Victoria File #

26250-20/ 2535 K-V

Golder Associates

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Golder Associates

REPORT ON

ELECTROMAGNETIC TERRAIN CONDUCTIVITY MAPPING: OKANAGAN UNIVERSITY COLLEGE, KELOWNA, B.C.

26250-20/2535 K-V

Submitted to:

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October 1999 992-1897

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1.0 SCOPE OF WORK

As requested, Golder Associates Ltd. (Golder) have carried out an electromagnetic terrain conductivity survey (EM-31) at the Okanagan University College campus (OUC) on K.L.O. Road in Kelowna, BC (Figures 1 and 2). The objective of the survey was to delineate buried oxbow channels that were in-filled with landfill debris and, in particular, to locate potentially hazardous targets on the scale of isolated metallic storage tanks and 55 gallon drums, particularly within the soccer field area. The geophysical investigation excluded the eastern quarter of the campus (east of Lot 39 in Figure 3) since the former City of Kelowna Landfill (operated until the 1960's) never included this eastern area. The survey consisted of two areas as shown in Figure 2:

1. the initial area of interest, the northern half of Lot 39 (Figure 3) encompassing the present soccer field, is the site of the proposed Kelowna Secondary School (KSS) sports field; and
2. the secondary area of interest consists of the majority of the remaining three-quarters of the OUC campus.

Outside of the KSS site the survey was optimized with a lower station density to provide the desired coverage at a spatial resolution sufficient to locate most of the possible isolated drum-like targets. Interpretation of the resulting contoured data indicated different areas, or concentrations, of landfill debris, including buried metal and possibly impacted soil to approximately 5.6 m depth.

Fieldwork for this investigation was conducted by Rob Luzitano, a Golder geophysicist, from August 4 to 10, 1999. This report summarizes the methods and results of the investigation.

2.0 METHODOLOGY AND SURVEY

A clear definition of survey objectives dictates the geophysical methodology to be carried-out. Initially, a Geonics EM-61 survey (a depth-focused metal detector with a 3.5 m investigation range) was considered for locating exclusively buried metal, particularly drum-sized targets. Since delineating impacted soil and detecting buried non-metallic debris was also of interest an EM conductivity survey was chosen. Selection of appropriate instrumentation also involves a trade-off between depth of investigation and spatial resolution. In general, depth of investigation increases with coil separation (Section 2.1) and decreases with frequency. Spatial resolution, however, is improved by decreasing the intercoil spacing and, consequently the volume of soil over which a given reading is averaged.

Resolution is defined as the ability to discriminate a target from the background variation or from a neighboring "target." The concern in this survey is to discriminate from the background variation. Resolution depends primarily on four factors:

1. electrical size, i.e., the combination of the target's physical size and contrast from the host material;
2. depth of burial;
3. coil spacing; and
4. station spacing.

Due to this combination of factors, resolution is difficult to quantify with a single value for a given survey. For a metallic target expected to produce a relatively clear response, such as a 55 gallon drum, resolution may depend more on the station spacing. In this case the station spacing of an EM-31 survey should be on the order of 1 to 2 times the target size to ensure adequate sampling to readily resolve the metallic target. The expected resolution for the survey reported here, with 1 m station spacing, is such that an isolated 55 gallon drum-like target, buried in a vertical orientation, could be located on the reference grid within an approximately 3 m hemispherical radius.

The survey reported here was carried-out using a Geonics EM-31 which provides an approximate depth of investigation of 5.6 m.

2.1 Electromagnetic Terrain Conductivity Mapping (EM-31)

The Geonics EM-31 electromagnetic terrain conductivity meter measures soil conductivity from the inductive response of the ground. Basic principles of electromagnetic conductivity mapping are illustrated in Figure 4. An alternating current is supplied to a wire transmitter coil, producing a time-varying (9.8 KHz) magnetic field $\mathbf{B}_p$ that penetrates the ground and induces electrical eddy currents $\mathbf{J}_e$ within the subsurface materials. These eddy currents give rise to a secondary magnetic field $\mathbf{B}_s$ that is measured, together with the primary field, by the receiver coil. Two components of the secondary field are measured:

1. the in-phase component, i.e. in-phase with the primary (transmitted) field; and
2. the quadrature component, i.e. that which is 90° out of phase with the primary field.

The quadrature component yields a direct measure of average ground conductivity in mS/m. The in-phase response, measured in parts per thousand (ppt) of the primary field, has no direct physical interpretation but is a useful indicator of buried metallic objects. Usually an EM-31 survey results in two contour maps. Apparent Electrical Soil Conductivity, and In-Phase Response.

Under natural geologic conditions, induced current flow and, consequently, the strength of the secondary magnetic field are approximately proportional to subsurface conductivity. Soil conductivity is controlled principally by porosity, relative pore saturation and pore-water ion concentrations. Soil texture and mineralogy are also significant. Clays and silts are typically conductive compared with coarser grained sands and gravels. Finally, both surface and subsurface metal (ferrous and non-ferrous), including fences, steel frame structures and underground utilities and storage tanks, produce a characteristic negative (or low)-valued response flanked by anomalously high apparent conductivities. This low or negative-valued response is purely a geometrical effect that occurs when the discrete metallic object lies between the transmitter and receiver coils where the vector addition of the fields result in a negative value. This response is also depth dependent where increasing target depth results in a smaller negative or even positive conductivity.

The EM-31 conductivity meter can be operated in vertical or horizontal dipole mode, meaning that transmitter and receiver coils are oriented such that their axes, and the resulting magnetic dipole field, are vertical or horizontal relative to the ground surface. Depth (range) and sensitivity are significantly different for the two modes as illustrated in Figure 5. Note that the depth axes in Figure 5 are normalized by intercoil separation. For the EM-31 coil separation, s = 3.7 metres, Figure 5 indicates that the horizontal mode yields maximum sensitivity at the surface, z/s = 0.0. The vertical mode, however, possesses peak sensitivity at approximately 1.3 metres, 35 percent of intercoil separation, and a range of about 5.6 metres. The data reported here were acquired with the vertical dipole orientation. For practical purposes, the EM-31 response should be interpreted as a weighted average (apparent) conductivity for hemispherical subsurface volumes that have a radius approximately equivalent to the 5.6 m range.

2.2 Field Procedure and Acquisition Parameters

Before acquiring the EM conductivity data a reference grid was established, by chaining, with the origin located near the southeast corner of the present soccer field (Figures 6 to 8). The origin was defined as the projected intersection of the outer edge of the stairs on the west side of Building Z and the intermediate south facing wall of Building Z. Grid locations are addressed as Northings and Eastings in metres where, for example, position (20W, 30S) is located 20 metres west and 30 metres south of the origin. Grid addresses were also noted for a number of widely scattered landmarks (including building corners, catch basins, and manholes) to provide additional location control and to aid in relocating a particular grid location. These additional ties were provided to Reid Crowther in a fax dated 12 August, 1999.

Apparent ground conductivity measurements were acquired at 1 m intervals along transects separated by 2 or 4 m, within the KSS sports field site and remaining areas, respectively. Conductivity readings were made at the standard height above the ground, waist level, with the instrument axis oriented parallel to the transect and using vertical dipoles. As discussed in the previous section, the vertical dipole orientation provides the maximum depth of investigation and is the least sensitive to surface conductivity effects. Data were automatically recorded by an Omnidata digital data logger and subsequently downloaded to a portable computer and processed in the field for quality control.

2.3 Site Conditions

Generally, the OUC campus was a favorable site for the survey. The flat terrain with mostly clear sightlines allowed for relatively easy layout of the reference grid. The primary challenge of the site was to keep parking lots free of cars during acquisition. This was more easily accomplished with most of the acquisition being carried out over the weekend. The other significant obstacle was areas of limited clearance from buildings and other infrastructure such as reinforced concrete and utilities. Electrically conductive infrastructure often affected the EM-31 measurements when within 5 to 10 metres, depending primarily on depth of burial and orientation relative to the EM-31. Areas of limited clearance included:

- the trades compound (minimal clearance from buildings and caches of scrap metal);

- the parking area between the library and trades compound (often within the influence of buildings or underground services); and
- some areas along K.L.O. Road (significant concentration of services and reinforced concrete in some areas).

Throughout most of the area surveyed, interference from infrastructure was not a significant problem.

Despite a few hours of rain and the overnight watering of lawns, changes in ground saturation were small enough not to have a noticeable effect on the background conductivity. A significant difference in ground saturation and background conductivity was noted, however, between the soccer field and the lawn around the residence building (Building R). The residence building area was noticeably more saturated with some sections of soft ground which probably accounts for the background conductivity being a few mS/m higher than at the soccer field (approximately 19 mS/m compared to 15 mS/m).

3.0 RESULTS

The EM-31 survey was expected to delineate the oxbow channels with or without buried debris, considering the effect of changes in sedimentation and saturation on conductivity, as discussed in Section 2.1. The buried debris, however, increases the natural conductivity contrast as well as produces unnatural erratic variations in both the in-phase and conductivity components. Additionally, water in and around buried debris often has a higher than normal ion concentration and thus higher conductivity.

Colour contour maps of apparent soil conductivity and in-phase response are provided as Figures 6 and 7 at 1:1000 scale. An AutoCAD base map, provided by Reid Crowther, and the geophysical survey reference grid are overlaid on the contour maps. Coverage is indicated in the contour maps where the traverses of discrete measurement locations have been denoted by "…." symbols. The contours and colour shading of the resulting maps are based on inverse-distance-weighted interpolations and extrapolations from the discrete measurement locations and subsequent fitting of a minimum curvature surface to the interpolated grid. Due to the density of measurements in the survey reported here, any variety of contouring algorithms or parameters should yield very similar results.

Note that the color scales of the maps were chosen to optimize the distinction of the buried channels and debris features over the entire survey area. The conductivity color scale clearly illustrates the difference in background conductivity between the soccer field and residence areas (field south east of Building R) which is probably due to the difference in soil saturation as noted in Section 2.3. Note that this scale colors conductivity values below 12 mS/m in shades of blue with the darkest blue (less than 5 mS/m) including both low positive and negative values. Recall from Section 2.1 that conductivities that are lower than the background typical of a given area could be due to either relatively low conductivity soil (coarser grained material or fresher water) or buried metal. Negative conductivities, however, are definitive of buried metal. Considering the apparent natural variation over the entire OUC survey area, most occurrences of conductivities lower than 8 mS/m are probably due to buried metal.

The interpretation map provided as Figure 8 incorporates the interpretations of both the conductivity and in-phase maps with the AutoCAD base and survey grid overlays. Additionally, the interpretation is overlaid on the 1938 air photo (Figure 9) to illustrate the excellent agreement with some of the known oxbow channels as well as to indicate the channel locations within areas of significant infrastructure.

Figures 8 and 9 are also provided as electronic copies, where the air photo is a separate layer within the interpretation AutoCAD file.

Note that the interpretation legend in Figure 8 consists of conductivity and in-phase anomalies which include zone features, channel-like features, and isolated targets. To aid in explaining the legend some examples are noted here while a more detailed discussion of particular features follows. An example of a region or zone feature is the extensive region of abruptly higher conductivity (above 24 mS/m within Feature A), north of the residence building (Building R), which encompasses some examples of channel-like features of even higher conductivity (greater than 30 mS/m in Feature B). This example, and others of extensive zones of buried metal, indicates that some areas exist where landfill debris were not restricted to the oxbow channels. In some areas the boundaries of the channel-like features are not well defined, such as west of the library (Building L) where the boundaries are dashed, due to interference from infrastructure such as buildings, chain-link fences, and buried services, or due to limited coverage. Of primary importance, the interpretation map also identifies isolated anomalies, some of which are clearly metallic, due to their extreme and/or erratic values in both components such as at (34W, 30N) within the soccer field (Figures 6 – 8). These discrete anomalies usually occur in clusters, or zones, of numerous individual targets ("Zones of discrete anomalies" in Figure 8) and in some areas the cluster may be too concentrated to resolve individual targets and are mapped as "Discrete and/or higher concentrations of discrete anomalies" in Figure 8).

3.1 Conductivity Anomalies with Air Photo Correlation

As illustrated by Figures 6 and 9, a number of distinct curvilinear conductivity highs (ridges) and in one case a trough (curvilinear low), correlate very well with oxbow channels observed in the 1938 air photo.

Most of the clearest correlations between conductivity anomalies and the air photo occur at the proposed KSS sports field site. The most obvious correlating channel anomaly (Feature C) traverses northward through most of the soccer field (area north of 40S) before meandering westward at 110N. East of this channel, a conductivity trough also exhibits an obvious air photo correlation (Feature D, Figures 8 and 9) curving northward from (16W, 5S) to (12W, 58N) with negative conductivities at the north end indicating buried metal. Another channel-like conductivity high (Feature E), intersecting Building Z at its north and east walls correlates with the channel along the east boundary in the northern section of Lot 39 (Figures 3, and 9).

In the area of the residence building (Building R) another clear channel feature (Feature F) that correlates with the air photo trends northwest from (288W, 283S) and begins to curve northward at a corner of the residence building at (352W, 240S) (Figures 6 and 9). Note that the lower contrast of this channel with the background conductivity is due to the slightly higher background as noted earlier. This "residence channel" appears to continue north of Building R, meandering northeastward through the extensive conductivity high and parking lot to the north (as Feature B) and crosses Campus West Road into the north border of the trades compound. Within the extensive high anomaly (Feature A), the channel is also suddenly much more conductive, and east of 280W exhibits some of the highest channel conductivities, suggesting significantly larger concentrations of buried debris and/or impacted water.

Although clearance within the trades compound was limited (as noted in Section 2.3) due to caches of scrap metal and numerous buildings, a highly conductive channel-like feature (Feature G in Figure 8) appears to correlate with the small oxbow in the southwest section of Lot 38 (Figures 3 and 9). The extremely high conductivities within this channel suggest a large concentration of buried debris and impacted soil.

Within most of the channel features distinct zones of higher conductivity occur which may be due to higher concentrations of buried debris and/or higher saturation levels. These variations are mapped in Figure 8 as "Isolated high conductivity areas." The channel variations having the greatest contrast occur within the soccer field. Although the variations within the channel northeast of the residence building (Building R) exhibit lower contrast (Feature B), compared to those variations in the soccer field (such as within Feature C), the overall channel conductivity is also noticeably higher in Feature B.

A number of anomalously conductive areas that are poorly defined due to infrastructure and/or limited coverage occur where oxbow channels exist as indicated by Figure 9. These inferred anomalies occur between the tennis courts and the library (Building L), in the parking lot immediately west of the library, and between Building T and K.L.O. Road (around 150 W).

3.2 Channel-like Conductivity Anomalies having no Air Photo Correlation

Additional channel-like conductivity features are clearly delineated that do not appear to correlate with any channels in the air photo. Geometrically, these channel-like features appear to be related to the correlated channel features as either former prograding or opposing meanders. These uncorrelated features may be older channels that exhibit a much more subtle surface expression. Alternatively, these channel-like anomalies could be man-made trenches filled with debris.

Along the west side of the soccer field a very clear high conductivity channel-like feature, (Feature H) that is not observed in the air photo, produces an approximate mirror image of the main channel meander (Feature C) thereby enclosing a lens shaped "island" of predominantly background conductivity values (about 60N to 95N and 66W to 86W) (Figures 6 and 8). This "island" is, however, included in one of two rectangular zones (Feature I, Figure 8) observed in the in-phase map (Figure 7) due to minor erratic variations that suggest buried metal exists within the "island."

Northeast of the residence building one or two clear channel-like features, of exceptionally high conductivity, are sub-parallel to the meander observed in the air photo (Feature B in Figures 6 and 8). One of these additional "channels," at 310W, is projected to merge into the main channel about 25 m north of the survey boundary. The other additional channel feature merges with the main meander at the localized high anomaly at approximately (350W, 125S).

3.3 Distinct Indications of Buried Metal or Debris

The contoured data, particularly the in-phase response, clearly indicate areas of significantly higher concentrations of buried metal both inside and outside of the delineated channels. Although much of the debris is concentrated in the channels, the debris does not appear to be restricted to the channels. Particular examples of these extended areas on the in-phase map (Figure 7) include:

- the soccer field area; and
- the high conductivity region north of the residence building.

Within the soccer field area much of the buried metal is concentrated within 2 adjoining roughly rectangular regions (Features I and J in Figure 8). These rectangular regions have an overall mottled in-phase appearance (erratic high-low readings in Figure 7) encompassing trench-like zones of even more extreme high-low in-phase responses (zones in orange in Figure 8). These higher concentration trench-like zones appear to occur primarily within primary channel features, while the areas of lowest concentration, within the rectangular zones, appear to "bridge" the primary channel features, possibly as a thinner layer of fill. Although these particular trench-like zones are probably landfill material they exhibit an in-phase character similar to buried metallic services, however they are not as sharply defined as services. Another significant zone is mapped at, and beyond, the north end of the soccer field (Feature K, Figure 8) which encompasses both a low conductivity area and a mottled in-phase response together indicating higher concentrations of buried debris particularly metal. The southern half of this zone also correlates with an oxbow channel in the air photo (Figure 9). Other isolated occurrences of debris, and probably metal, (shaded orange in Figure 8) include locations within the berm west of the soccer field along 100 W (primarily between 0N and 50N), and numerous discrete anomalies within the channel that intersects Building Z (Feature E).

The area north of the residence (north of 160S and west of 280W, i.e. Feature A) exhibits an extensive area of elevated conductivity and increased erratic variation of the in-phase response indicating numerous occurrences of buried debris including metal. Within this extensive area a more concentrated zone of buried metal (Feature L, Figure 8) extends beyond the boundaries of one of the additional channel-like features. To the east, the main meander channel within Campus West Road exhibits a high and somewhat erratic in-phase response (Figures 7 and 8) suggesting some of the highest concentrations of buried debris, particularly metal.

4.0 SUMMARY AND CONCLUSIONS

The EM-31 survey has revealed the distribution of buried metal and other debris, both within and outside of, the buried oxbow channels. Most of the channel-like features illustrated in Figure 8 exhibit an excellent correlation with the oxbow channels observed in the 1938 air photo as shown in Figure 9. Additional channel-like features that have no apparent correlation in the air photo appear to be related to the known channels as either older opposing meanders or older prograding meanders. Alternatively, these additional channel-like features could be in-filled trenches. Although most of the buried debris is concentrated within the delineated channels, a number of areas were identified where zones of buried debris, particularly metal, extend beyond the channel boundaries. The most extensive area is north of the residence building where the entire region north of 160S rises abruptly above 24 mS/m with significantly higher conductivities within the channel (greater than 30 mS/m) possibly due to thicker and/or more saturated landfill material. The channels in this area and immediately to the east (north of and within the trades compound) exhibit some of the highest channel conductivities suggesting greater concentrations of buried debris and possibly impacted water.

The interpretation map (Figure 8) outlines the significant features revealed by the EM-31 survey. The five feature types in the legend are arranged in approximate order of importance from discrete targets or high concentrations of targets, particularly metal, to the interpreted channel boundaries. The first two feature types are mostly derived from the in-phase response, thus they are most indicative of buried metal. The third and fourth feature types identify areas of isolated or notably extreme values of conductivity and in most cases delineate significant variations within the oxbow channels. These anomalous conductivity zones may contain greater concentrations of debris, possibly including metal, and/or possibly impacted soil and water. Although some of these conductivity anomalies (the third and fourth feature types) could be due to natural variations in soil type and saturation, the larger their magnitude, the more likely their cause to be man-made. The areas of highest priority are where the in-phase features (legend feature types 1 and 2) overlap with the conductivity features (feature types 3 and 4).

We emphasize that the foregoing findings should be verified and constrained by direct investigations. In particular, the geophysical mapping reported here should guide the location of subsequent intrusive investigations. The intrusive investigations will, concurrently, provide an assessment of the nature of conductivity anomalies such as the distinct conductivity highs and lows within the channels.

5.0 CLOSURE

We trust that the geophysical investigation presented here has adequately addressed your requirements. Should you have any questions or require clarification of any information please do not hesitate to contact us.

GOLDER ASSOCIATES LTD.

Rob Luzitano, M.Sc.
Geophysicist

Michael (Max) Maxwell, Ph.D., P.Geo.
Associate

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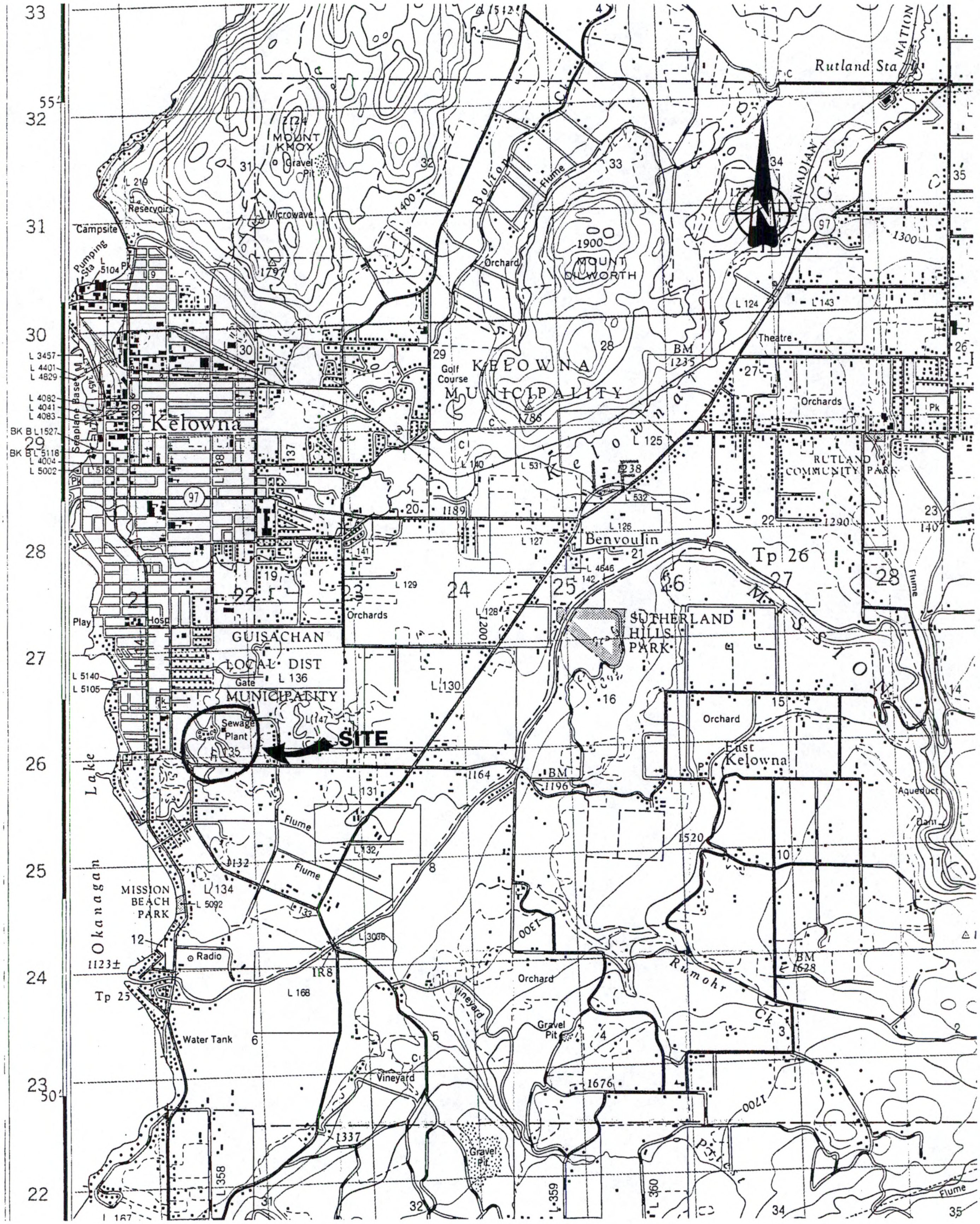

Project No. 992-1897 Drawn RDL Reviewed KGH Date SEPT., 1999

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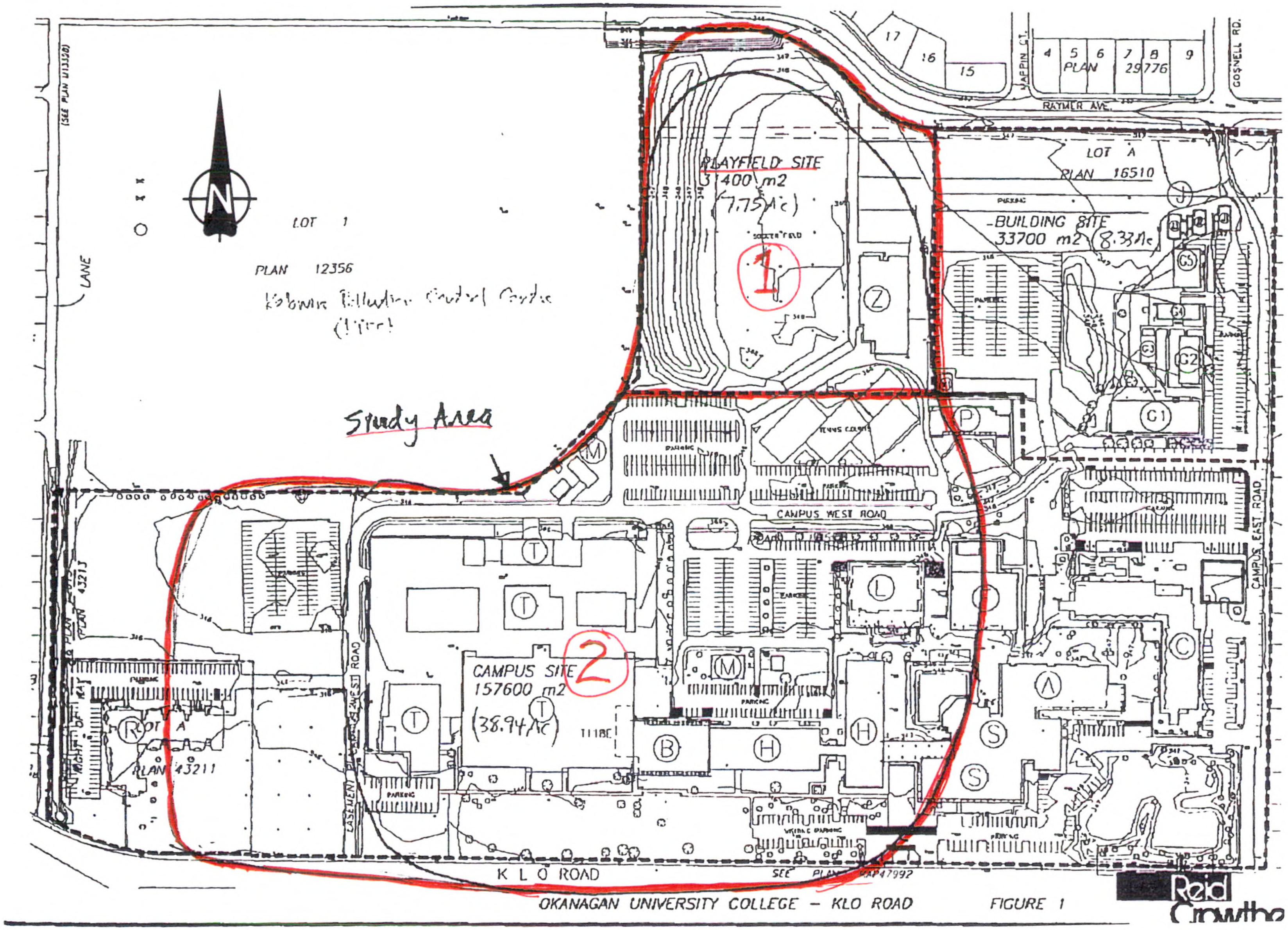
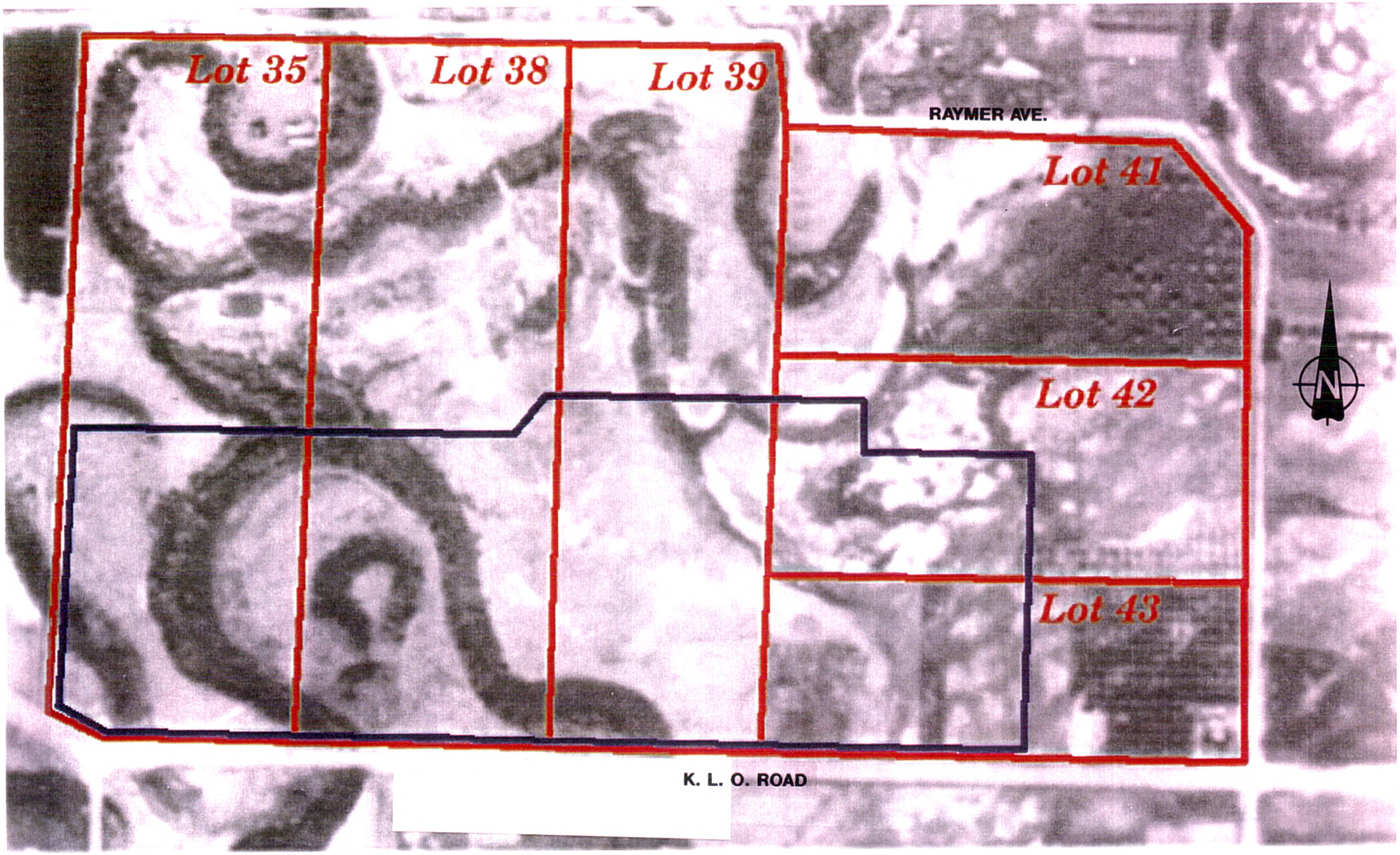
SITE LOCATION MAP

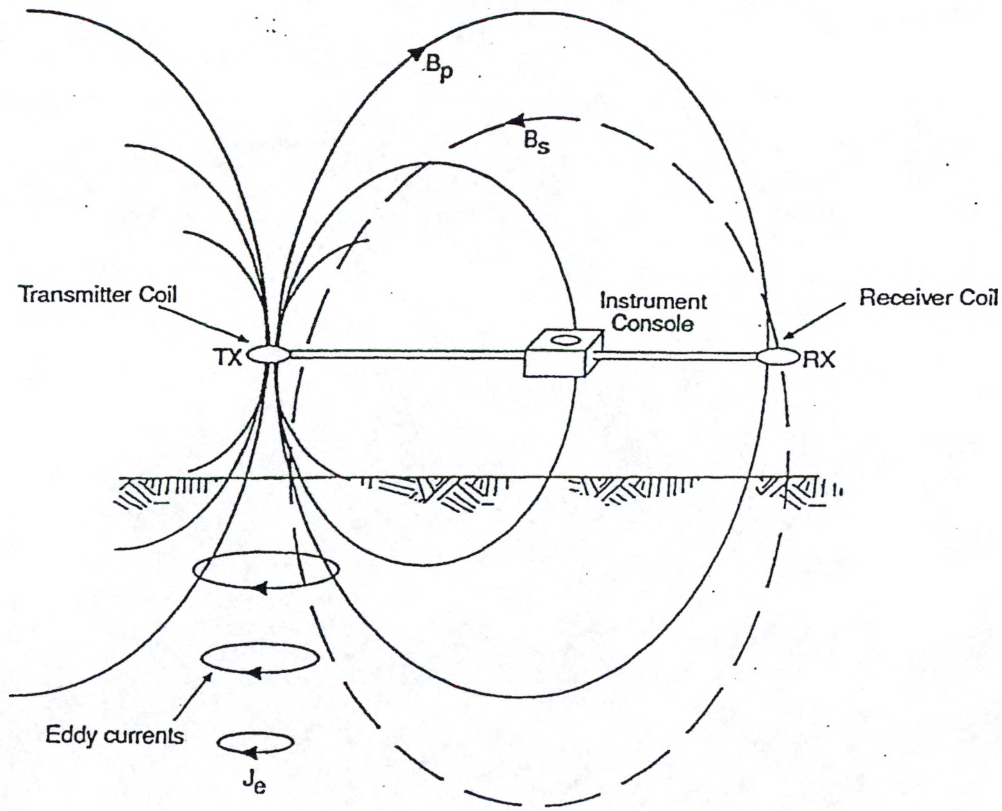
Figure 1



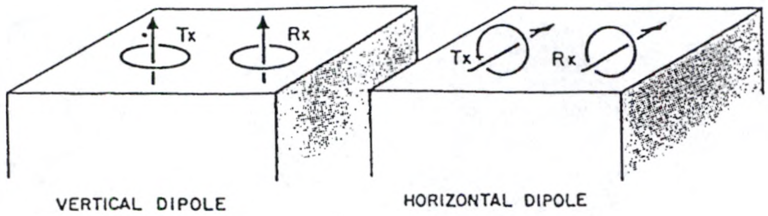
Project No. 992-1897 Drawn RDL Reviewed MGM Date SEPT., 1999	Golder Associates	**SITE MAP**	Figure **2**



Project No. 992-1897 Drawn R.D.L. Reviewed MGM Date SEPT., 1999	Golder Associates	1938 Air Photo with Lot Boundaries	Figure 3



Project No. 93-1410 Drawn GMC Reviewed Date	Golder Associates	ELECTROMAGNETIC MEASUREMENT	Figure 4



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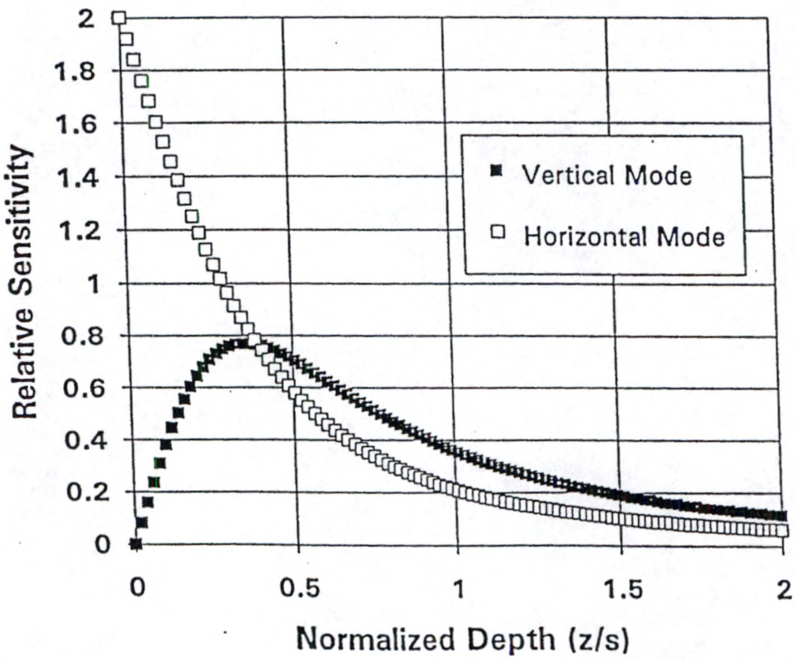
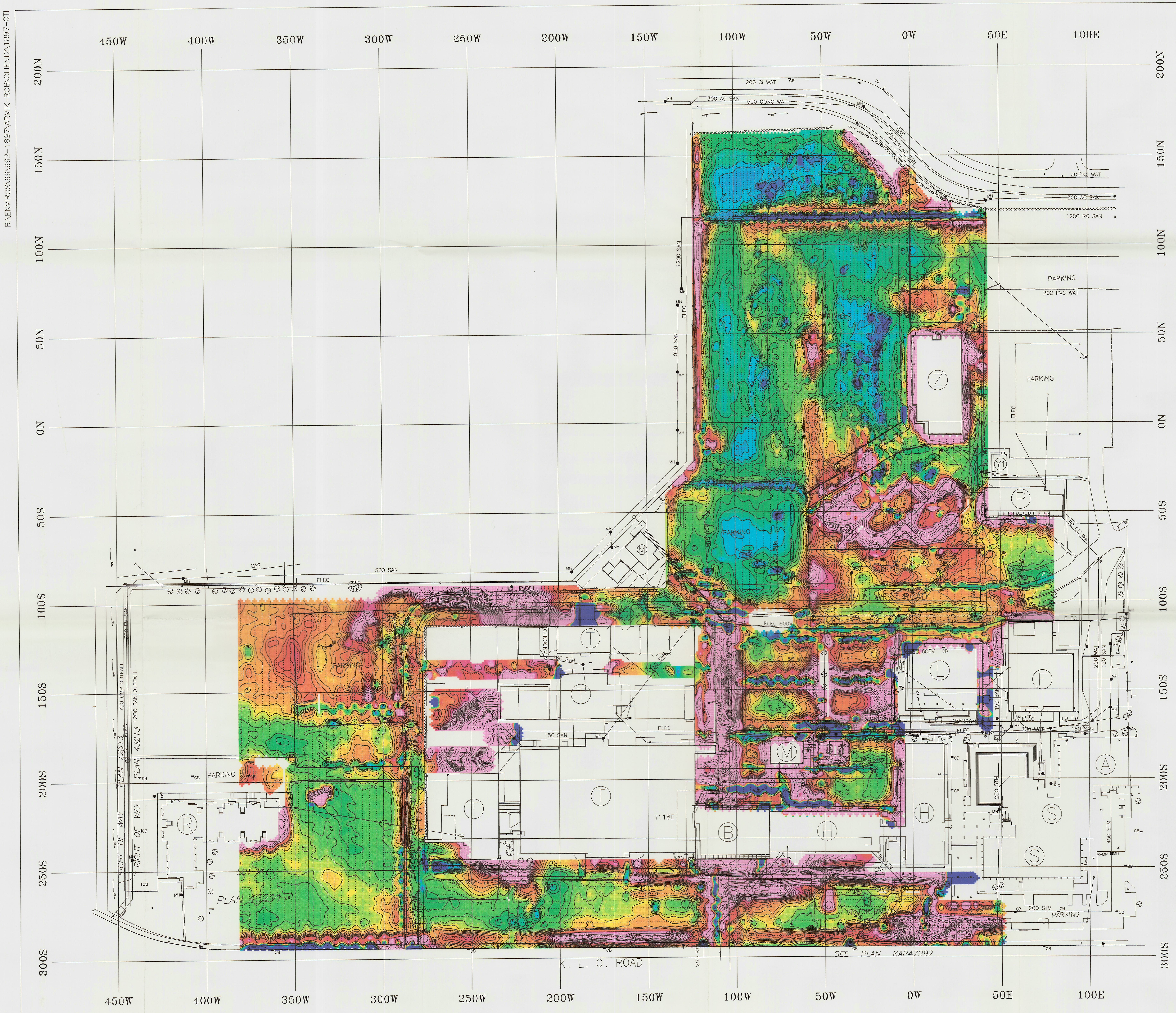
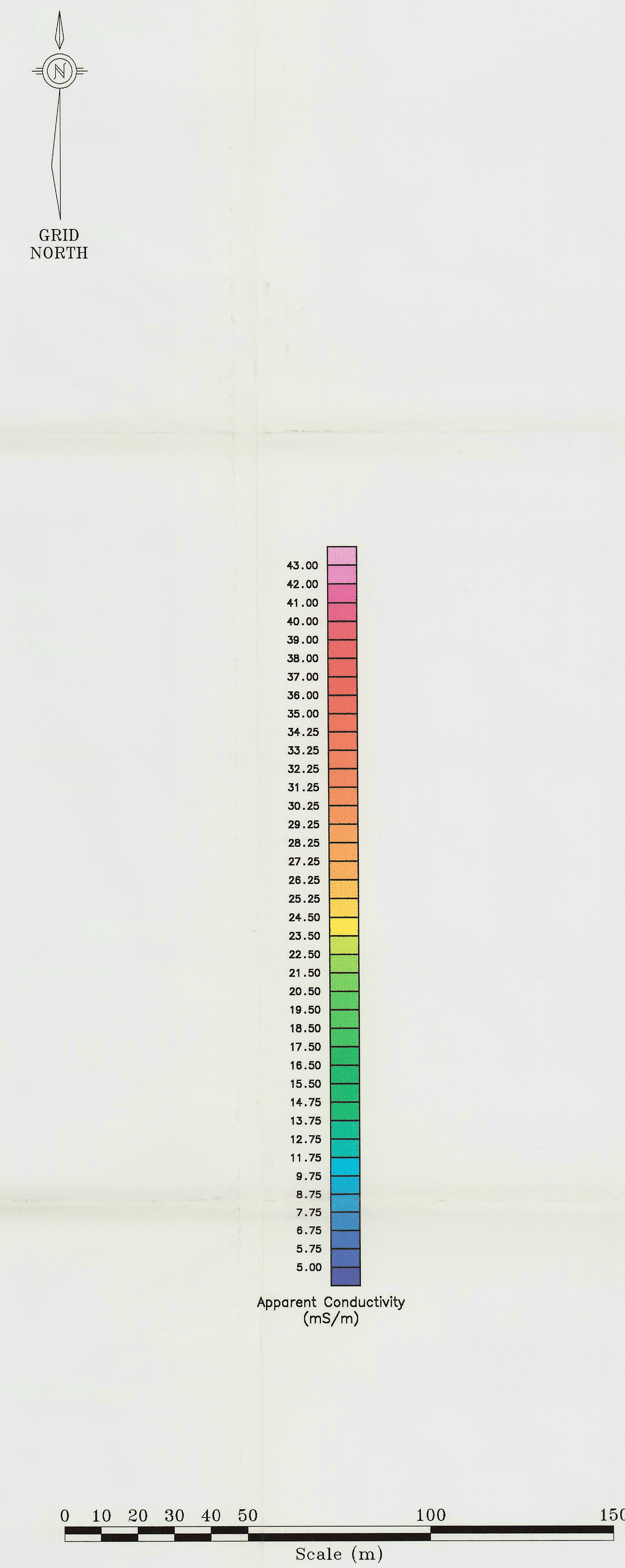


Project No. 931410 Drawn GMC Reviewed Date JUNE, 1995

Golder Associates	**GEONICS ELECTROMAGNETIC RESPONSE CHARACTERISTICS**	Figure **5**





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EM31 APPARENT CONDUCTIVITY
OKANAGAN UNIVERSITY COLLEGE, K.L.O. RD.
KELOWNA, B.C.

DRAWN: AY	APPROVED: RL	DATE: Aug. 31, 1999
PROJECT: 992-1897		FIGURE: 6

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EM31 IN-PHASE RESPONSE
OKANAGAN UNIVERSITY COLLEGE, K.L.O. RD.
KELOWNA, B.C.

DRAWN: AY	APPROVED: RL	DATE: Aug. 31, 1999
PROJECT: 992-1897		FIGURE: 7

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GRID NORTH
LEGEND
Discrete and/or higher concentrations of discrete anomalies
Zones of discrete anomalies
Isolated high conductivity areas
Isolated low conductivity areas
Channel-like conductivity anomalies
Boundary and Label of feature as referenced in report
NOTE
Dashed lines indicate extrapolated limits.
Scale (m)
0 10 20 30 40 50 100 150
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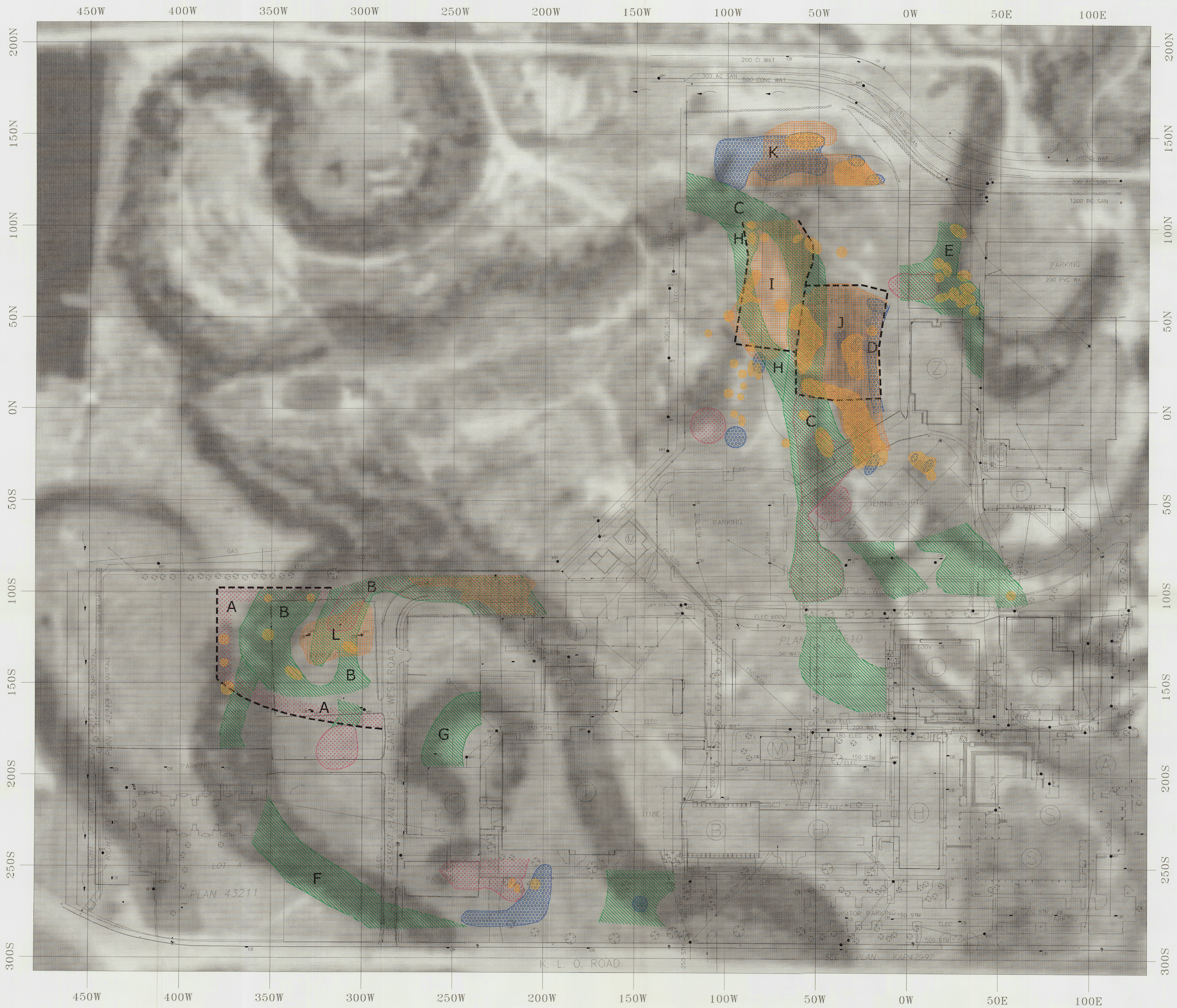
EM31 INTERPRETATION
OKANAGAN UNIVERSITY COLLEGE, KLO RD.
KELOWNA, B.C.
DRAWN: AY
APPROVED: RL
DATE: Aug. 31, 1999
PROJECT: 992-1897
FIGURE: 8
PARKING
TENNIS COURTS
CAMPUS WEST ROAD
K. L. O. ROAD
VISITOR PARKING
PLAN 43211
LOT A



N

GRID NORTH

LEGEND

- Discrete and/or higher concentrations of discrete anomalies
- Zones of discrete anomalies
- Isolated high conductivity areas
- Isolated low conductivity areas
- Channel-like conductivity anomalies
- B — Boundary and Label of feature as referenced in report

NOTE

Dashed lines indicate extrapolated limits.

0 10 20 30 40 50 100 150

Scale (m)

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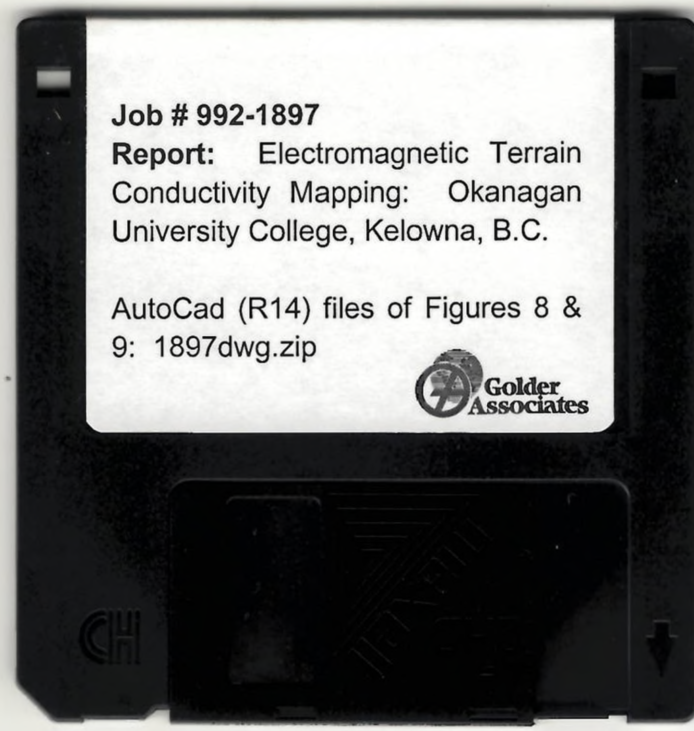
EM31 INTERPRETATION WITH 1938 AIR PHOTO
OKANAGAN UNIVERSITY COLLEGE, K.L.O. RD.
KELOWNA, B.C.

DRAWN: AY	APPROVED: RL	DATE: Aug. 31, 1999
PROJECT: 992-1897		FIGURE: 9


Job # 992-1897
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AutoCad (R14) files of Figures 8 & 9: 1897dwg.zip
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