SEEPAGE INVESTIGATION USING GEOPHYSICAL TECHNIQUES AT COURSIER LAKE DAM, B.C., CANADA

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ABSTRACT

Subsurface seepage flow at Coursier Lake Dam was identified by onshore and offshore self-potential surveys, and electrical resistivity profiles and soundings during a Deficiency Investigation by BChydro. For typical seepage investigations baseline geophysical data are collected at "low-pool" level and the measurements are repeated when high hydraulic gradient conditions exist. At Coursier Lake Dam a rather unanticipated outcome of the low-pool surveys was that significant seepage beneath the structure was detected. The low-pool results were conclusive enough that, when combined with visual inspection and observation of sinkholes on the embankment, an immediate restriction was placed on the pool elevation. Thus, because of the identified potential hazard, the remaining geophysical investigations were conducted under a "minimum-pool" reservoir level in order to complete the comparative study. Therefore, the dam was studied under low- and minimum-pool reservoir conditions in the spring and fall of 1993, respectively.

Low-pool data indicated very high resistivities (3000 to 5000 ohm-m) throughout the embankment indicating a coarse-average grain size, probably unsaturated sands and gravels. Higher resistivities (>5000 ohm-m) were obtained within the foundation deposits along the downstream toe indicating a combination of lower moisture content, coarser average grain size and higher porosity than the embankment. These electrical data indicate the subsurface conditions in the embankment and the foundation to be conducive to seepage.

Results from low-pool SP surveys, performed both on-shore and offshore, indicate a dispersed or sheet flow seepage occurring nearly 1100 feet upstream of the intake. Therefore, apparently the seepage source begins far upstream of the embankment within the foundation deposits. Modeling the SP data indicated a number of anomalous areas interpreted as concentrated seepage flow paths within the foundation and lower portion of the embankment.

The minimum-pool data, acquired when only a stream entered the intake structure, confirmed the low-pool electrical and SP interpretations. Remediation of the seepage problems at Coursier Lake Dam was completed in 1996 utilizing a combination of an upstream cutoff trench to reduce the seepage flow through the foundation, and placement of a geomembrane (tied into the cutoff trench) over approximately two-thirds of the core to reduce the flow gradients within the embankment.

INTRODUCTION

Seepage problems have been an ongoing problem at Coursier Lake Dam. Hence, British Columbia Hydro and Power Authority (BChydro) contacted the Bureau of Reclamation for the objective of acquiring geophysical data to assess the subsurface seepage conditions. Self-potential (SP) methods were of particular interest for the detection of seepage paths, if present, which may be associated with internal erosion and piping within the embankment.

Coursier Lake is a mountain storage reservoir contained by one embankment, located in British Columbia near the town of Revelstoke. The reservoir had its first filling in 1962 and it has had a history of continued seepage. The embankment is approximately 2100 ft (640 m) long and has a maximum height of 74 ft (23 m). Crest elevation is 4217 ft (1285.3 m) with a maximum storage capacity of 24,000 acre-ft.

Alpine glaciation created the morphology, soil deposits, and a natural lake that made up the pre-embankment geologic setting in South Cranberry Creek. The dam is an earthfill embankment with a core composed of silty sand with gravel and cobbles; with sand, gravel, and cobbles as the primary portion of the embankment. Independent studies determined that there was very little foundation treatment, that is: "...something less than well stripped of organic and other undesirable materials, and there is little evidence that the sloping core was keyed into till". The dam is founded on undifferentiated layers of sand and gravel and silty sand and gravel (BChydro investigations, 1993).

Typically, high- and low-pool comparative investigations are performed to allow determination about which variations are and are not related to seepage (i.e., do not change with pool level). That was the original geophysical program established for Coursier Lake Dam. However, after completion of the first phase (low-pool) of geophysics and field inspection of the dam by BChydro, there was enough concern for the safety of the structure that rapid drawdown of the reservoir was carried out and the pool level restricted.

GEOPHYSICAL APPROACH

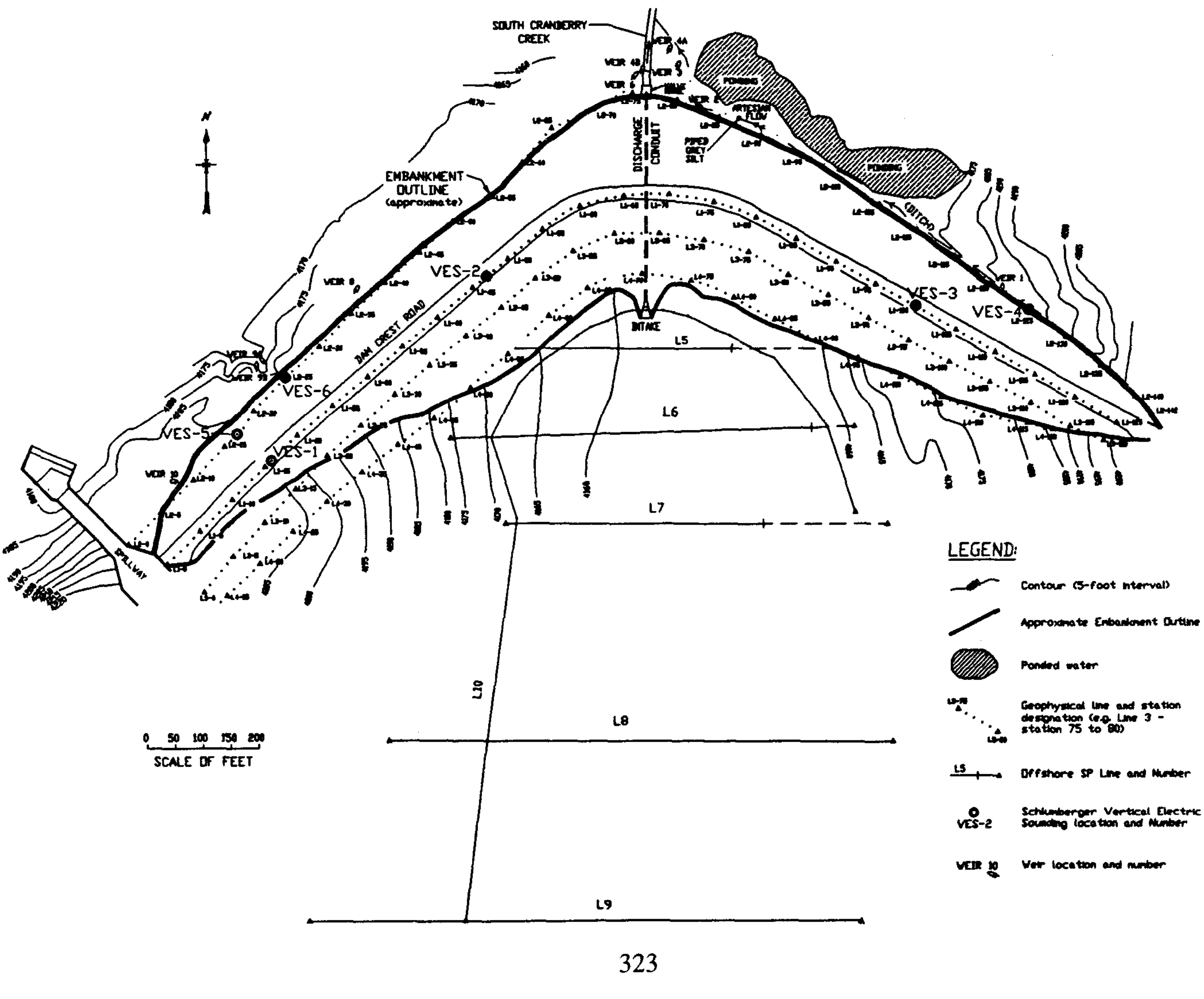
Low-pool geophysical investigations were performed in two stages because of access problems encountered during the spring when most of the site was snow covered and the reservoir was frozen. The purpose of the investigation was to obtain geophysical data under different hydraulic head conditions. The objective of the geophysical investigation was to help determine the seepage conditions at the dam. That is, if present, does seepage occur in concentrated seepage flow paths, or, more uniformly over large dispersed areas as "sheet-flow".

The following surveys were performed: Self-potential (SP), profile electrical resistivity (Wenner), Schlumberger vertical electrical soundings (VES), and magnetics. Figure 1 shows a plan view of Coursier Lake Dam and the locations of the geophysical surveys performed. All onshore geophysical surveys were conducted along four lines: the dam crest, downstream toe, and two lines on the upstream face. SP measurements were taken at 16.4-foot (5 m) intervals along each of the onshore lines. Additionally, five offshore SP lines were surveyed covering approximately 1100 ft (340 m) upstream of the intake. Data acquisition along the offshore lines consisted of sampling the SP at one second intervals while a boat towed a pair of electrodes at a rate of approximately 3.28 ft per second (1 m/sec). The offshore gradient SP set-up provided a sample rate that was nearly five times the sample density of the onshore SP data.

The flow of water through subsurface soil or rock generates electrical voltages called streaming potentials. Both the onshore and offshore SP methods used during this investigation involved measurement of the electric potential fields generated by subsurface water flow. These electric potential fields were then interpreted in terms of the location and characteristics of seepage flow paths through modeling of each SP data profile. The individual SP source characteristics determined through the modeling (e.g., depth, intensity, and shape) were then compared and combined with results from each line to permit a final interpretation of subsurface seepage flow. The interpreted flow paths are then plotted in plan view.

Data were acquired from six Schlumberger VES's and one resistivity profile using a Wenner array. Magnetic surveys were performed along Lines 1, 2, and 3 (L1, L2, and L3) for detection of buried objects that might create anomalous SP readings.

FIGURE 1.
COURSIER LAKE DAM - PLAN AND LOCATION OF GEOPHYSICAL SURVEYS



VES measurements (sometimes referred to as "electric drilling") provide a one-dimensional model of the resistivity layering beneath a single station. Good vertical detail and resolution of layers as well as greater depth of investigation can typically be obtained from VES data. Wenner electrical profiling (sometimes referred to as "electrical trenching") provides a nearly continuous resistivity profile with the measurement focused at a pre-selected depth range. The depth range depends on the electrode "a" spacing and subsurface conditions. Wenner profiling performed at Coursier Lake Dam used an "a" spacing of 82 ft (25 m), which focused the vertical depth range around 55 ft (16.7 m).

GEOPHYSICAL RESULTS

Even though the site was snow- and ice-covered, data acquired during the low-pool surveys indicated significant and anomalous SP and electrical variations. Therefore, the emphasis shifted to the safety of the structure and visual inspections were conducted as soon as the site cleared. Numerous sinkholes were found on the upstream face and in the reservoir area, hence the reservoir was drawn down and the pool level restricted. The objective of assessing subsurface seepage needed to be addressed using the low-pool data. Offshore SP data were acquired as soon as the pool level dropped to the same elevation as that of the earlier onshore surveys (approximately 4165 ft, 1284.5 m).

Electrical Resistivity Data

Low-pool electrical data (VES and Wenner) indicated high to very high resistivities within the embankment and its foundation (Figure 2). These data are interpreted to represent relatively coarse grained materials throughout the embankment and little to no fines within the foundation soils. The lateral resistivity changes obtained along the crest indicate that significant changes in average grain size, saturation, and/or permeability occur within the embankment as well as the foundation.

Generally, it is safe to assume that moisture content, pore fluid chemistry, and average grain-size characteristics remain fairly uniform within an embankment dam; then, in the left abutment area the higher resistivities would imply that the foundation has materials with higher porosity (possibly permeability also). The combination of factors interpreted from the electrical data suggest the presence of geologic conditions conducive to seepage within the lower portion of embankment and the foundation. This is particularly true to the right of the spillway in an area where depressions and sinkholes were identified.

Self Potential Data

The low-pool SP data were of sufficient quality and character that modeling could be performed in order to meet the technical objective. All the SP modeling was performed using the PC program SPGEN (Asch, 1993) designed specifically for calculations and modeling of either onshore or offshore SP data. For this investigation only point current sources were used to model the SP data profiles. Point

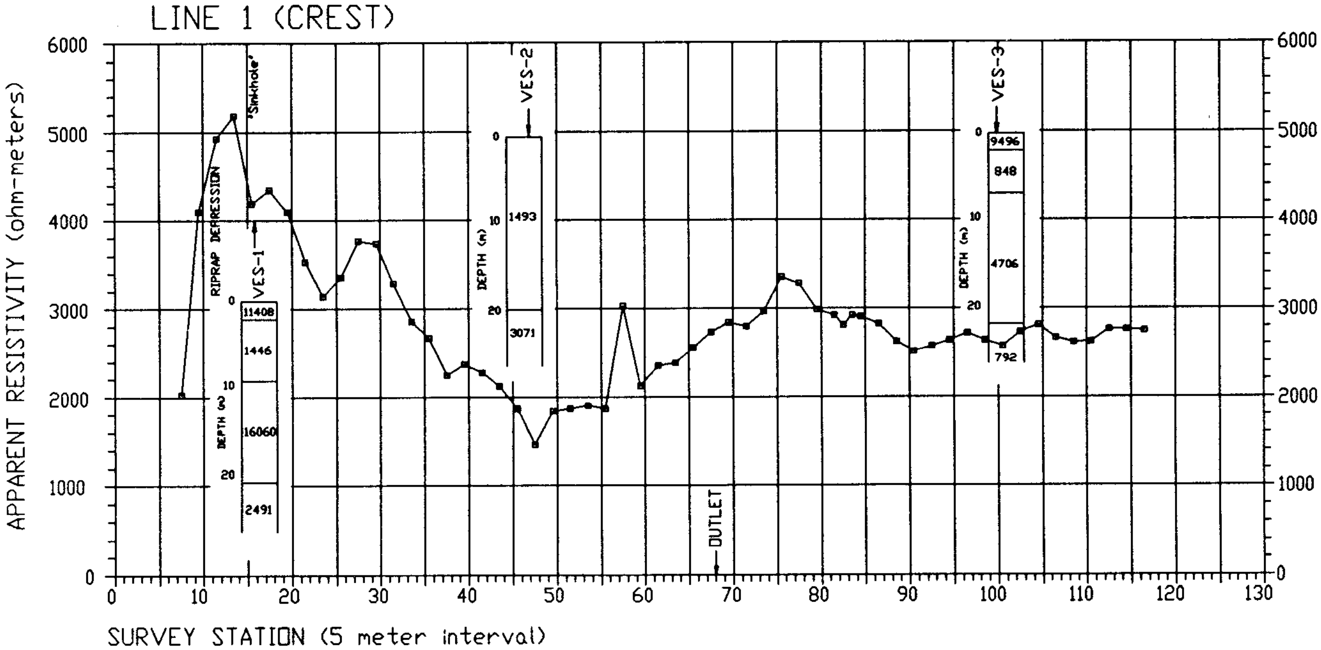


FIGURE 2.

WENNER RESISTIVITY PROFILE WITH VES EARTH MODELS

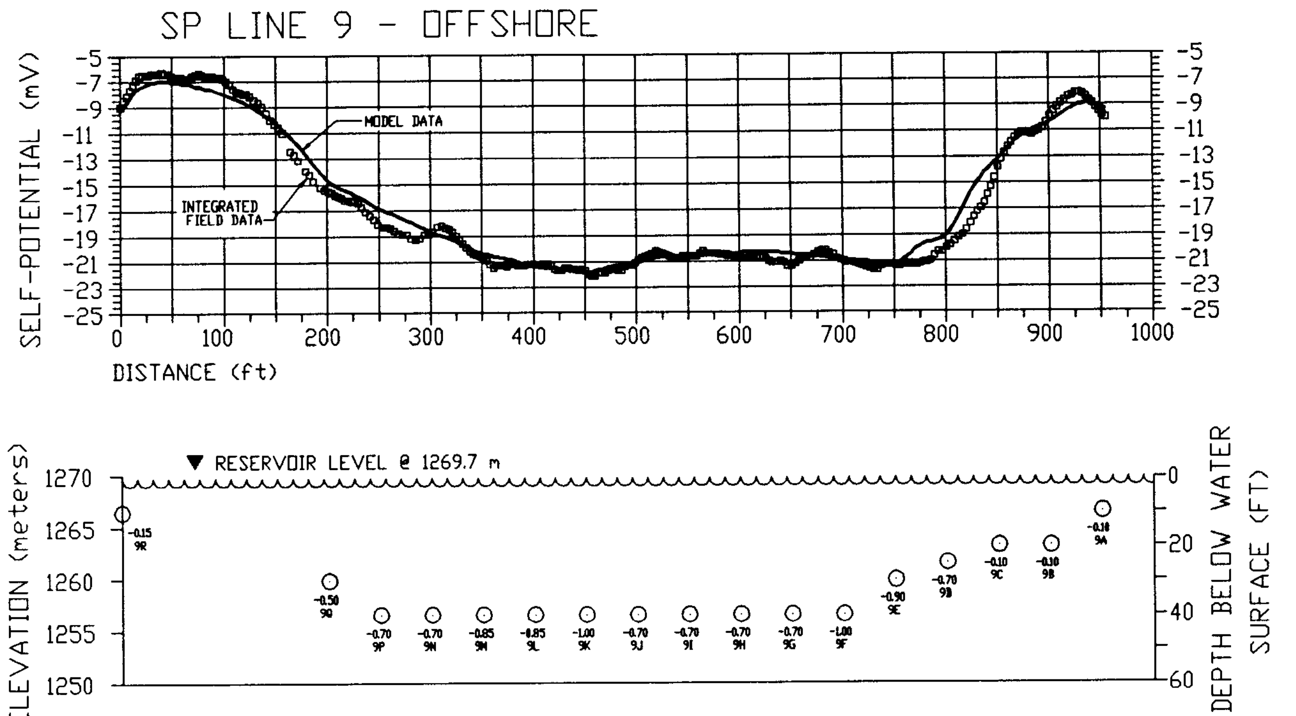


FIGURE 3.

OFFSHORE SP FIELD AND MODEL DATA

current sources represent a simple (first) approximation of an area where subsurface water flow is occurring.

As with any potential field modeling the depths calculated for source points represent water flow which would not be much deeper than the maximum depth presented, but the SP source could be shallower. For modeling the SP data acquired on this project either the known piezometric surface or the reservoir level was taken as the minimum depth for an SP anomaly that would be caused by seepage flow. Hence, the calculated depth values are constrained by the theory of a maximum source depth (i.e., not deeper than...) and the minimum acceptable depth to be seepage (i.e., below the water table).

Base levels for the onshore SP profiles were corrected to appropriate background zero values and the data profiles did not need to be smoothed in order to perform modeling. Not all the anomalous SP variations were modeled, particularly if they were apparently caused by known metal sources detected by the magnetic surveys (e.g., weirs and piezometers).

Figure 3 shows the offshore SP profile and model data for Line 9 (the upstream-most SP line). Figure 3 represents an example of what was generated for each SP profile acquired at Coursier Lake Dam. The values associated with each source point represent the (negative) current amplitude of the source in milliamps. It is fairly obvious that seepage was occurring in the subsurface even at the low pool level evidenced by the broad line of negative anomalies modeled beneath Line 9 (Sirles and Corwin, 1993).

<u>ONSHORE LINES:</u> Figure 4 is a combined plot of all the onshore data profiles. Although the geophysical lines are not equal length, they are parallel to one another (Figure 1) so the profiles are lined up with respect to the intake or valve house. The intake was detected on all profiles except on the dam crest which is attributed to its depth of burial or the line crossing over the null of the SP field. Three main features are apparent on Figure 4: one long-wavelength negative >50 millivolt SP anomaly on the left side of each line (centered about station 15 - Line 1); a narrow area just left of the intake/valve house with at number of positive and negative SP sources; and, the right side of each line generally consists of a large number of relatively short wavelength negative SP anomalies. The onshore data indicate there is continuity of the seepage paths from the upstream toe to the downstream toe for a number of the SP sources detected. To the left of the valve house along the downstream toe (L2), there are several positive and negative SP sources modeled at equal depths and spread over approximately 165 ft (50 m). These SP sources are interpreted to represent inter-related or sheet-flow seepage occurring within a relatively narrow area, rather than individual seepage flow paths.

<u>OFFSHORE LINES:</u> Figure 5 is a combined plot of all the offshore SP data profiles (excluding Line 10) where lines connecting interpreted continuous SP trends have been shown. The offshore data for Lines 8 and 9 indicate the presence of a broad negative trend in the SP profile, which is indicative of a central flow path. This central flow path is interpreted as an area of dispersed or sheet-flow seepage occurring over a wide area. The interpreted sheet-flow appears to

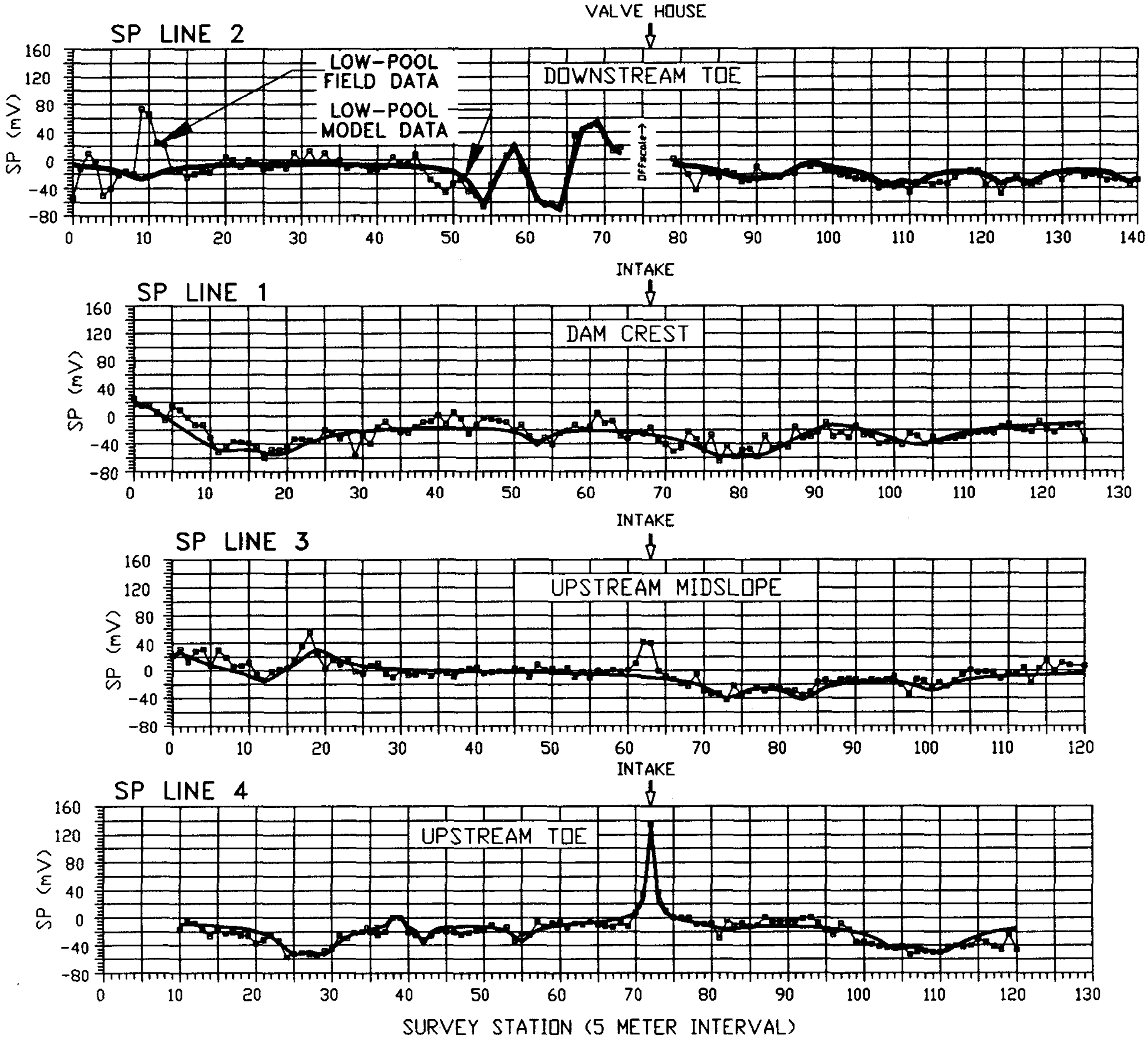


FIGURE 4.

ONSHORE SP DATA PROFILES

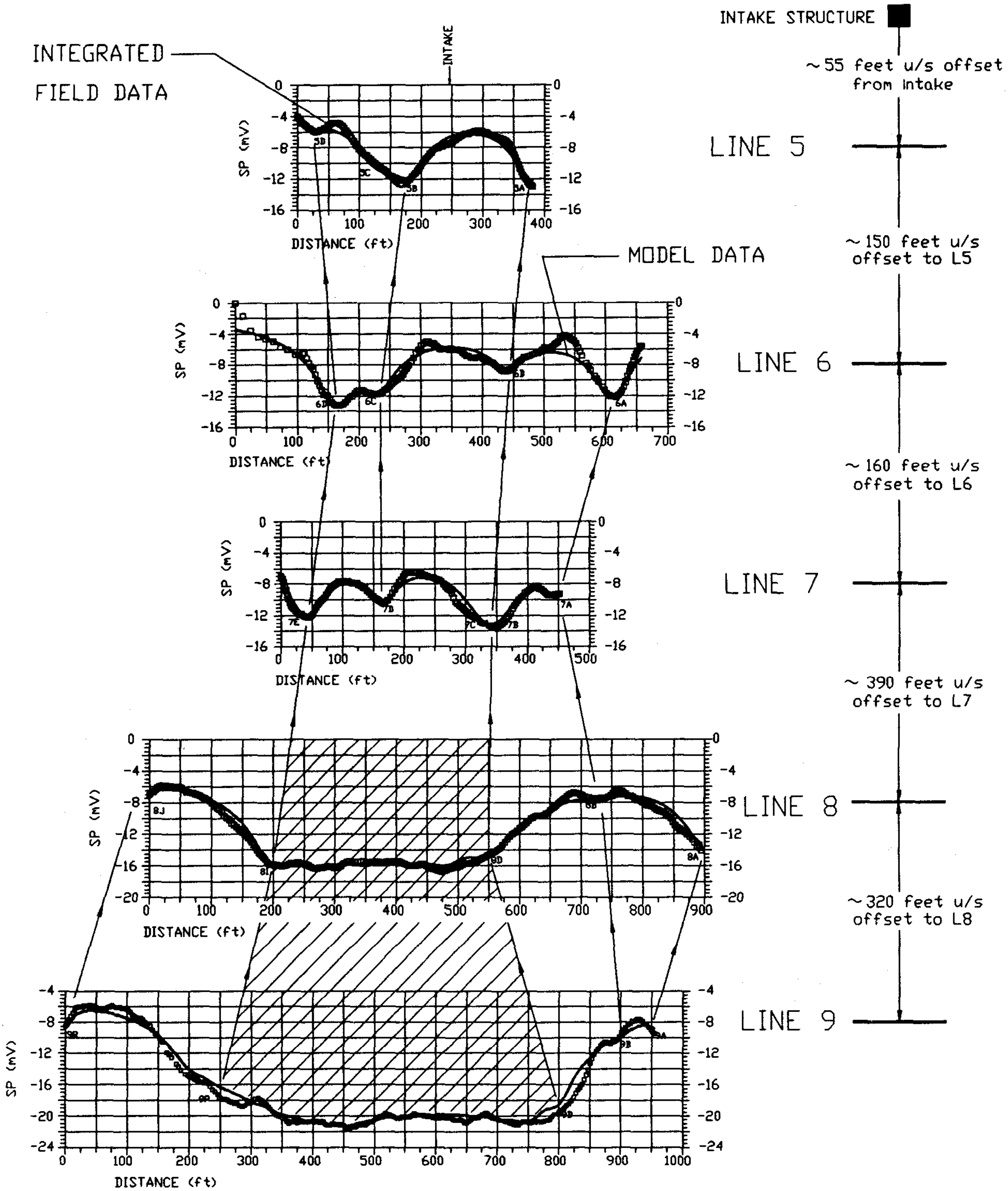


FIGURE 5.

OFFSHORE SP PROFILES

develop into a series of more concentrated seepage paths as the subsurface flow draws nearer to the embankment (e.g., Lines 7, 6, and 5).

INTERPRETIVE SUMMARY OF ALL SP LINES: Figure 6 shows all the interpreted SP anomaly source points (shown as "donuts") and the interpreted seepage flow path axes (shown with arrows) overlain on the embankment outline. The data presented on Figure 6 indicate the offshore flow paths are interpreted to extend from the offshore SP lines to the onshore SP lines. Because of the low reservoir pool and the associated low piezometric surface within the embankment at the time of this survey, the majority of seepage path axes shown on Figure 6 represent seepage flow through the foundation materials. Although, near the maximum section the interpreted seepage is probably occurring at or near the embankment/foundation contact.

The interpreted seepage flow paths extending through SP sources at the right end of offshore Lines 5 and 6, right of the intake on onshore Lines 4, 3, 1, and near the artesian flow near Line 2 represent a flow path axis delineated by correlative negative SP point sources. The area defined by this flow path axis is interpreted as an area of concentrated seepage. This area specifically correlates with the location of the sinkholes on the upstream face of the embankment, and the artesian flow and piped grey silt observed along the downstream toe (Sirles and Corwin, 1994).

There is an obvious lack of SP point sources and associated flow path axes in the central portion of the embankment. A number of attempts were made to distinguish seepage-related SP anomalies in the vicinity of the intake, discharge conduit, and valve house. The SP point sources identified offshore on either side of the intake may be an indication that seepage-related sources are present near this structure. However, both the spatial proximity and SP field generated by the intake structure itself generally prohibit modeling and interpretation of SP data obtained near or over these appurtenant features.

CONCLUSIONS

SP and electrical geophysical surveys conducted at Coursier Lake Dam indicate that concentrated seepage flow paths which might be of concern for internal erosion and piping exist within the foundation deposits and possibly at or above the embankment/foundation contact. A number of the seepage paths interpreted from the geophysical investigation correlate well with known sinkholes and depressions identified on the embankment and in the reservoir area. Anomalous geophysical results similar to those obtained at Coursier Lake Dam, which are interpreted to relate to concentrated seepage, have been observed at damsites with known concentrated seepage and associated internal piping.

Electrical properties of the materials present within the embankment and foundation indicate subsurface conditions which are conducive to seepage. There are relatively distinct lateral changes (three areas) within the embankment itself which are attributed to a combination of factors that cannot be differentiated without additional in situ

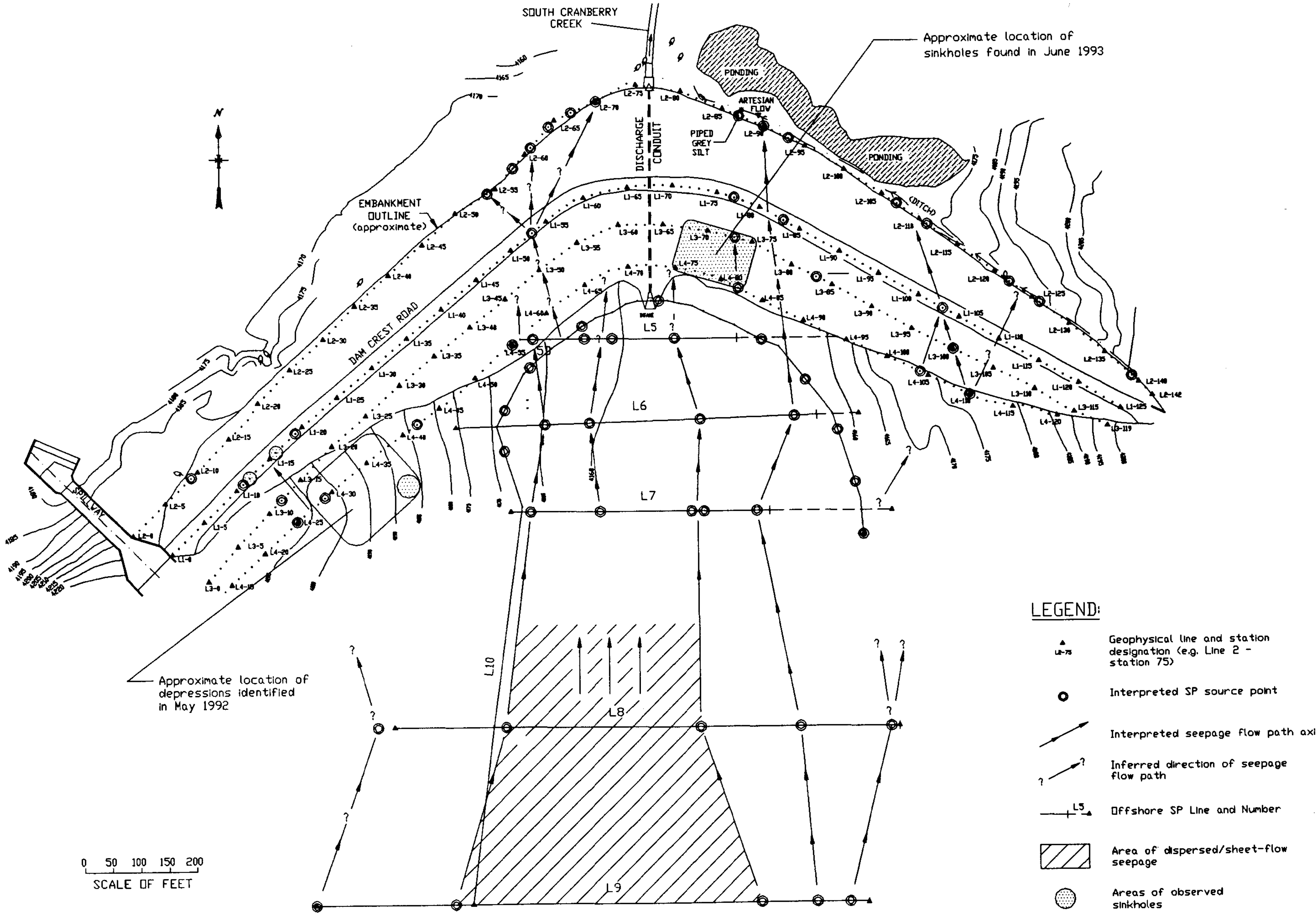


FIGURE 6.

COURSIER LAKE DAM - FINAL INTERPRETATION OF SEEPAGE FLOW PATHS geologic information. A number of concentrated seepage paths were interpreted from high-amplitude, short wavelength SP anomalies obtained along each of the ten geophysical lines. There appears to be continuity in the upstream-downstream direction of many of the SP point sources. The interpreted seepage flow path axes originate nearly 1100 ft (335 m) upstream of the embankment in an area of dispersed or sheet-flow seepage; then, the seepage appears to develop into a series of distinct flow paths which extend to, beneath, and possibly through the embankment itself (dependent upon the piezometric surface).

Coursier Lake Dam underwent a variety of geological investigations during 1994 to design a fix. The accepted remediation was a combination of: an upstream cut-off trench excavated into the till deposits and backfilled with less permeable soils; and, placement of a geomembrane blanket on the sloping core over approximately two-thirds of the embankment. Due to the short construction season it took two years to completed the fix, finished in November 1996. BChydro anticipates the first filling to be in the summer of 1997.

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