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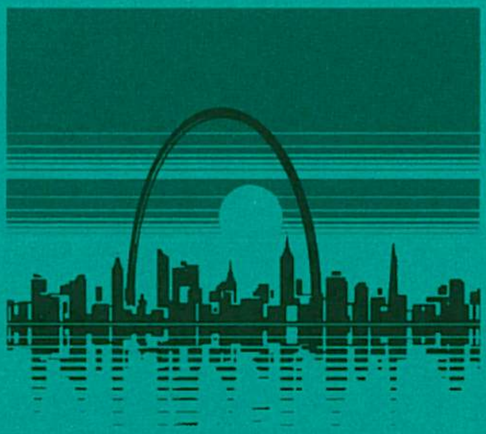

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Excessive Seepage Losses at Westwood Lake Dam

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SYNOPSIS: Excessive seepage losses at Westwood Lake Dam in east-central Indiana were apparent in 1974 during first filling of the lake when seepage areas developed downstream of the dam and abutments. Several remedial studies were performed which included additional test borings, field and laboratory tests, installation of observation wells, and a review of the site geology and hydrology. Data and observations from these studies were used to develop semi-quantitative assessments of seepage loss rates as related to lake levels. These analyses served as a basis for design of a major repair which consisted of blanketing a significant portion of the lake bottom with on-site, low-plasticity clays and clayey silts. The blanketing was completed in 1984 and post-repair filling required about two years. Subsequent monitoring and observations indicate that the lake level is holding at or within 1.5 ft of the original design normal pool.

Judgments and decisions regarding seepage control are among the most difficult faced by dam designers. Where granular soils or permeable rock strata are encountered in foundations or abutments, design decisions include considerations of cutoffs, upstream blanketing, drains, or other measures to help ensure a safe structure and hold seepage losses to within tolerable limits. However, in complex geologic conditions, especially for dams of small to intermediate size, it is often not possible to determine accurately the in-situ permeability of granular materials, the continuity of these deposits, the effect of weathering on exposed clays, and combinations of these factors. Under these circumstances, quantitative seepage analyses with flow nets or by other means typically do not sufficiently represent the actual conditions. Several of these factors came into focus during analyses and investigations for Westwood Lake Dam as described in this case history.

BACKGROUND

Westwood Lake Dam was constructed in Henry County, Indiana as one of several similar earth dams on tributaries of the Big Blue River for flood control, water supply, and recreational purposes. The homogenous embankment dam is 1,200 ft long and 60 ft high. The drainage area encompasses almost four sq miles and the normal pool lake surface covers 173 acres. The dam crest is at Elevation 1023.6 (ft,MSL) and the normal pool is controlled by the principal spillway intake riser at Elevation 1015.2. An earth channel emergency spillway is located in the left abutment. A total of 300,000 cu yd of compacted fill was placed for the original embankment construction.

Initial geologic and geotechnical studies disclosed the presence of granular soils in the dam foundation and abutments. Seepage control measures for the original embankment construction in 1973 to 1974 included a cutoff trench to impervious foundation soils at a depth of about 10 feet in the recent alluvium. Also, blanketing with compacted impervious soils was placed over limited areas of exposed granular soils in the vicinity of the upstream abutments.

Early concerns with seepage losses were indicated in November, 1974, when the lake level reached Elevation 984 on first filling. Three seepage areas developed downstream of the dam and early remedial steps included installation of shallow trench drains to "dry up" the surface and restore these areas to their original use. Flows from these seepage areas were monitored with a flume device placed in the stream channel downstream of the dam.

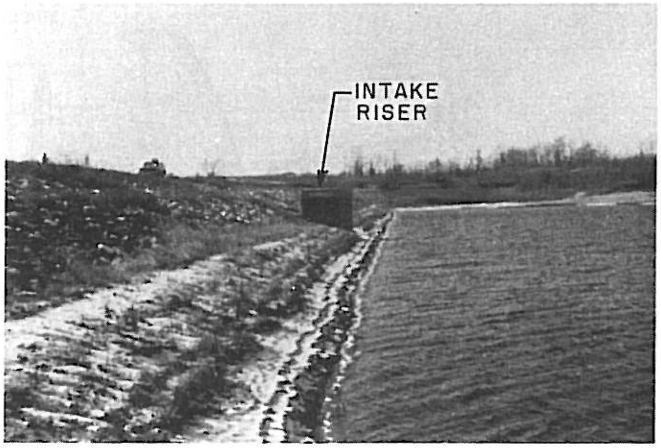

Figure 1. Pre-Repair Lake Below Intake Riser (Normal Pool) Control on Upstream Slope of Dam

Several series of post-construction test borings were drilled and groundwater observation wells were installed at intervals between 1975 and 1980. Records of lake elevations also have been maintained since 1975. Lake levels have fluctuated between Elevation 994 in October, 1977 and near the design normal pool (Elevation 1015.2) for a brief period in September, 1979. The typical lake level was well below the intake riser control level as shown in Figure 1.

Based on the remedial studies, a major repair consisting of draining the reservoir and blanketing of about half of the lake area was completed in 1984. This included a total of 416,000 cu yd of compacted blanket fill. The reservoir filled to the design normal pool within about two years and since has remained at or near that level.

GEOLOGY

According to published geologic information (Schneider and Gray, 1966), Silurian limestone is approximately 200 ft below the existing ground surface. The overburden soils were deposited by Kansan, Illinoian, and Wisconsin ice sheets (Wayne, 1965). The maximum extent of glaciation in Indiana during the Wisconsin Age is shown in Figure 2 (Wayne, 1966). The site is located between two former sublobes of the Wisconsin ice sheet along a mapped stagnation front north of the maximum glacial extent. The stagnation front developed approximately 20,000 years before present (BP). Meltwater discharge from both sublobes likely occurred at this location during the stagnation period. This flow then would have continued into an outwash channel, containing the present-day Big Blue River, with flow to the southwest. It is hypothesized that the granular soils beneath the dam and in the abutments were deposited in an "esker-like" manner with flow through ice-walled channels or tunnels. Esker deposits are often typified by a wide range for gradation of granular soils as found at this site.

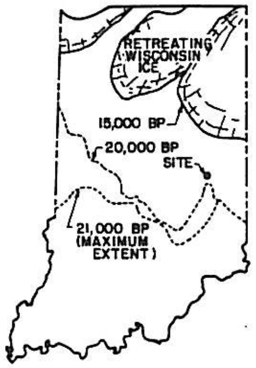

Figure 2. Wisconsin Glacial Stages in Indiana

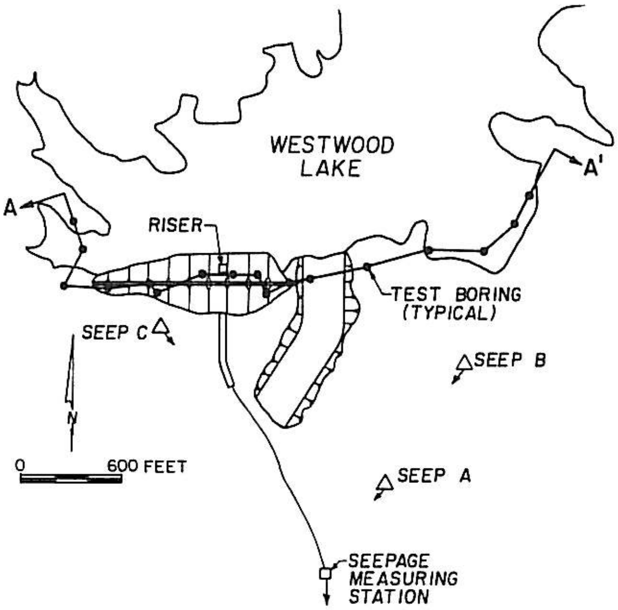

Figure 3. Locations of Site Features

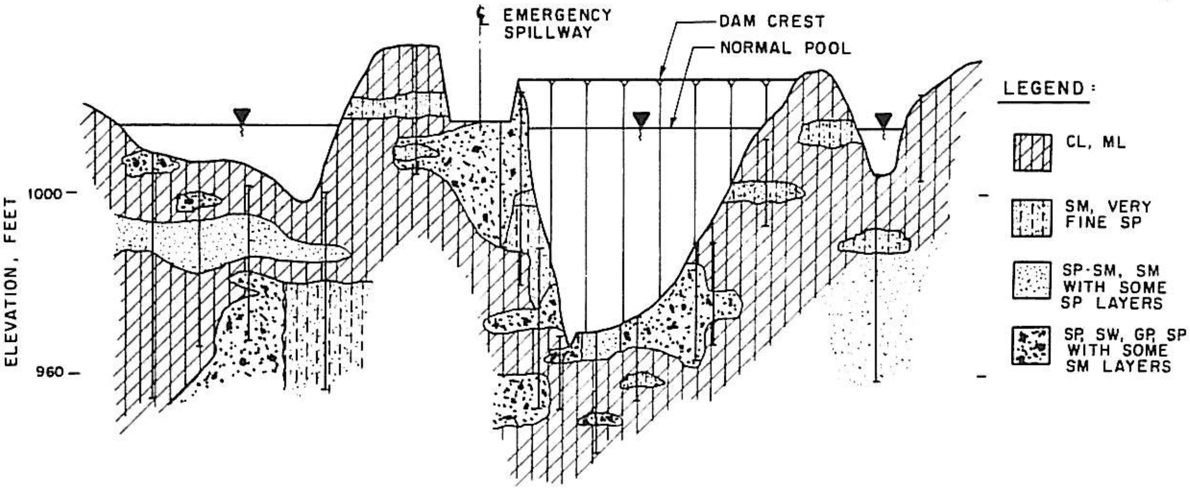

Figure 4. Subsurface Profile Beneath Dam (Section A-A', Figure 3)

These geologic considerations and test boring data suggested a southerly orientation to the granular deposits in the vicinity of the dam and abutments. The locations of several of the pre- and post-construction test borings in the vicinity of the dam are shown in Figure 3. The three seepage areas (Seeps A, B, and C) also are shown along with the seepage flow measuring station.

A subsurface profile (east-west Section A-A') developed from these borings is shown in Figure 4. This profile illustrates the extremely complex distribution of soils with widely varying permeabilities. Within the relatively impermeable glacial till are numerous deposits or channels of granular soils. Gradations for these granular soils varied over a wide range from poorly graded coarse gravel to silty fine sands. Many of the Unified Soil Classification System groups were represented in this profile.

HYDROLOGY

An average annual rainfall of 39 in. and an annual lake evaporation of 33 in. are estimated for this site. Several hydrologic analyses of the Westwood Lake watershed were performed based on more detailed seasonal runoff data. Among these was a determination of the theoretical time to fill the lake versus seepage loss rates at the normal pool elevation based on water balance calculations, shown in Figure 5. From this figure, it can be seen that for a total seepage loss rate on the order of 4.0 cfs, the lake will not fill. For the major blanketing repair, it was decided to use a maximum seepage loss rate of 2.0 cfs as a design criterion.

From the records of lake elevation maintained after the original construction, it was possible to estimate total seepage loss rates based on the relationship between reservoir storage versus time, prior to repair, shown in Figure 6. The stream inflow was determined to be approximately equal to the evaporation loss rates during these periods.

SEEPAGE

Results of the observed flow at the downstream seepage measuring station are summarized in Figure 7. It can be seen that the pre-repair points (solid circles) essentially form a linear relationship with the lake elevation. The pre-repair data were also utilized to estimate the portion of the "total lake seepage" (TLS) that exited the lake through granular deposits in the foundation and abutments and was monitored downstream of the dam. This is hereafter referred to as "front end seepage" (FES). At the normal pool Elevation 1015, an FES seepage rate of 2.8 cfs was measured. A limited number of post-repair data points also are shown in Figure 7 as open circles.

To develop a working hypothesis for the blanketing repair, these seepage relationships and the previously-described hydrologic observations are combined in Table 1. This table was developed by estimating a TLS rate of 2.0 cfs at lake Elevation 1002 from Figure 6 and a FES rate of 1.4 cfs from Figure 7. At lake Elevation 1015 (normal pool), the FES rate is 2.8 cfs, also from Figure 7. If it is assumed that the ratio between the FES and TLS rates remains constant with pool elevation, then the TLS rate would be about 4.0 cfs at the normal pool level.

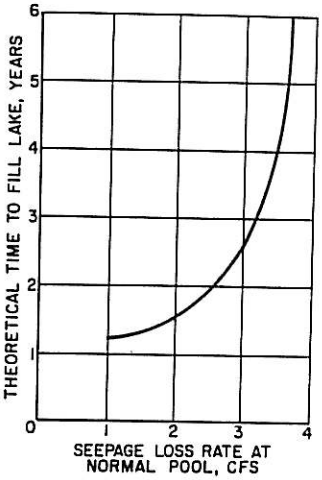

Figure 5. Theoretical Lake Filling Times

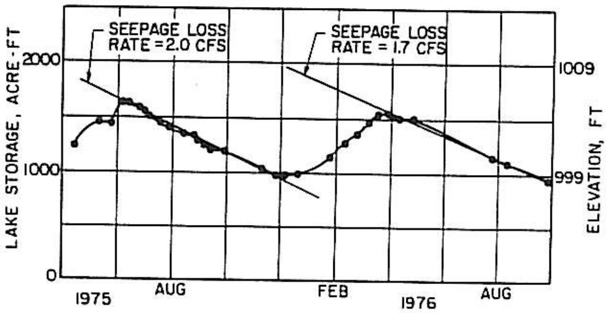

Figure 6. Total Lake Seepage (TLS) From Lake Elevation Records

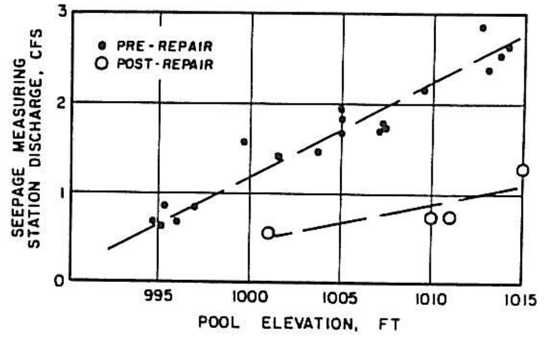

Figure 7. Measured Front End Seepage (FES), vs. Lake Elevation

Table 1. Summary of Lake Seepage Observations

Lake Elevation ft	Front End Seepage (FES) cfs	Total Lake Seepage (TLS) cfs
1002	1.4	2.0
1015	2.8	4.0

This TLS rate is consistent with Figure 5, in which the lake theoretically would not fill at a seepage loss rate of 4.0 cfs and the observation that the lake did not fill after the original construction (prior to the repair). To achieve a maximum normal pool TLS rate of 2.0 cfs (determined to be acceptable from Figure 5), it was decided to attempt to reduce the normal pool FES rate from 2.8 to 0.8 cfs, taken as a blanketing repair criterion.

BLANKETING

The blanketing repair was indicated by the complex soils and the great depth to bedrock. Low plasticity silty and sandy clays and clayey silts (Unified Soil Classifications: CL, CL-ML, ML, liquid limit: 15 to 20, plastic limit: 3 to 9) were available in borrow areas adjacent to the lake. A design coefficient of permeability of 1×10^{-6} cm/sec was selected based on laboratory tests tempered with judgment regarding the anticipated ratio of field to laboratory permeabilities (Olson and Daniel, 1981).

The blanket thickness was determined using the idealized model shown in Figure 8 and the ensuing theoretical Equation (1) derived from Darcy's Law. This model assumes complete head loss through the blanket and is generally conservative for most locations in the lake area as compared to a more comprehensive analysis that assumes head loss through the blanket and underlying natural soils.

$$T = \frac{kH'}{q_a - k} \tag{1}$$

in which

T = required blanket thickness
k = coefficient of permeability for blanket
H' = height of water over blanket
q_a = allowable leakage per unit area

The value for q_a was determined by dividing the allowable normal pool FES seepage criterion of 0.8 cfs, as established in the preceding section, by the estimated contributory area to the FES. Design relationships between the parameters in this equation are shown in Figure 9 illustrating the sensitivity to the design k-value. It can be seen that if the field k-value is on the order of 10^{-7} cm/sec, then the blanket thicknesses based on $k = 1 \times 10^{-6}$ cm/sec are very conservative. On the other hand, if k approaches 10^{-5} cm/sec, the blanket is pervious and would serve no useful purpose.

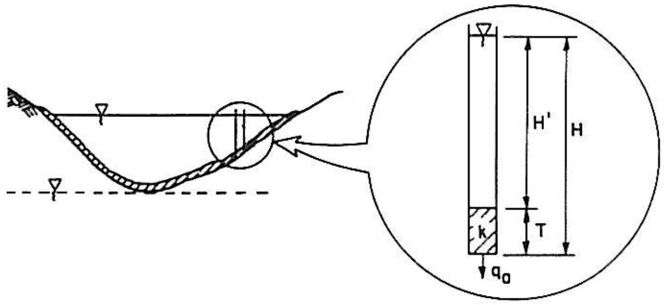

Figure 8. Idealized Seepage Model for Blanket

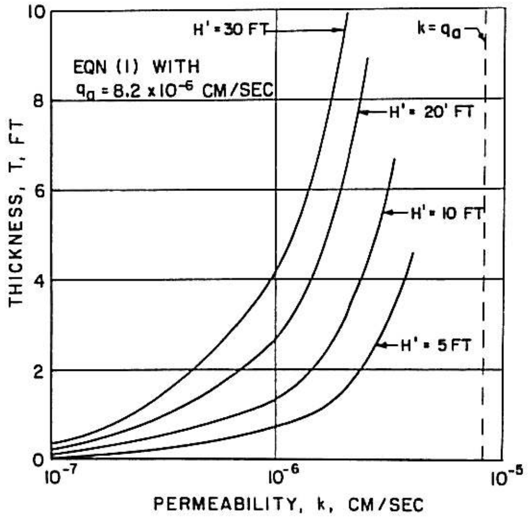

Figure 9. Blanket Thickness vs. Permeability

Field permeability testing of natural exposed soils around the lake perimeter and results of test borings within the lake area were used to delineate areas where natural clays were present at the lake bottom. The design blanket thicknesses ranged from two ft (determined to be a practical minimum) to four ft in deeper lake areas. The blanketing fill was placed and compacted in lifts to 95 percent of the Standard Proctor value at moisture contents above two percent below the optimum moisture. Compaction near or above the optimum moisture level is important to achieve a high degree of imperviousness for fine-grained soils (Mundell and Bailey, 1985).

The extent of the contributory area to FES seepage was estimated based on the locations of Seeps A, B, and C, measured groundwater levels in observation wells, regional topography, and water well data. Although regional flow nets were judged to be only marginally applicable to such a heterogeneous soil deposit, probable flow directions were determined from the pre-repair groundwater contours as shown in Figure 10. Possible maximum and minimum FES contributory areas were estimated from these analyses. The possibility of extremely permeable coarse granular strata extending well upstream of the dam, suggested by the downstream location of Seep A and as depicted in Figure 11, led to the decision to extend the blanketing to a point about midway in the lake, as shown in Figure 10. This also provided a margin of safety considered appropriate in light of the very approximate nature of the above analyses.

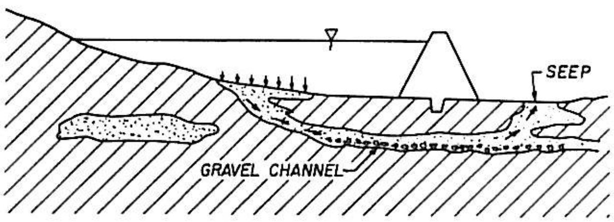

Figure 11. Possible Seepage Flow Path

PERFORMANCE

After the blanketing repair was completed in late 1983, the lake refilled to its design normal pool level in about two years under relatively normal rainfall conditions. In the summer of 1986, the water level dropped slightly to about one foot below normal pool level, but raised again after the fall rains. This closely matched the performance predicted for a final TLS rate of 2.0 cfs. However, in 1987, during a period of significantly below-normal rainfall, the lake level dropped to 1.5 ft below normal pool.

During refilling, the seepage flow re-emerged, at a low rate, at Seep B. The available post-repair seepage flow measurements as shown in Figure 7 indicate that the FES level was reduced from its original normal pool rate of 2.8 to 1.2 cfs, but not to the intended design level of 0.8 cfs.

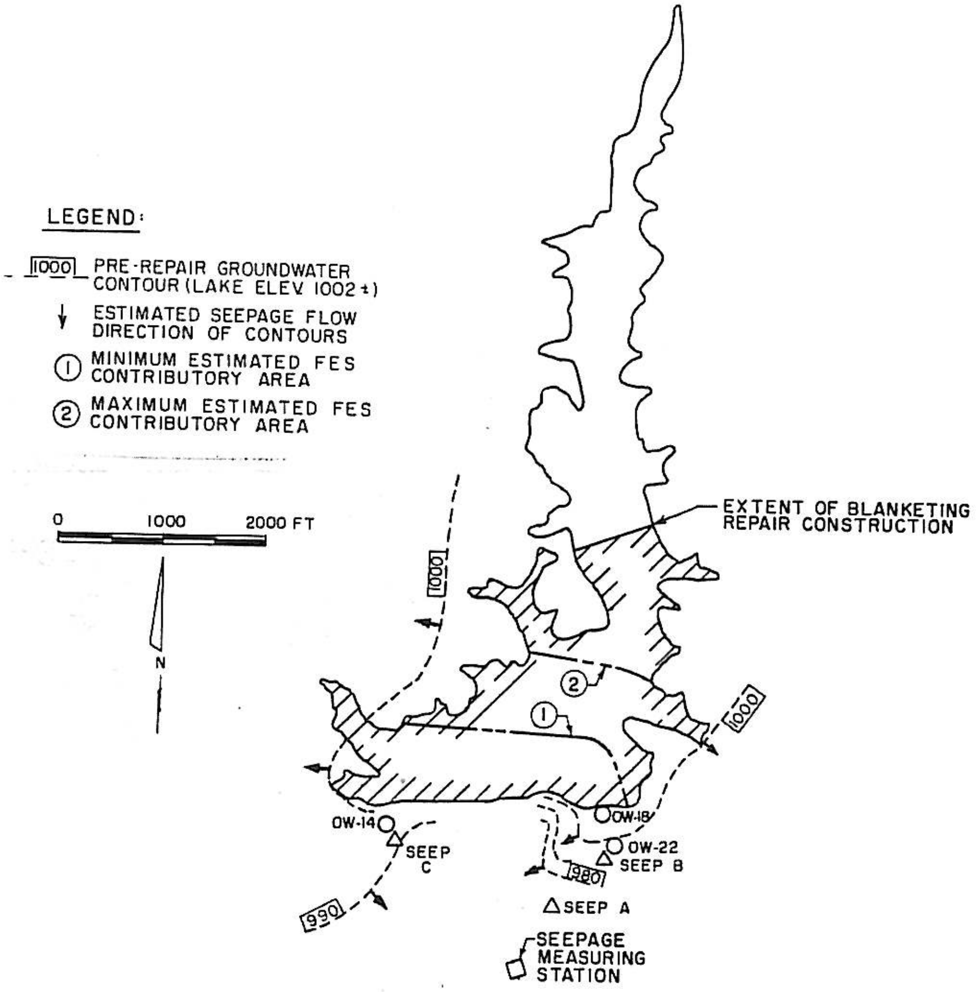

Figure 10. Estimated FES Contributory Areas and Extent of Blanketing

In general, the observation well readings were erratic, as would be expected for these conditions. However, some insight to the blanket performance is indicated by the readings in three typical groundwater observation wells, OW-14, OW-18, and OW-22, judged to be responsive to the lake levels before and after the blanketing repair, at locations shown in Figure 10. These readings are plotted in Figure 12. The before and after readings for OW-14 and OW-18 indicate an increased head loss or degree of separation between the lake and groundwater after the repair. The same holds true for OW-22 for lake levels above Elevation 1000.

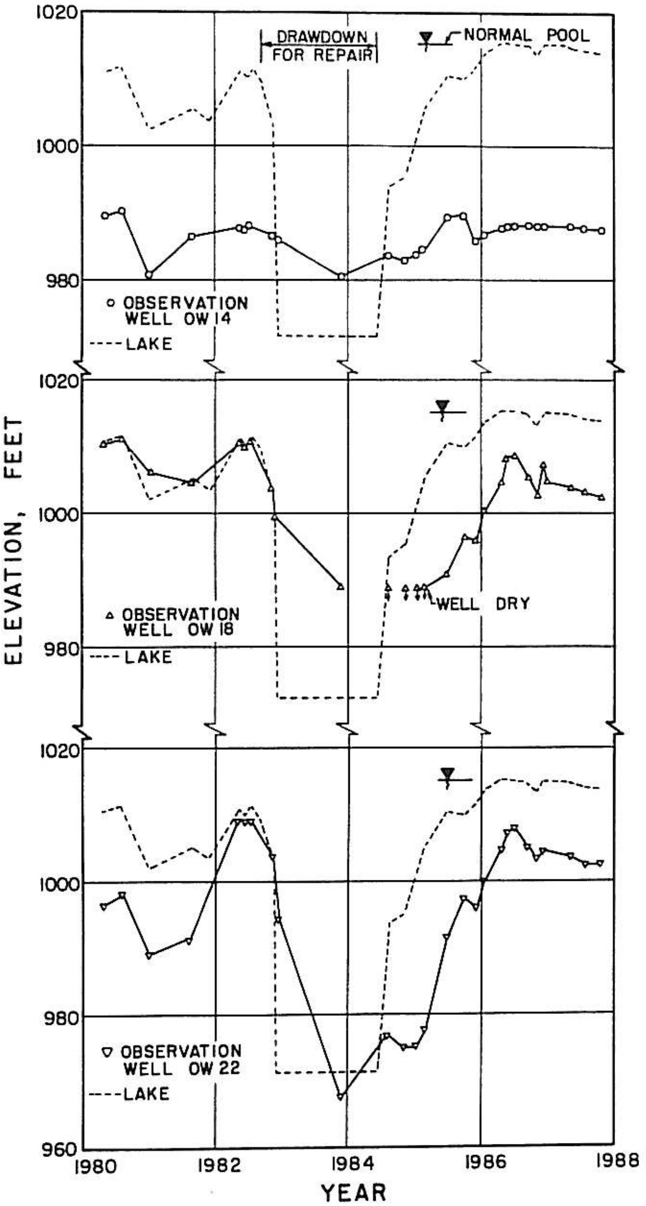

Figure 12. Measured Pre- and Post-Repair Groundwater Levels in Three Observation Wells

CONCLUSIONS

Based on these analyses and observations, the following "lessons learned" or conclusions were developed:

1. The unusually large amount of information collected for this size project over this period of time permitted several different types of analyses to be made. However, because of the extremely complex geology, even this amount of information was not adequate to completely determine the seepage loss mechanisms and quantities.
2. The blanketing repair ultimately selected at this site required more volume of compacted fill than the embankment itself. This is due, in part, to the marginal permeabilities of the available on-site blanket soils. The repair generally appears to be functioning satisfactorily. However, what might have been regarded as a conservative repair still was not adequate to maintain the normal pool level during periods of significantly below-normal rainfall.
3. An early and complete understanding and appreciation of the site geologic conditions relative to seepage potential are often difficult to achieve. This requires the exercise of considerable engineering judgment and close coordination among the geotechnical engineer, engineering geologist, and hydrologist.

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