CASE HISTORY: SITING SHALLOW GROUNDWATER WELLS WITH THE AID OF GEOPHYSICS

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Abstract

Although the Colorado Division of Wildlife's Bellvue Fish Hatchery site is relatively small, covering approximately 30 acres, groundwater drilling results across the site are variable and unpredictable; the site includes both productive, artesian wells as well as dry wells. The site is underlain primarily by the Lykins Formation, which includes interbedded siltstones, limestones, claystones, and evaporites. In preparation for new wells, geophysical surveys were done in an attempt to better understand the subsurface with respect to groundwater production. Both transient electromagnetic (TEM) and galvanic dipole-dipole resistivity lines were run, and substantial variations in resistivity within the Lykins are evident (as might be expected from the prior drilling results). The first test well after the geophysical survey was sited to test a locally conductive zone; the well was successful and flowed artesian. Similarly, a second test in a conductive zone also flowed artesian, while a third hole, not based on the geophysical survey (but sited primarily on the basis of permits and logistical considerations) was unproductive. The geophysical data confirm the heterogeneous nature of the Lykins at this site, agrees well with downhole logging, and has been clearly useful in successfully siting groundwater production wells.

Introduction

The Bellvue Fish Hatchery is an interesting site geologically and geophysically. It is roughly triangular in shape, covering only 30 acres. The Lykins formation is at the surface across the entire site, and extends beyond the depth of interest (approximately the upper 200 feet) over the entire site with the exception only of the westernmost lines, where the deeper Lyons sandstone and Satanka shale are evident. The Lykins is far from a homogeneous subsurface, however, and is comprised of interbedded siltstones, limestones, claystones, and evaporites dipping approximately 25 degrees to the east. Just a few miles to the south, the Lykins underlies the Horsetooth Reservoir, where it is considered a geologic hazard due to the sinkholes that occasionally develop. The heterogeneous nature is manifested at Bellvue as variable production from groundwater wells; dry wells and production wells can be separated by only hundreds of feet. The site is surrounded by fences, and includes active power lines, operating electric pumps, pipelines, cased wells, and other cultural features that can contaminate geophysical measurements. As a result, two different methods were proposed at Bellvue: TEM and galvanic resistivity. After two short test lines, 10 lines of resistivity data were acquired in the dipole-dipole array, and 275 TEM soundings were made. The locations and orientations of lines were determined primarily by the location and orientation of the cultural features. Figure 1 is an aerial photograph, showing the locations of the survey lines and soundings. Cultural effects were evident in much of the data, but since cultural effects vary based on the type of survey and survey parameters (dipole size, orientation, etc.), it was possible to develop a good electrical understanding of the subsurface from the combined data sets.

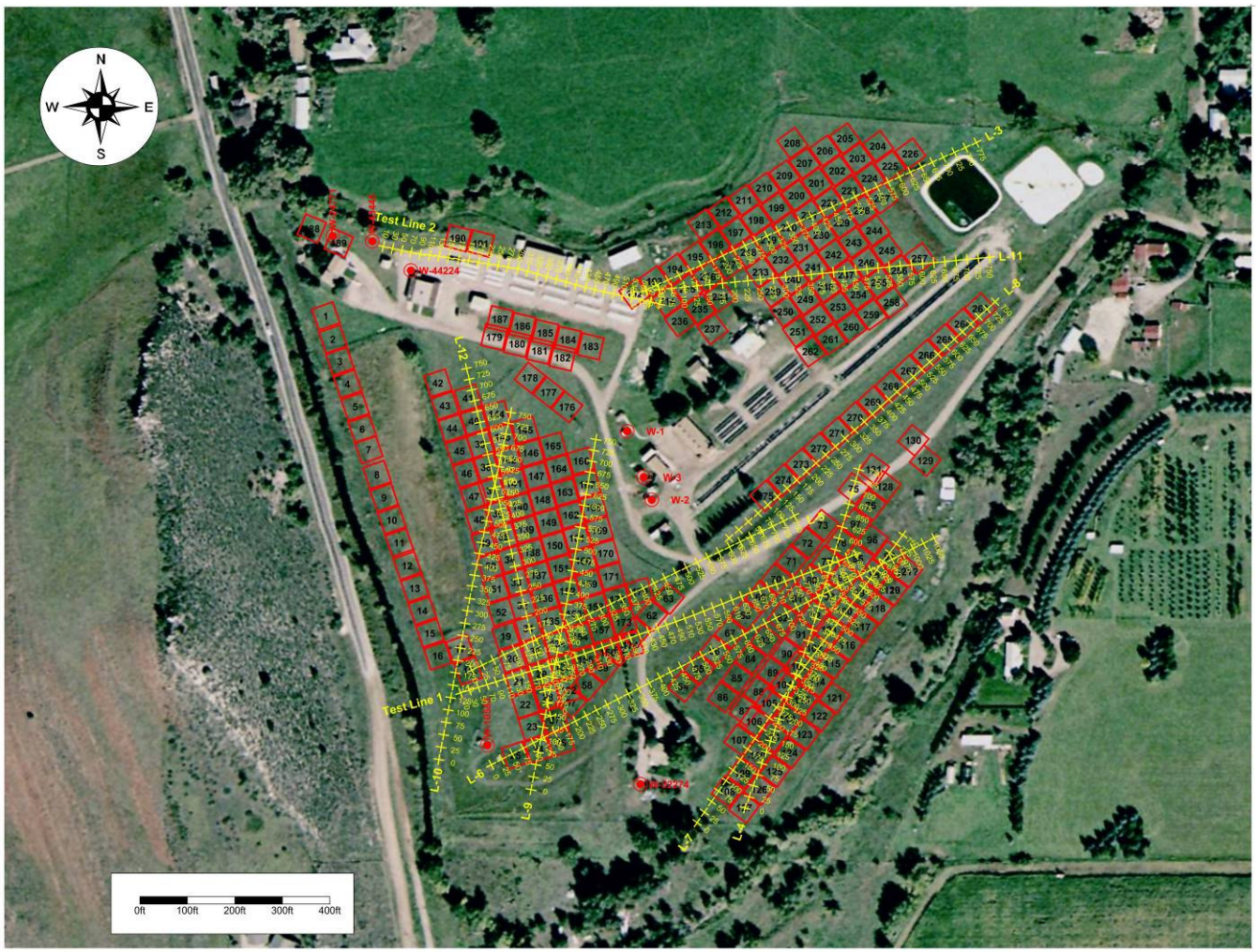

Figure 1: Locations of the dipole-dipole lines (shown in yellow) and the TEM soundings (shown as red squares) at the Bellvue Fish Hatchery.

Survey Results

Figure 2 shows the results of a typical dipole-dipole survey line on this project. Measured apparent resistivities are generally moderately low, usually ranging only from around 20 ohm-meters to 100 ohm-meters in the depth range of interest, and 2D smooth-model inversion results usually showed very good fits between the observed (raw) resistivities and the calculated model resistivities. Good correlation of features between survey lines was seen; broad low resistivity zones labeled “C” and “D” on Figure 2 were evident on other lines, and the line-to-line correlations of these features established a north-northwest trend, in good agreement with the mapped geologic strike of contacts and faults in this area. In addition to broad zones of low resistivity, several narrow zones of sharp resistivity contrasts (also oriented north-northwest) were identified, and may represent fault or fracture zones within the Lykins.

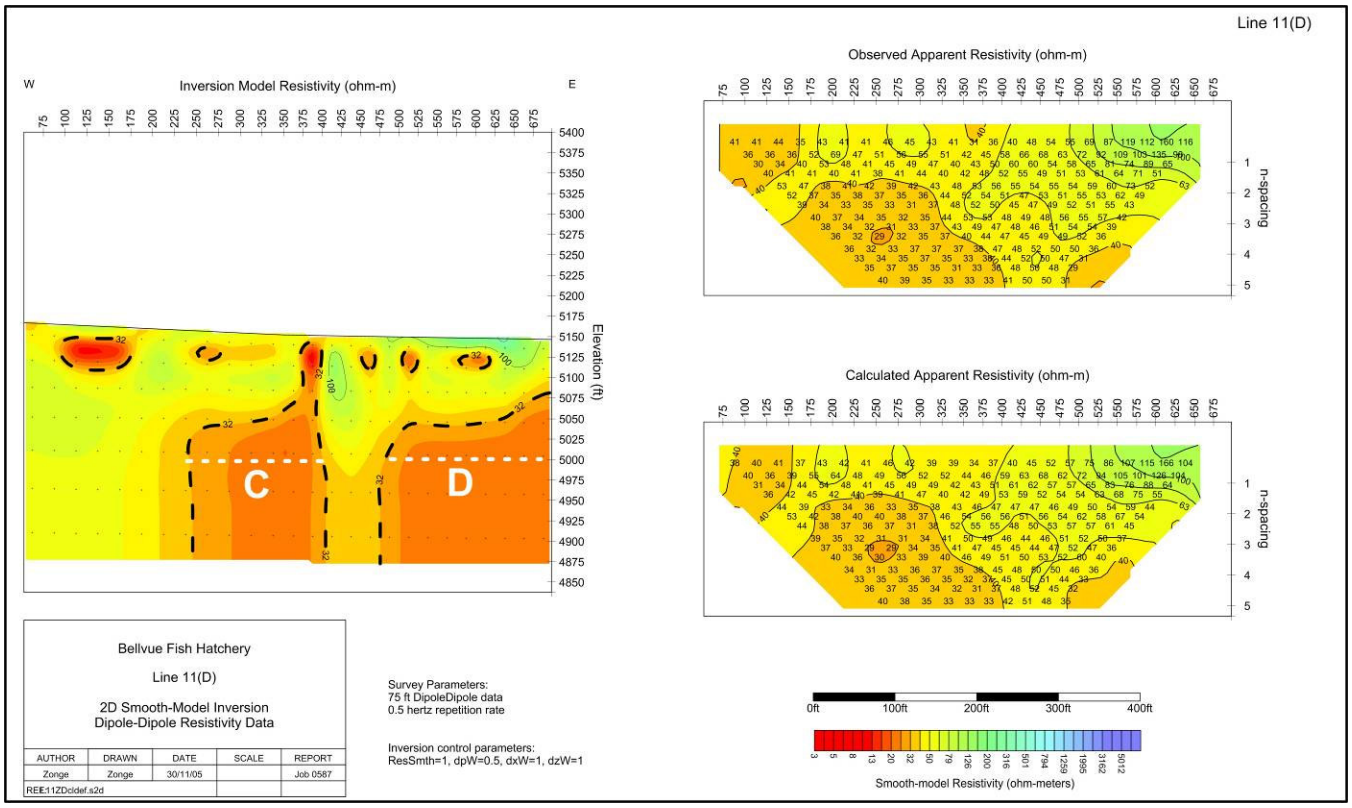

Figure 2: Typical dipole-dipole results on the Bellvue project, showing raw (Observed) resistivity and calculated model resistivity pseudosections (right) and 2D smooth model inversion results (left). The areas labeled C and D are low resistivity zones correlatable from line-to-line.

The combined interpretation of the survey results is shown in plan view in Figure 3. Broad conductive zones A, B, C, and D are outlined in orange dashed lines, and narrow, sharp changes in resistivity contrast are shown as blue dashed lines. The conductive zones could represent increased amounts of groundwater, but might also represent increased clay content, which can be problematic for groundwater production. Similarly, the sharp contrasts identified could indicate increased groundwater production from fractures, but may also represent flow barriers. After considering the known hydrology and geology of the area, the decision was made to site the first of two test holes (called the JRE #1) in conductive zone B. This well flowed artesian, and the results were good enough that the second well was also sited on a conductive zone, rather than to test one of the narrow zones of sharp contrasts. The JRE #2 was sited to the north in conductive zone C, and also flowed artesian. Subsequently, a third well was drilled, although the site selection was based entirely on well permits and logistical considerations. The location was near the west end of Test Line 2, in the northwest corner of the project site, and no interpretation of that specific location was possible from the geophysics. This third well did not produce water, but because it was drilled very near the end of a line, in an area complicated by cultural features, it is not known whether the location is in one of the low resistivity zones, in one of the narrow features, or simply in the geophysical "background" for this site.

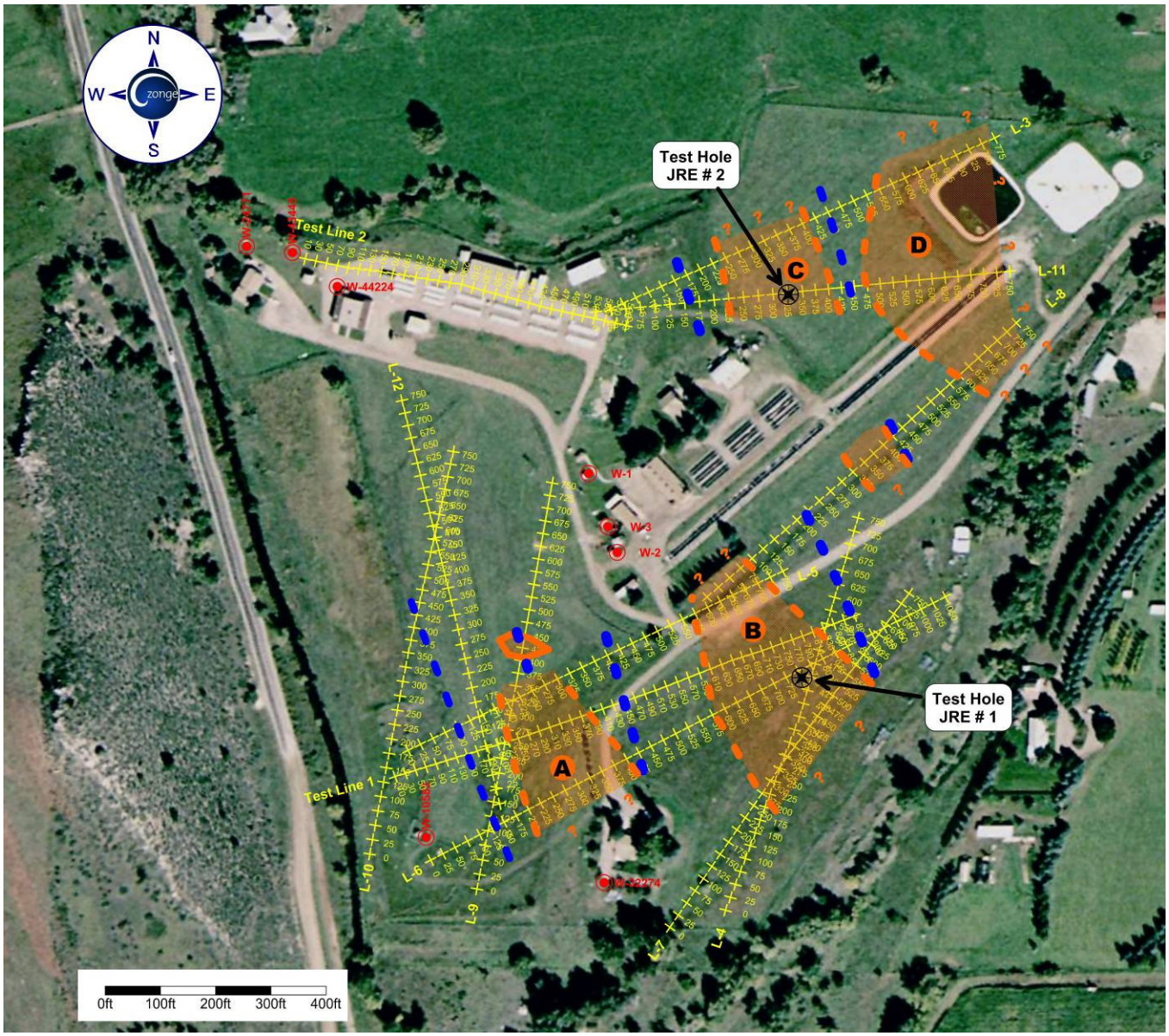

Figure 3: Plan view of the interpretation of the survey results, showing broad conductive zones A, B, C, and D (outlined in orange), with the locations of the two test wells JRE #1 and JRE #2.

Conclusions and Caveats

Although the interpretation was complicated by cultural effects, the survey results showed good correlation to the known and suspected geology at this site, good line-to-line correlation, and most importantly, two test holes drilled on the basis of the geophysics resulted in good groundwater wells. The significance of the narrow zones of sharp resistivity contrasts remains unknown at this time however, and it has not yet been determined how groundwater production in the low resistivity zones compares to production from "background" areas. As more drilling is completed, and down hole lithology and well logs can be added to the interpretation, geophysical surveys in this area should not

only be able to direct successful drilling, but may lead to a better understanding of the local groundwater recharge of this sensitive site.

Figure 4: The JRE #1 test hole.

References

US Bureau of Reclamation, 2007, Resource management plan/environmental assessment: Horsetooth Reservoir, Carter Lake, Pinewood Reservoir, Flatiron Reservoir, RMP dated June 29, 2007.

Pearson, R.M. and Hurcomb, D.R., 2002, Gypsum karst of the Lykins formation and effects for the Colorado Front Range water projects; Horsetooth and Carter Lake reservoirs, Paper 93-10, presented at the 2002 Denver Annual Meeting, Geological Society of America, October 2002.