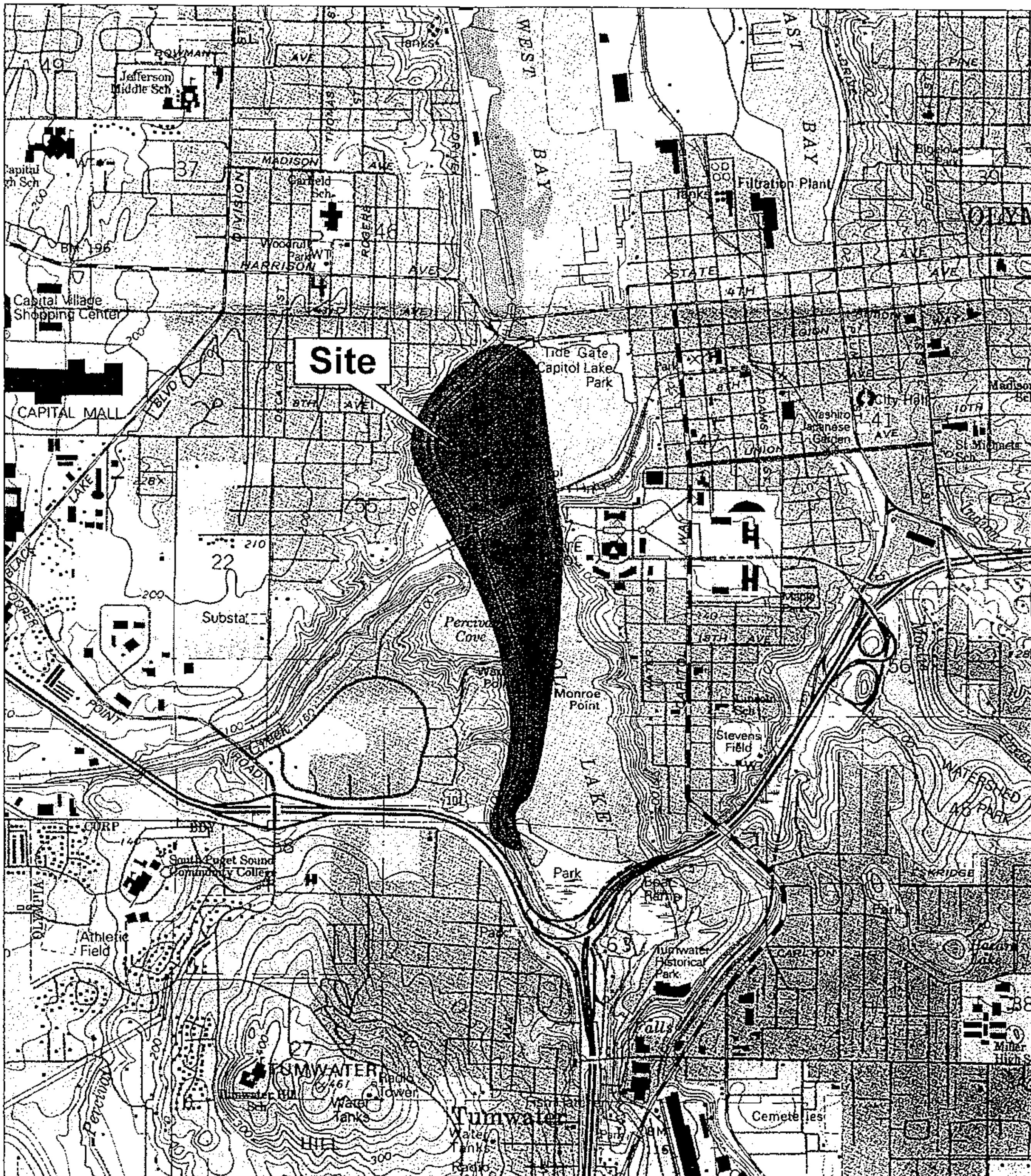


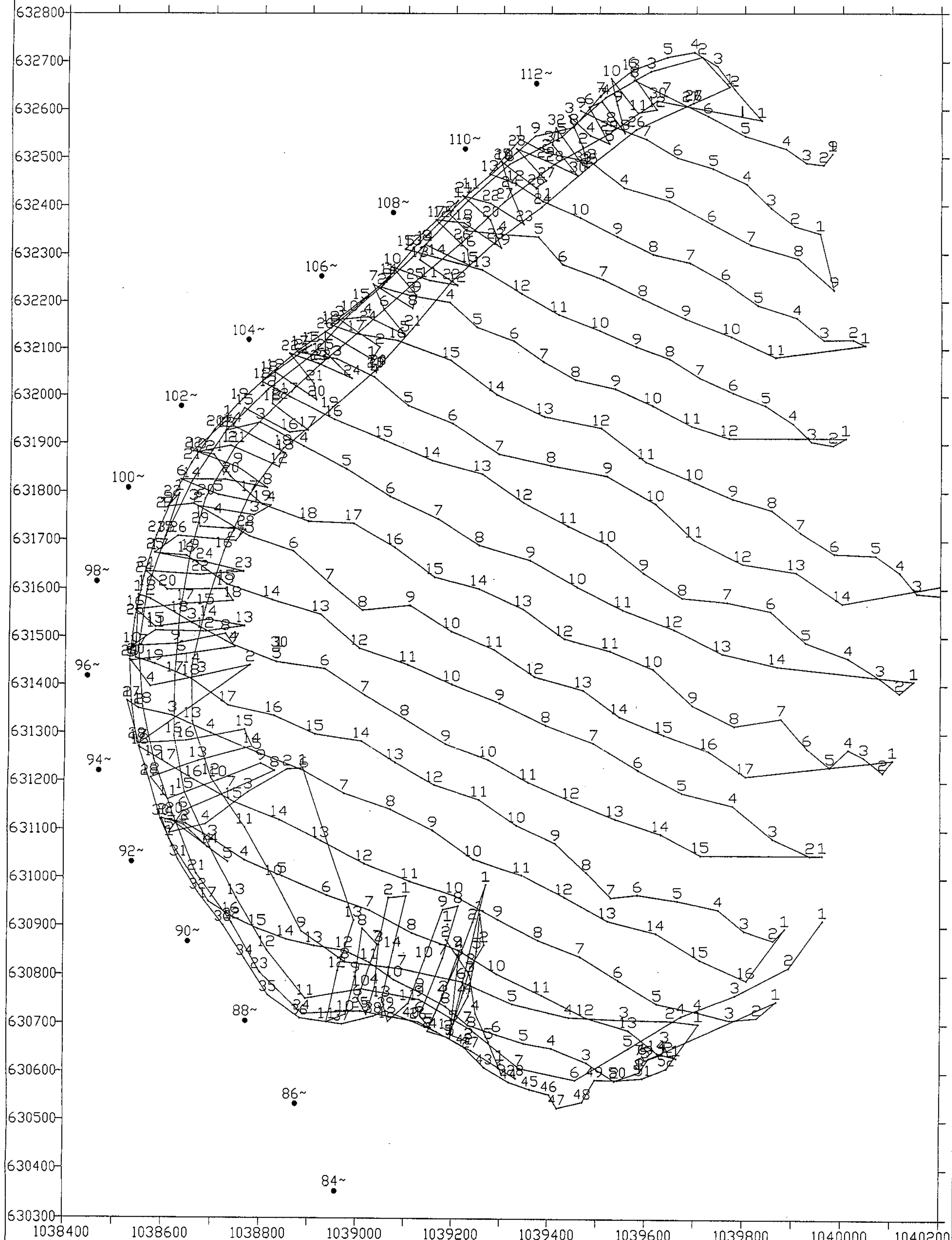
FIGURE **1**

SITE LOCATION MAP

J.W. MORRISSETTE/CAPITAL LAKE/WA

PROJECT NO. 013 1432.100 DRAWING NO. 92664 DATE 04/24/01 DRAWN BY EL

Golder Associates



LEGEND:

89~ CENTERLINE OF ROADWAY STATION MARK (89+00)

SURVEY TRACKLINES AND EVENT NUMBERS FOR BATHYMETRIC DATA

FIGURE **2**

BATHYMETRIC TRACKLINE MAP FROM CAPITAL LAKE

JWM & A/CAPITAL LAKE GEOPHYSICS/WA

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Golder Associates

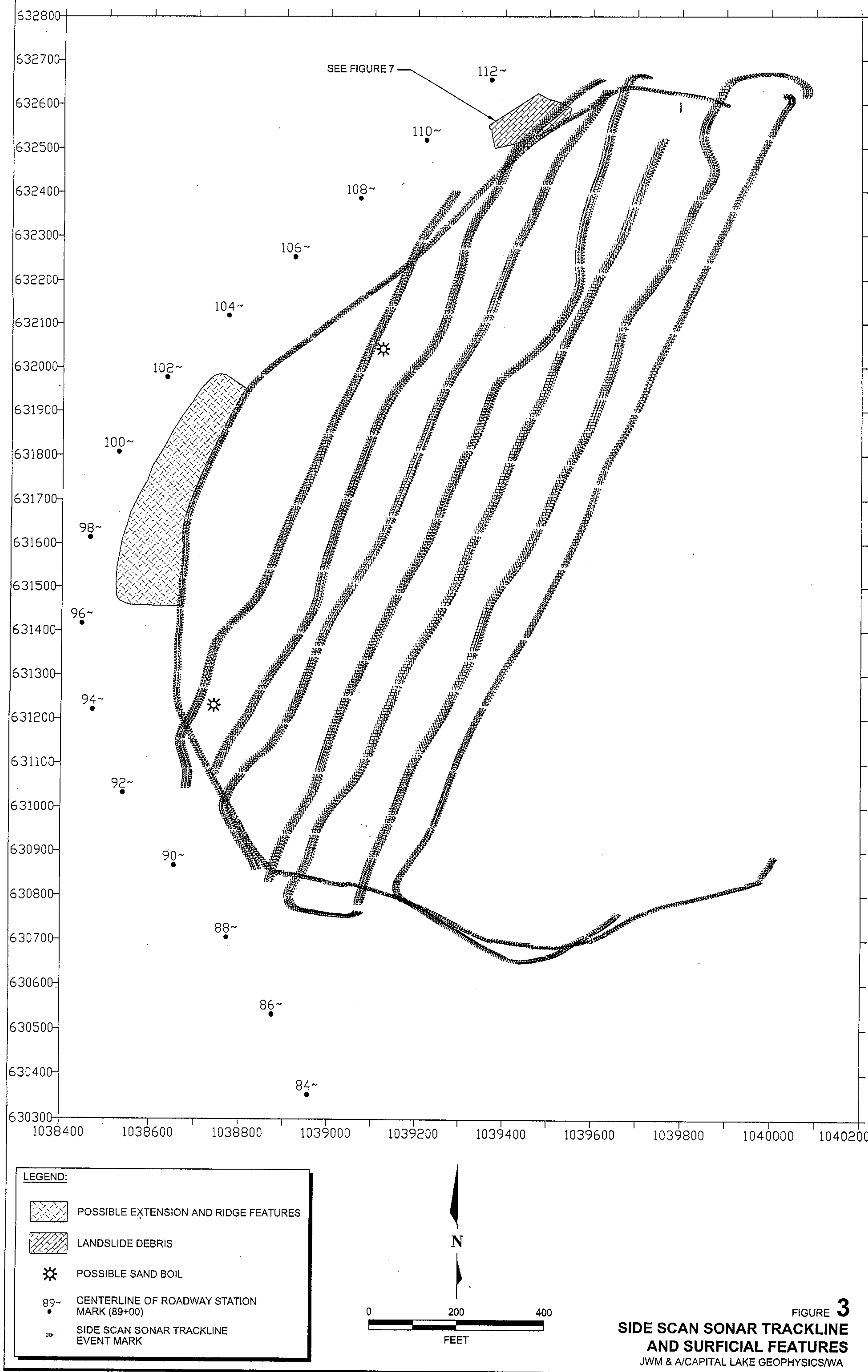

FIGURE 3

SIDE SCAN SONAR TRACKLINE AND SURFICIAL FEATURES

JWM & A/CAPITAL LAKE GEOPHYSICS/WA

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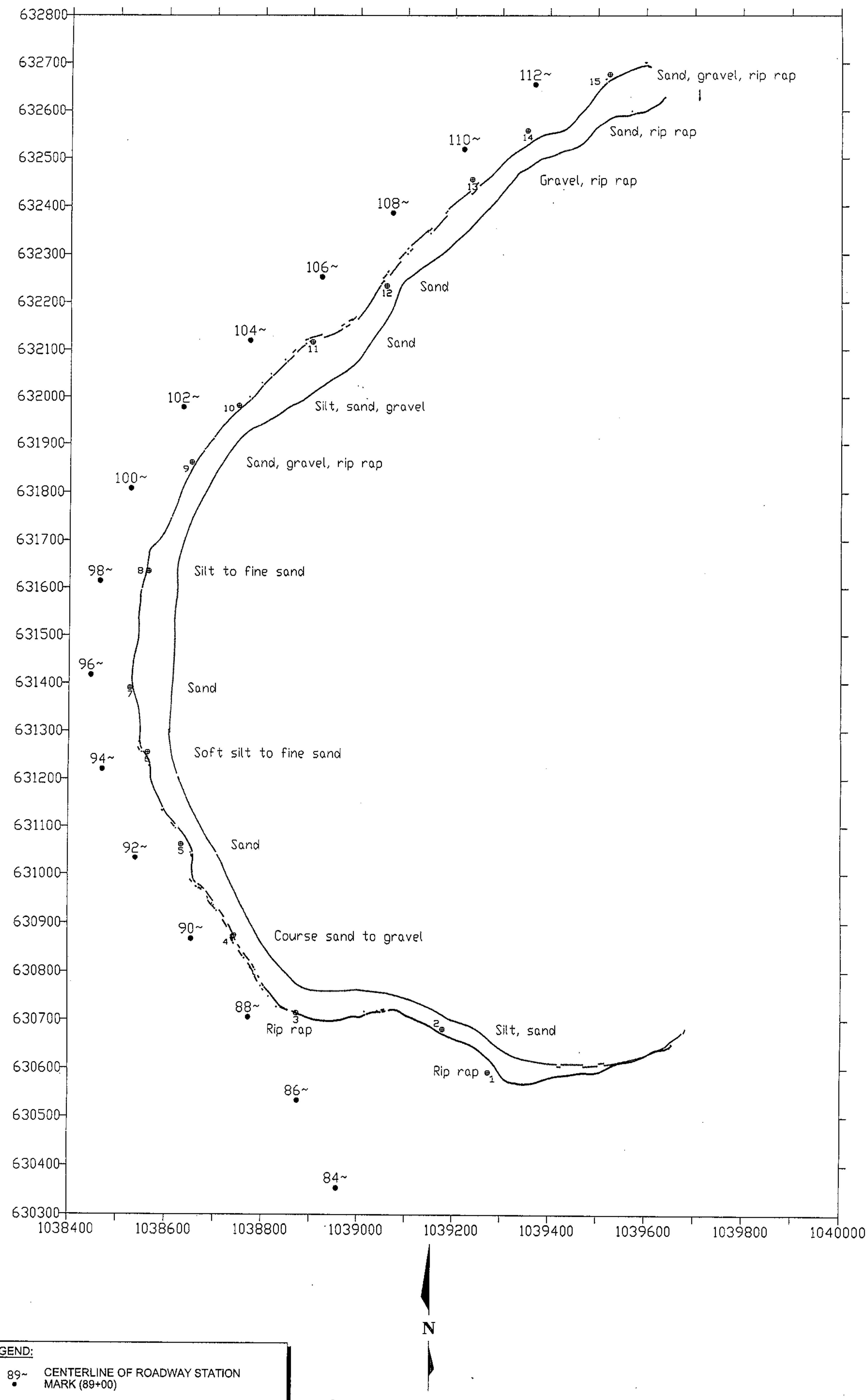
Golder Associates



LEGEND:

- 89~ CENTERLINE OF ROADWAY STATION MARK (89+00)
- ⊕ 2 PROBE LOCATIONS AND QUALITATIVE SEDIMENT DESCRIPTION
- SUBBOTTOM PROFILER TRACKLINE

FIGURE 4

SUBBOTTOM PROFILER TRACKLINES AND SEDIMENT PROBE LOCATIONS

JWM & A/CAPITAL LAKE GEOPHYSICS/WA

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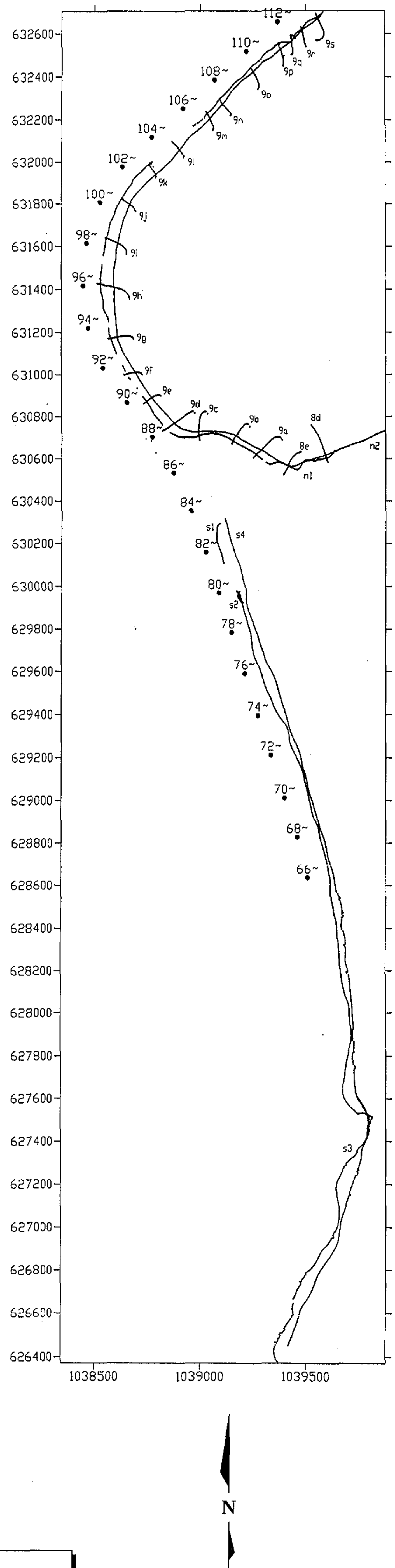
Golder Associates



LEGEND:

89~ •	CENTERLINE OF ROADWAY STATION MARK (89+00)
9d	GPR CROSS TRACKLINE REFERANCE NUMBER
/	GPR TRACKLINE

FIGURE 5

GROUND PENETRATING RADAR TRACKLINES ON CAPITAL LAKE

JWM & A/CAPITAL LAKE GEOPHYSICS/WA

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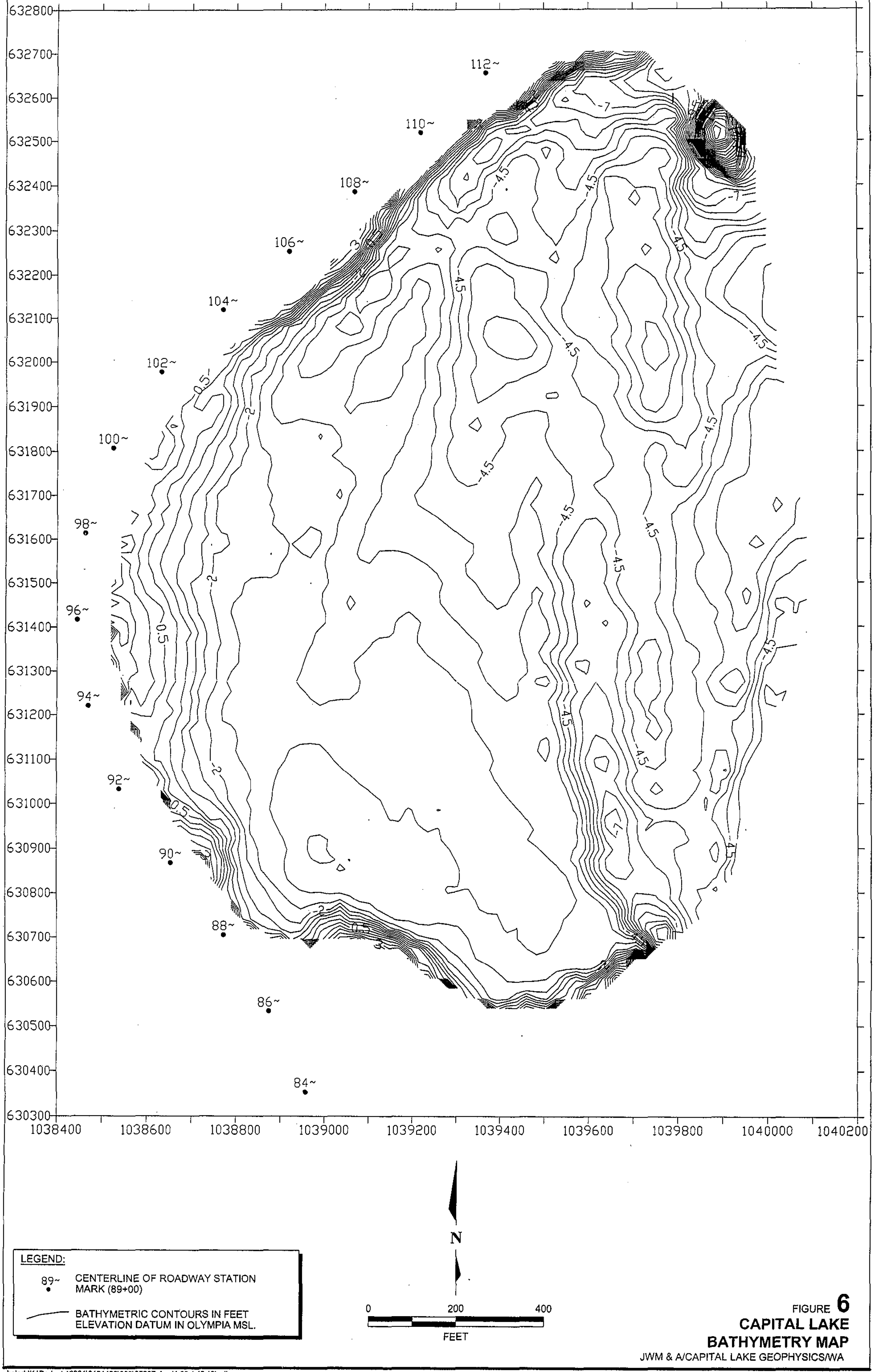

LEGEND:

89~ • CENTERLINE OF ROADWAY STATION MARK (89+00)

BATHYMETRIC CONTOURS IN FEET ELEVATION DATUM IN OLYMPIA MSL.

FIGURE **6**

CAPITAL LAKE BATHYMETRY MAP

JWM & A/CAPITAL LAKE GEOPHYSICS/WA

Golder Associates

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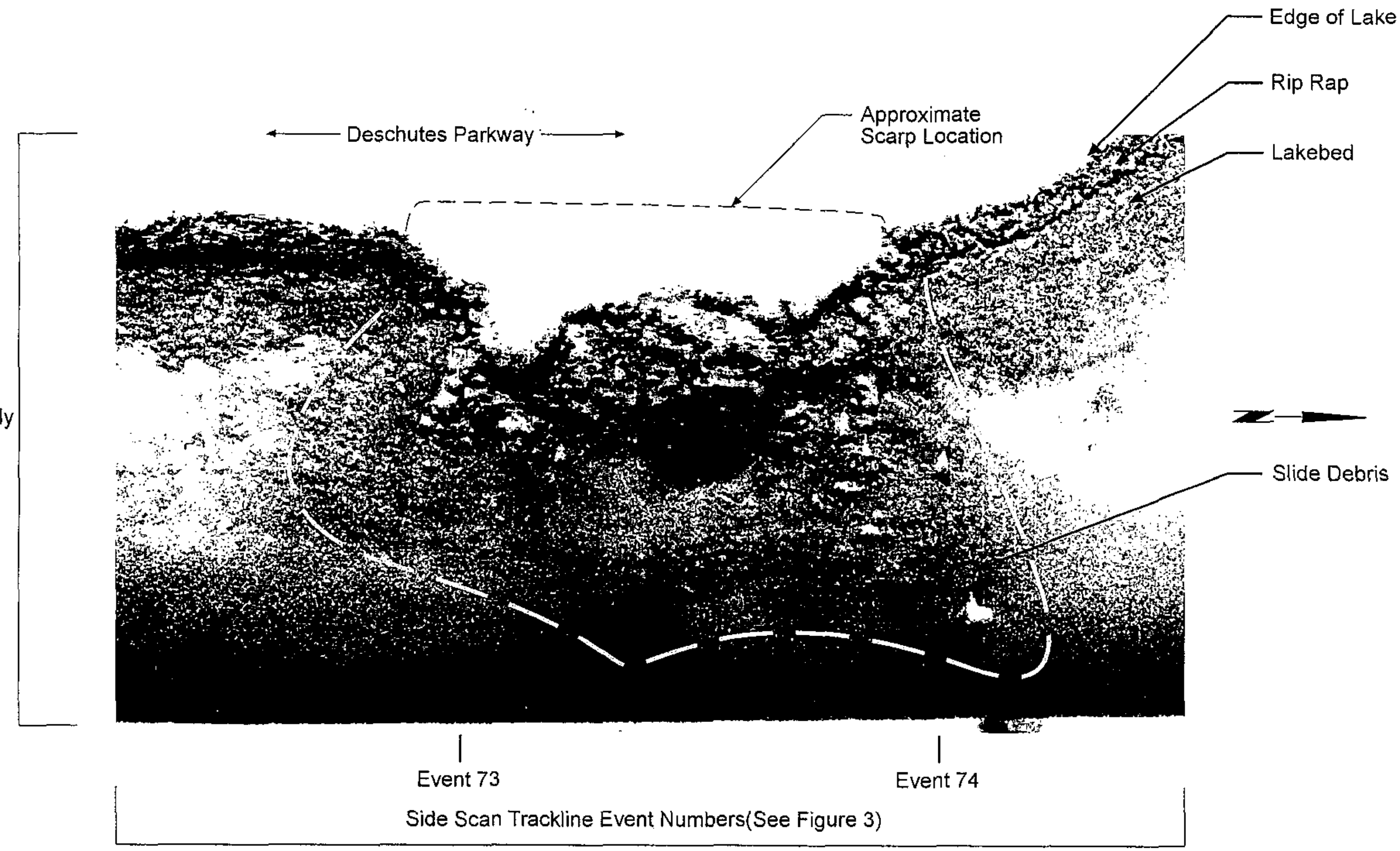
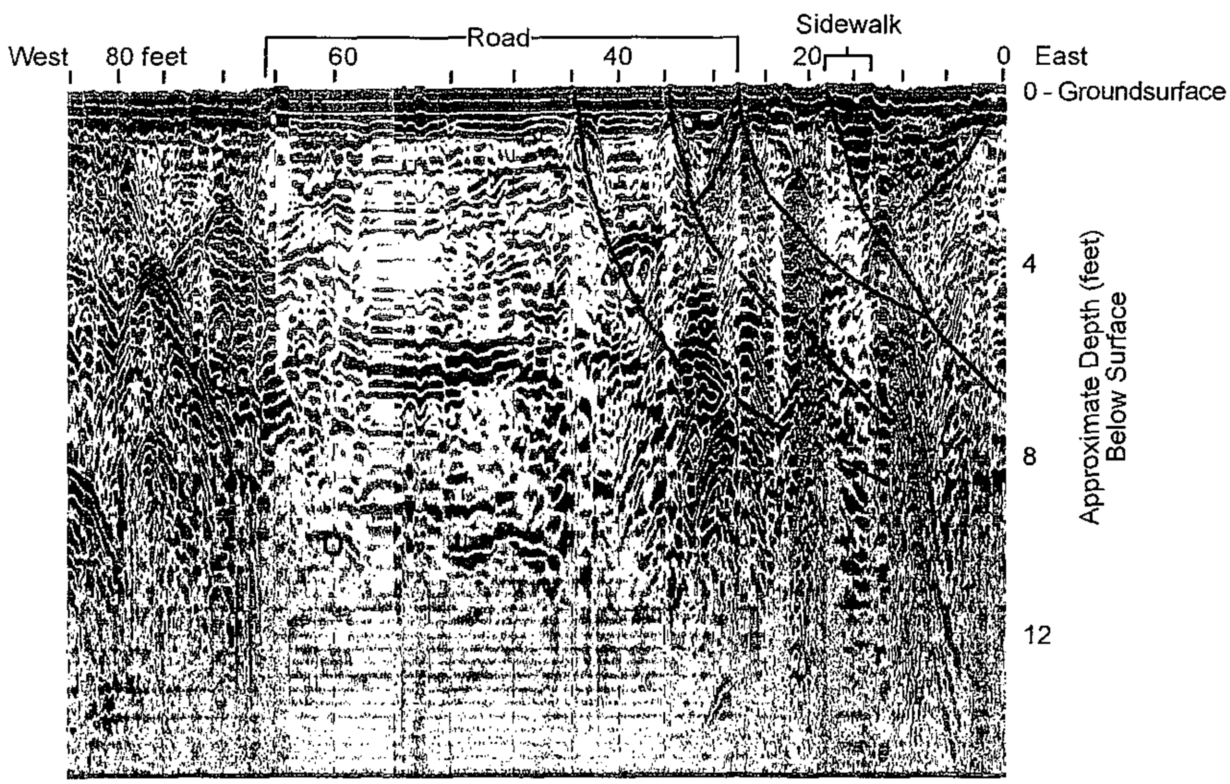


FIGURE 7
SIDE SCAN SONAR IMAGE SHOWING SLIDE DEBRIS NEAR STATION 112+00
J.W. MORRISSETTE/CAPITAL LAKE/WA

PROJECT NO. 013 1432.100 DRAWING NO. 95311 DATE 04/12/01 DRAWN BY EL

Golder Associates

Photo looking north. Collecting ground penetrating radar data on crossline at Station 99+90



LEGEND

- ○ Utility
- \ Interpreted Slip Plane Location

FIGURE **8**

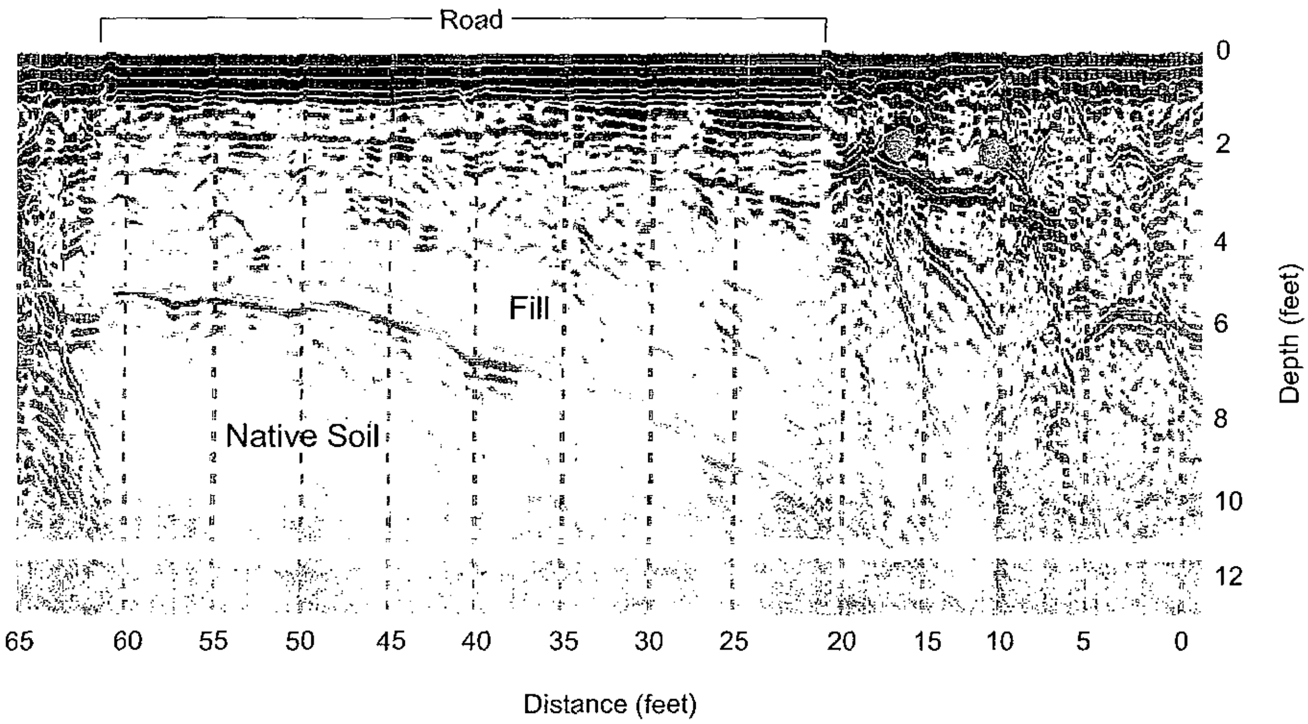
EXAMPLE GROUND PENETRATION RADAR PROFILE WITH INTERPRETATIONS FROM STATION 99+90

J.W. MORRISSETTE/CAPITAL LAKE/WA

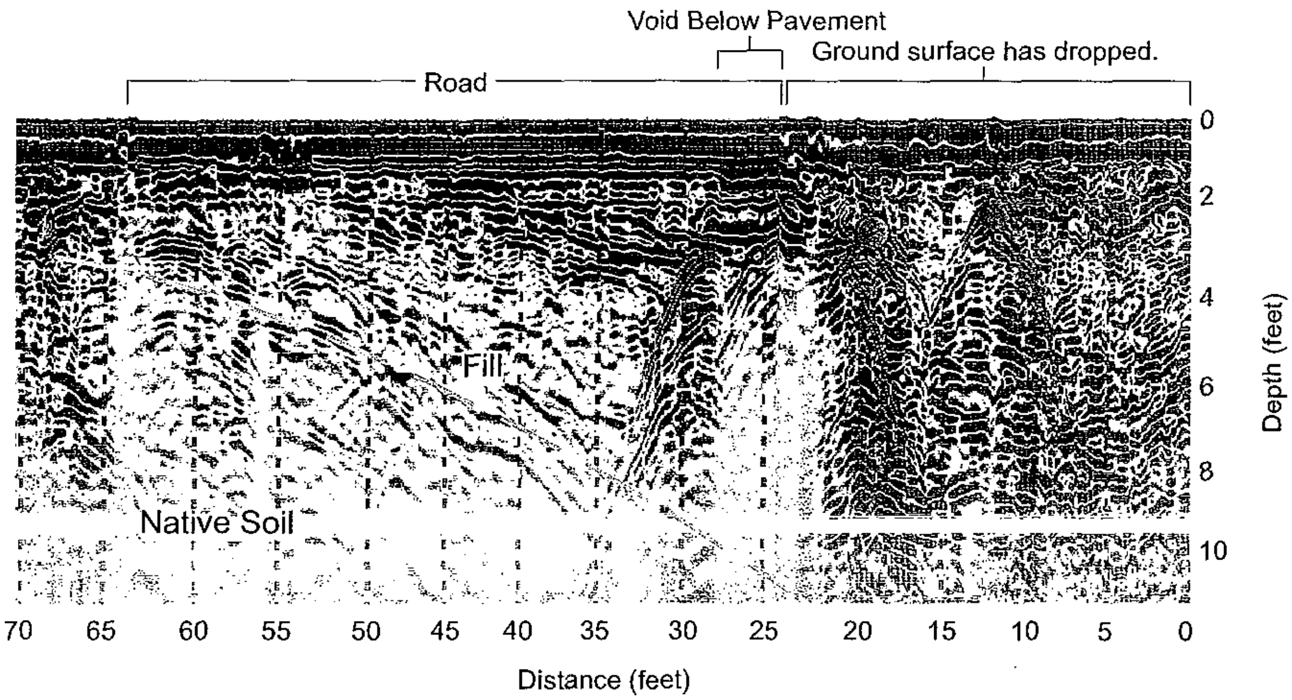
PROJECT NO. 013 1432.000 DRAWING NO. 95252 DATE 04/24/01 DRAWN BY EL

Golder Associates

Cross line at station 47+00 showing undisturbed fill and native soil



Cross line at station 49+32 showing disturbed fill where a failure has occured



LEGEND

Utility

FIGURE 9

GROUND PENETRATING RADAR PROFILE DATA WITH INTERPRETATIONS

J.W. MORRISSETTE/CAPITAL LAKE/WA

PROJECT NO. 013 1432.200 DRAWING NO. 95323 DATE 04/24/01 DRAWN BY EL

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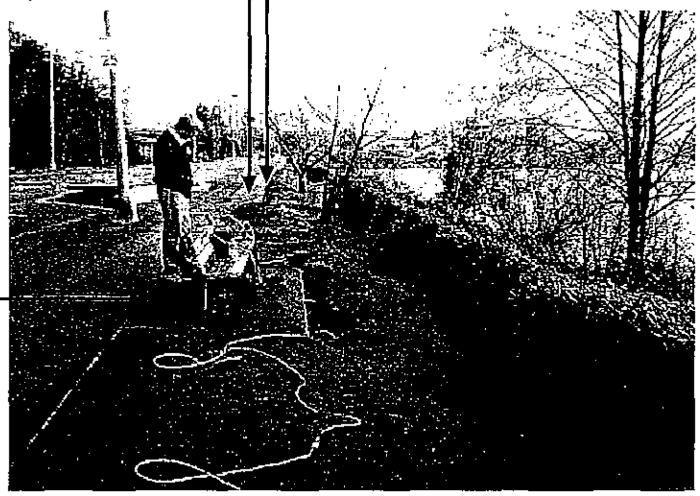
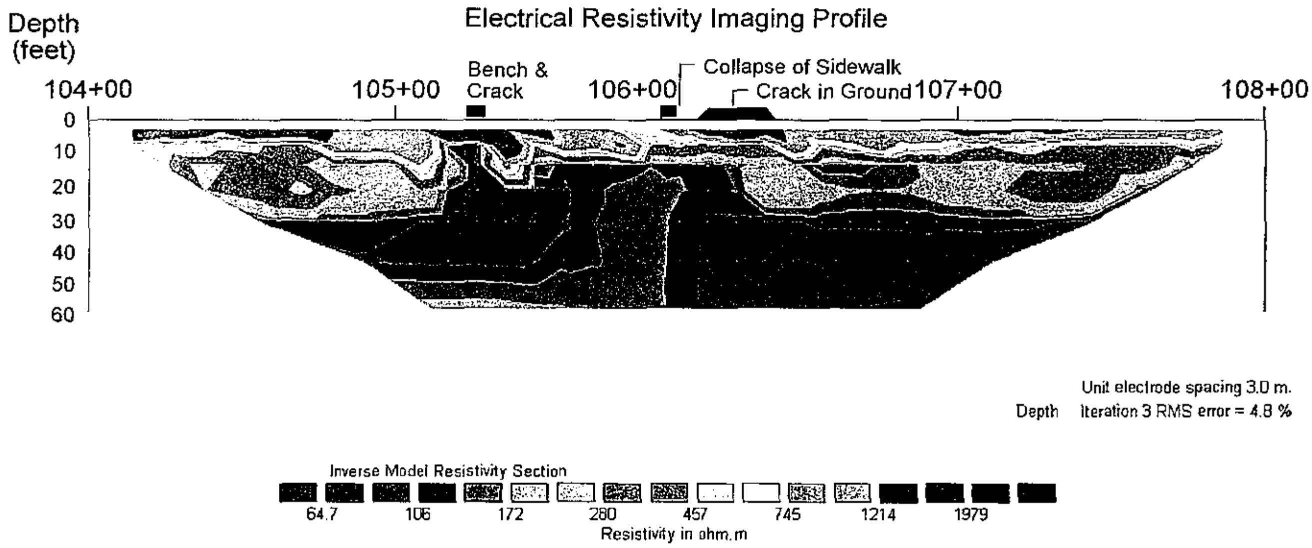


Photo looking north along Deschutes Parkway showing electrical resistivity imaging data collection.

Electrical Resistivity Imaging Profile



Resistivity values less then 200 ohm.m are intrepreted to be silts to clays or salt saturated sediment. Higher resistivities are interpreted to be sands to gravels, voids, and/or fill material.

FIGURE **12**

ELECTRICAL RESISTIVITY IMAGING PROFILE & DATA COLLECTION PHOTO

J.W. MORRISSETTE/CAPITAL PARK/WA

PROJECT NO. 013 1432.000 DRAWING NO. 95324 DATE 04/24/01 DRAWN BY EL

Golder Associates

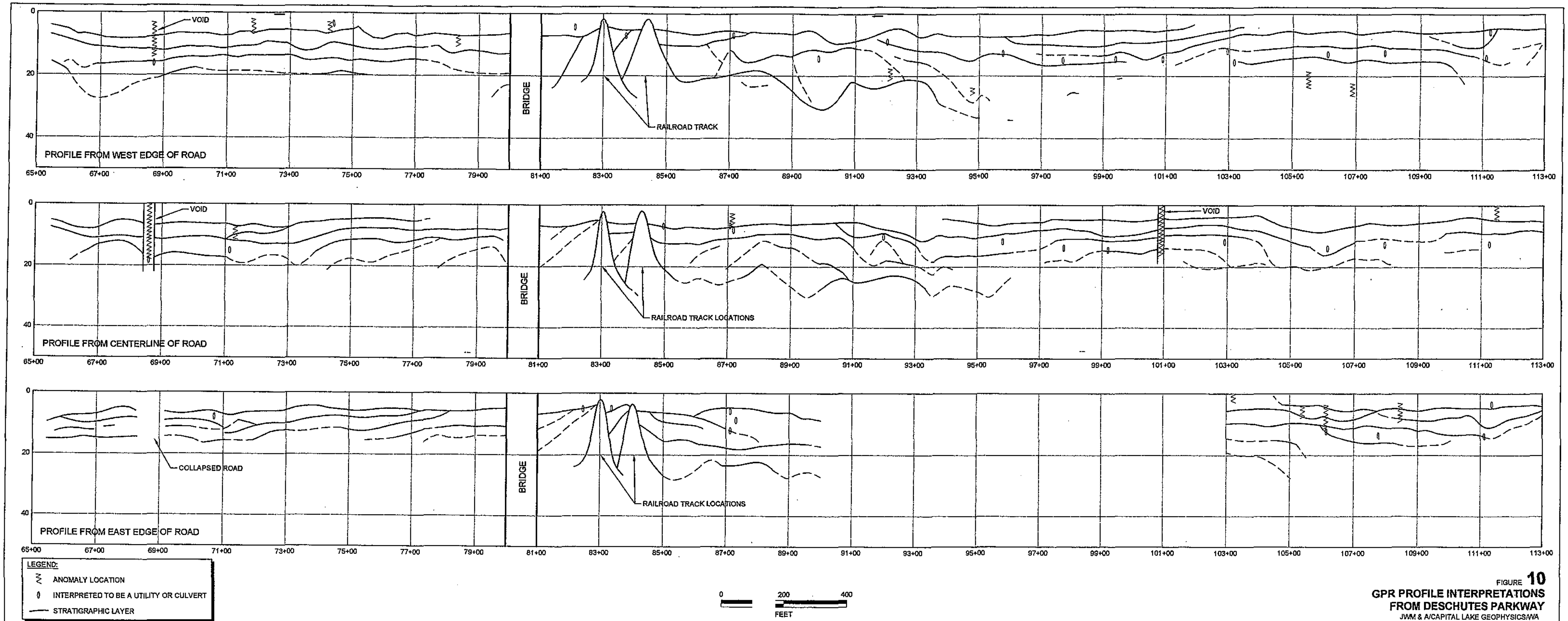


FIGURE 10

GPR PROFILE INTERPRETATIONS FROM DESCHUTES PARKWAY

JWM & A/CAPITAL LAKE GEOPHYSICS/WA

Golder Associates

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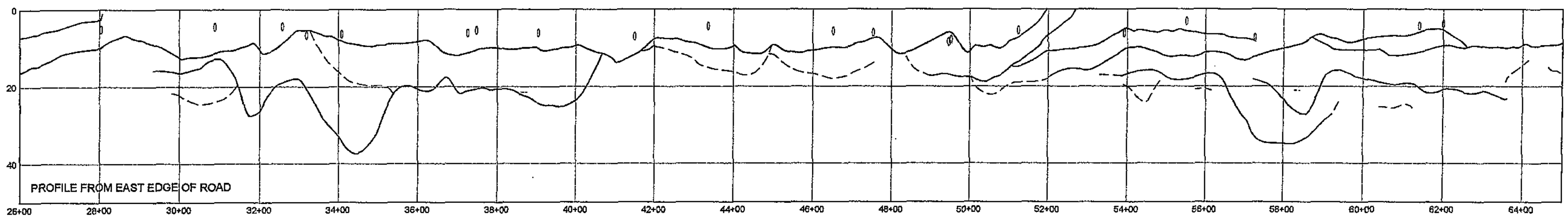

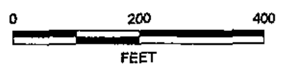

LEGEND:

- ANOMALY LOCATION
- INTERPRETED TO BE A UTILITY OR CULVERT
- STRATIGRAPHIC LAYER

FIGURE **11**

GPR PROFILE INTERPRETATIONS FROM DESCHUTES PARKWAY

JWM & A/CAPITAL LAKE GEOPHYSICS/WA

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Golder Associates