Environmental Engineers and Scientists

January 6, 2004

Clyde Dabbs Jr., P.G.
Lead Hydrogeologist
Lower West Coast Regional Service Center
South Florida Water Management District
2301 McGregor Blvd.
Fort Myers, FL 33912

Re: Hydrostratigraphy Review Report

Dear Mr. Dabbs:

In accordance with the work Plan for Task Order 1 of the South West Florida Regional Model Development Work Order (Hydrology and Hydraulic Modeling Support; WO1), and in response to the review comments from the Workshop Meeting (October 21-22, 2003), BEM is hereby submitting the final deliverables. This deliverable is a letter report summarizing the activities undertaken by the BEM team in developing a geologic model of the region covered by the South West Florida Feasibility Study and extending it to cover the Regional Model Simulation Boundary. Specific issues that were raised at the Workshop Meeting are addressed in this report. Electronic copy of the aquifer surfaces has been delivered to the study team and is currently being used by the SFWMD staff to generate the regional model.

This report is submitted for your review and consideration. We look forward to your comments and/or suggestions. If you have any questions concerning this report, please address them Mr. Wexler, or myself.

Sincerely,

Maged Hussein, PhD, P.E.
Project Manager
BEM Systems, Inc.

11785 Saint Andrews Place, # 101, West Palm Beach, FL33414 Tel. (561) 784-5157 Fax. (253) 830-1773

New Jersey Florida Arizona Washington, D.C. Kansas City New Mexico Virginia

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Lead Hydrogeologist
Lower West Coast Regional Service Center
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Re: Hydrostratigraphy Review Report

Dear Mr. Dabbs:

In Task 3.1 BEM Team member Earth*f*x conducted a preliminary review of the hydrostratigraphic surfaces generated by Water Resources Solutions, Inc. (WRS) and the DHI Water and Environment, Inc (DHI). Our preliminary review consisted of comparing data within the WRS database for consistency with data available in South Florida Water Management District's (SFWMD) DBHYDRO hydrogeologic database as well as from other sources such as recent U.S. Geological Survey (USGS) reports and data from the Florida Geological Survey (FGS) borehole database. Our team checked the adequacy and completeness of the data used and reviewed the methodology used in interpolating the surfaces.

In our report for Task 3.1, we recommended a comprehensive and detailed examination of the data to ensure consistency of information and interpretation. Task 3.2 and 3.3 were re-structured to allow us to conduct this comprehensive review. This review turned out to be quite labor intensive and we allocated considerable resources beyond what was budgeted to achieve a level of consistency adequate for modeling. We believe that through this effort we have developed hydrostratigraphic surfaces that will be more conducive to numerical modeling. Results of our review and definition of the hydrostratigraphic surfaces are provided below.

1. Data Sources

Earth*f*x was provided with two main sources of data for the SWFFS area: (1) a database assembled by WRS and (2) the SFWMD DBHYDRO database. These data were supplemented by reports from the USGS, FGS, SFWMD, and other consultants. We also have access to the original FGS data and some of the raw data that went into the geophysical data tables in DBHYDRO.

1.1. WRS Database

The WRS database is composed of wells from the FGS, USGS, Bureau of Oil and Gas (BOG), SFWMD, and WRS internal files. The WRS database is divided into four "databases", which are actually four MS-Excel spreadsheets that were imported into four tables in MS-Access. The primary data in each table are:

Database 1: well name, location, elevation, construction (total and cased depth), and owner. WRS used local names for all wells but provided a cross-reference to well names used by the USGS, FGS, and SFWMD.

Database 2: well name, location, elevation, depth to lithologic and hydrostratigraphic units, and/or unit thickness.

Database 3: well name, location, elevation, aquifer monitored, May 2001 water level and September 2001 water level.

Database 4: well name, location, construction (total and cased depth), aquifer tested, transmissivity, storage coefficient, specific yield, leakance value, and test method.

The wells in the database offer good spatial coverage of the SWFFS area and contain information on deeper wells. WRS did not have complete access to the DBHYDRO database and, therefore, there are wells in the DBHYDRO database that are not in the WRS database. There is some overlap, however, since both DBHYDRO and the WRS database share common information regarding FGS, USGS, and SFWMD wells. We were able to match 613 of the 2179 with station names or aliases in the DBHYDRO database. WRS had adjusted the locations of many of the USGS and FGS wells in their database. The locations generally differ within a ½ mile. Because WRS changed locations of wells without saving the original locations, it was difficult to cross-reference other wells (i.e., non-USGS or FGS wells) based on location.

In our preliminary review, we noted that the design of the WRS database limited its usability for extracting information needed to cross check and verify the data. The four databases also contain duplicate information (e.g., well locations and well construction). There are many duplicate wells in each database and not all wells in Databases 2 through 4 can be found in Database 1, which is the master well location table. Most of the data fields that should contain numeric values (for example, datum elevations, tops of geologic units, and unit thicknesses) were formatted as text fields. Most fields contain numbers (as text) but many contain a mixture of text, numbers and sometimes symbols (e.g. ">50?"). To do our review, we had to rewrite all of these fields by parsing the data and creating separate fields for the numeric value and for additional text and symbols. The revised relational database containing the original WRS data was created at considerable effort.

WRS produced stratigraphic surfaces based on the data in the database. These were provided for our review in a number of formats including PDF files, AutoCAD drawing (DWG) files, and Surfer GRID files. The drawings were done in several different coordinate systems and the GRID files were created with several different grid definitions. Despite this, we were able to successfully import all the maps and gridded data into VIEWLOG for our review.

DHI has also created lithologic surfaces for the SWFFS area, using the data collected by WRS. DHI noted some difficulty interpreting the lithologic data from WRS into modeling data because stratigraphic data were provided as a mix of depths to the top of units and unit thickness. DHI provided their surfaces to us as ArcInfo ASCII grid files and included samples of the raw data used in their "de-clustering" technique for surface generation.

1.2. DBHYDRO Data

The DBHYDRO database has a total of 2026 wells in the six counties (Lee, Collier, Charlotte, Glades, Hendry, and Monroe). Of these, 401 have tops of stratigraphic units defined. The majority of these wells were in Lee (136 wells), Collier (97 wells) and Charlotte County (74 wells). A total of 203 wells have tops of aquifer units defined. The majority of these wells were in Charlotte (59 wells) and Hendry County (60 wells).

The data have been entered into a relational database with a well-designed data model. Overall, there are no significant problems with the data (such as duplicate entries) although a few location errors (e.g. incorrect county names assigned) were noted. The areal coverage of the data is limited compared to that of the WRS data.

1.3. Water Use Permit Data

A third data set contains information related to water use. A limited amount of information related to well construction was also included in this database, specifically, well location, total depth, cased depth, and the aquifer tapped. To use this information, we first estimated the well top elevation from a new digital elevation model (DEM) provided by SFWMD.

This data set has been has been used as an independent check on the accuracy of the stratigraphic data in the other two databases. The data, however, were felt to be of limited use in identifying the tops and bottoms of the aquifers since the cased depth may extend deeper than the top of the aquifer because drillers do not know a priori where the top of a unit is located. Most wells in the database have casing depths in multiples of 10 and 20 ft, indicating that the drillers likely drilled a number of drill rod lengths and, after examining the cuttings, decide to drill the open-hole portion of the well

2. Delineation of Model Layers

2.1. Approach

WRS concluded that the “there was no need to modify the commonly used historical terminology for the surficial and intermediate aquifer systems”. The primary features of the historical terminology are illustrated in Figure 1a, and include:

1) the Water Table aquifer is unconfined and is comprised of all unconfined permeable stratigraphic units at a particular location;
2) the geologic units which comprise the Water-Table aquifer can vary depending on location;
3) the lateral extent of the Lower Tamiami aquifer is restricted to where it is confined by an overlying unit (usually the Bonita Springs marl or Caloosahatchee Clay); and

4) the Sandstone aquifer is defined from the top of the first confined sandstone unit (Lehigh Acres Sandstone) in the Peace River Formation to the top of the basal clay unit in Peace River Formation

WRS and DHI generated surfaces defining the top and bottom surfaces of the Water-Table aquifer and Lower Tamiami aquifer that conform to these functional rules. Based on our experience with numerical models, however, the Earth*f*x/BEM team has recommended that the surfaces used for the Regional Simulation Model (RSM) be developed with rules that better reflect continuity of geologic and hydrogeologic layers rather than based on the presence or absence of a confining unit. Accordingly, we have defined:

Aquifer Layer 1 – Holocene to Pleistocene sands and Late Pliocene (Pinecrest) limestone, where present.

Aquitard 1- Bonita Springs Marl and Caloosahatchee Clay, where present.

Aquifer Layer 2 – Early Pliocene (Ochopee Limestone). This unit conforms to the historical definition of Lower Tamiami aquifer where confined and to the lower part of the Water-Table aquifer where unconfined. The vertical extent of the unit is defined from the top of Ochopee Limestone to the top of the Peace River Formation. The unit is missing in the northern part of the study area and outcrops in the southern part of the study area.

Aquitard 2 – Upper clays in Miocene Peace River Formation, referred to locally as the Cape Coral Clay. Clays between the base of the Ochopee Limestone and top of the Miocene were included in this unit.

Aquifer Layer 3 – Sandstone aquifer. This-unit is defined from the top of the first sandstone unit (Lehigh Acres Sandstone) in the Peace River Formation to the top of the basal clay in the Peace River formation. This definition conforms to the historical definition of the Sandstone aquifer except where the formation is unconfined. The Sandstone aquifer contains clay beds within the aquifer. Total thickness of sandstone and internal clay were calculated from WRS data. The unit outcrops in the northern part of the study area where the Tamiami Formation is missing.

Aquitard 3 –Basal clays in the Peace River Formation, referred to locally as the Fort Myers Clay. The unit extends vertically to the top of the Arcadia Formation, which we presumed to be equivalent to the top of the Mid-Hawthorn aquifer.

Figure 1b shows a sketch of the current definitions of the aquifer and aquitard stratigraphy.

3. Interpolation Methods

Creation of aquifer top and bottom surfaces requires interpolating the point data (i.e., the elevations of the aquifer tops and bottoms defined at each borehole) to a regular grid that represents the study area. WRS interpolated the data for the various aquifer surfaces to different grids depending on the location of data points. While this is a reasonable approach for constructing the geologic model, the numerical model requires definition of the surfaces at all points on a common grid. DHI used a common grid with a 1500-ft cell size that covered most, but not all of the RSM model area. The BEM/Earth*f*x team designed a grid with square cells, 750 ft on a side, to cover the entire RSM model area with a higher degree of resolution. The grid origin (lower-left corner of the grid) was set at x,y coordinates of 289800, 439850 so that our grid and the DHI grid would overlay.

Various methods were used to interpolate the available borehole data to the grids. WRS used an ordinary kriging technique and assumed linear variograms (the default option in the SURFER program). Linear variograms have no sill or range, indicating that the data are assumed to be correlated over large distances compared to the scale of the data interpolation being done. It is our understanding that WRS did not conduct variance analyses to verify that this assumption was correct. Our analysis of the data found that use of a linear variogram was justified in some cases but, in most cases, data were interpolated over distances larger than the correlation lengths and that other variogram shapes were more appropriate. The variogram properties used in our interpolations are discussed further on in this report.

DHI found the surfaces generated by WRS to be highly variable and sought to generate smoother surfaces using a moving-window averaging technique. While the surfaces can be more esthetically pleasing, the method does not honor the data values at individual points as well as kriging does. Because different sets of wells may be used to interpolate different surfaces, it is possible for averaged surfaces to cross over. It was also found that some of the data used to generate the DHI surfaces had been incorrectly converted from the text fields in the WRS database. In these cases, the depths to the tops of various units were interpreted as equal to 0.0 instead of the true depth and the interpolated elevations of the surface reflect these errors.

The Earth*f*x/BEM team created a combined data set that consisted of borehole data from both DBHYDRO and WRS tables. Where duplicate data points were encountered, we generally used the WRS locations and picks, except where noted below. As well, many of the intermediate units, such as the confining unit beneath the Lower Tamiami Aquifer and the confining unit beneath the Sandstone Aquifer are only defined in the WRS database. The DBHYDRO database contained some revised picks made by the FGS in 2003. These data values were selected over the earlier picks and WRS values in most cases.

The Earth*f*x/BEM team first screened the combined borehole data for outliers, then conducted an analysis of variance to fit the theoretical variograms to the experimental variograms, and finally interpolated the data to the geologic model grid using the geostatistical analysis module of VIEWLOG. These steps are described below.

3.1. Updates to Data Sources

In accordance with the recommendations made at the workshop held on October 21-22, 2003, the following changes were made to the database:

a) Lithologic data were added from printed logs for:

W-50050 (HY-202, Well ID 22956)	HY-308 (HE-1056, Well ID 4937)
W-15794 (HY-124, Well ID 22943)	C-2044 (C-987, Well ID 6135)
HY-206 (Well ID 21511)	HY-314 (Well ID 20908)
C-2059 (C-531, Well ID 6322)	HY-126 (W-50047, Well ID 22953)

b) For wells that already existed in the DBHYDRO database but were previously excluded, geologic picks were included for:

W-15531 (C-2040)	C-2033 (W-17403)
C-2041 (W-15530)	C-2030 (W-14920)
C-2038 (W-15529)	HY-103 (W-5029, HE-621)

c) Geologic picks for the top of the Tamiami Formation were excluded for:

W-14920	W-14934

3.2. Updated Geologic Surfaces

Once the data were revised and incorporated into the database, new geologic surfaces were generated. These surfaces were generated either by interpolating the borehole data to a grid using kriging, or by calculation (e.g., subtracting one interpolated unit top surface from an interpolated bottom surface to determine the unit's thickness). Table 1 shows the statistics derived from the kriging process of the various surfaces.

Thickness of Holocene/Pliocene (Aquifer Layer 1): Borehole data from the WRS database were interpolated to the geologic model grid. The interpolated values were then corrected in VIEWLOG by setting the aquifer thickness to zero if the kriged value was less than 0.

Thickness of Bonita Springs Marl (Aquitard Layer 1): Borehole data from the WRS database were interpolated to the geologic model grid. The interpolated values were then corrected in VIEWLOG by setting the aquitard thickness to zero if the kriged value was less than 0. Thickness of the Holocene/Pliocene and thickness of the Bonita Springs Marl were then added together in VIEWLOG to get a total thickness, which was then subtracted from land surface topography to get the calculated surface for the bottom of the Bonita Springs Marl. This surface was used as a check with the Top of the Ochopee Limestone surface, described below.

Top of Ochopee Limestone (Aquifer Layer 2): For this surface, borehole data from the WRS database were first interpolated to the geologic model grid. Next, borehole data from DBHYDRO were kriged independently to the geologic model grid. The two surfaces were compared in VIEWLOG, and this resulted in the exclusion of Well 1703 from the WRS database, as well as the following seven wells from the DBHYDRO database (due to overlap with WRS wells and/or significant differences when compared to WRS wells):

10276 (W-14920)	10289 (W-15529)
10291 (W-15531)	21511 (HY-206)
15164 (W-16913-2)	12045 (W-15487)
10268 (W-14003)	

After these wells were removed, the data sources were combined and kriged together to generate the surface for the top of the Ochopee Limestone. The interpolated values were corrected in VIEWLOG by (1) setting the top of Ochopee limestone to land surface elevation if the kriged value exceeded to land surface elevation, and by (2) setting the top of Ochopee Limestone to the bottom of the Bonita Springs Marl if the kriged value exceeded bottom of the Bonita Springs Marl.

Top of Peace River Formation: Borehole data from the WRS and DBHYDRO databases were interpolated to the geologic model grid. Two wells (W-14920 and W-14934) were excluded from DBHYDRO data based on discussions at the workshop. The formation picks for two wells, HY-202 (W-50050, Well ID 22956) and W-15531 (C-2040, Well ID 10291) were added to the data set but later excluded because there were duplicate WRS wells with similar picks. The formation tops for two additional wells, HE-1056 (HY-308, Well ID 4937) and W-15794 (HY-124, Well ID 22943) were picked from printed logs, added to the data set and used in the interpolation.

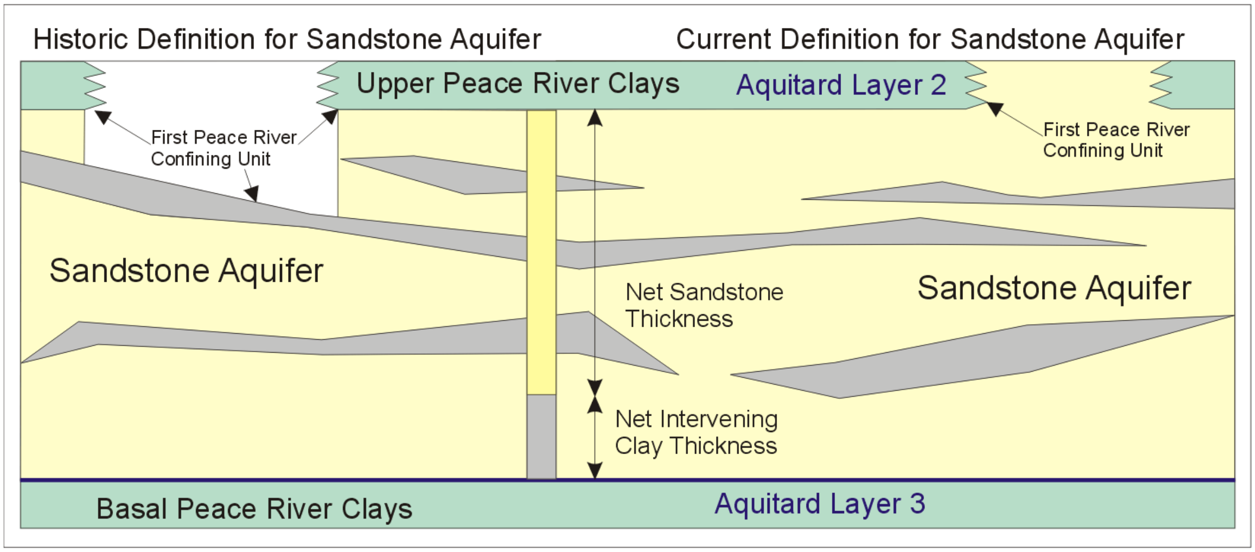
Other wells, aside from those mentioned in the workshop, were considered for addition to the data set. The top of the Peace River was picked from the lithologic logs for wells C-2044 (C-987, Well ID 6135), HY-206 (Well ID 21511), HY-314 (W-16032, Well ID 20908), and HY-126 (W-50047) (Well ID 22953) but later excluded, because they were duplicated by WRS wells. Formation picks for wells C-2033 (W-17403, Well ID 10320), C-2030 (W-14920, Well ID 10276), C-2038 (W-15529, Well ID 10289), and HY-103 (W-50029, HE-621, Well ID 15296) were also excluded because they were duplicated by WRS wells. Formation picks for wells C-2041 (W-15530, Well ID 10290) and C-2059 (C-531, Well ID 6332) were added to the data set and used in the interpolation.

The combined WRS and DBHYDRO data were then kriged together to generate a surface for the top of the Peace River Formation. The interpolated top of the Peace River Formation was compared with the top of Ochopee Limestone. If the elevation of top of the Peace River Formation exceeded the top of Ochopee Limestone, the elevation was set to the elevation of the top of the Ochopee Limestone.

Thickness of Ochopee Limestone (Aquifer Layer 2): The thickness of the Ochopee Limestone was calculated as the difference between the top of the Ochopee Limestone and the corrected top of the Peace River Formation.

Thickness of Upper Peace River Clays (Aquitard Layer 2): The original WRS database contained information on the thickness of the "first" Peace River confining unit. In many cases, this unit represents the clay that separates the Ochopee Limestone from the uppermost sandstone unit in the Peace River Formation (see sketch below). In other cases, where the Bonita Springs Marl was not present and the uppermost sandstone was unconfined, this uppermost sandstone unit would be included as part of the Water Table Aquifer and the first Peace River confining unit would be the clay unit below the uppermost sandstone unit. As was noted earlier, for purposes of this study, the first sandstone unit was selected as the top of the Sandstone Aquifer and any clay unit above the sandstone was considered the upper Peace

River confining unit. Values for the thickness of the upper Peace River confining unit for wells in the WRS database were modified accordingly. Thickness values for the wells in the WRS database were interpolated to the geologic model grid.



Next, the interpolated Top of Peace River Formation and the interpolated thickness of the upper Peace River confining unit were written back to a new table in the DBHYDRO database. An assumed thickness of the upper Peace River confining unit was calculated in DBHYDRO as the difference between the interpolated top of the Peace River Formation and the top of the Sandstone Aquifer (for wells with a pick for the top of the Sandstone Aquifer). The assumed thickness was compared against the interpolated thickness and, if reasonable, the assumed thickness was added to the data set and the thickness values were re-interpolated. This procedure resulted in the inclusion of four DBHYDRO wells, wells W-16098 (Well ID 12061), W-50043 (Well ID 15316), W-50039 (Well ID 15301), and W-14072 (WELL ID 12021). Finally, the interpolated values were corrected by setting the aquitard thickness to zero if the kriged value was less than 0.

Top of Sandstone Aquifer (Aquifer Layer 3): The top of the Sandstone Aquifer was calculated as the top of the Peace River Formation the minus the interpolated thickness of upper Peace River clay.

Thickness of the Sandstone Aquifer (Aquifer Layer 3): The WRS database contains data on the net thickness of sandstone in the Peace River Formation and the net thickness of confined sandstone in the Peace River Formation. As noted earlier, the definition of the Sandstone Aquifer was modified for this study to include all the sandstone units in the Peace River Formation. Accordingly, values for the net thickness of sandstone at wells in the WRS database were interpolated to the geologic model grid. There were no corresponding measurements in the DBHYDRO database. The interpolated values were then corrected by setting the aquifer thickness to zero if the kriged value was less than 0.

Base of the Sandstone in the Peace River Formation: The Sandstone Aquifer contains interbedded clay units (see sketch above). The WRS database provided data on the net thickness of sandstone in the Peace River Formation, but did not provide information on the tops or thickness of the clay beds. It was possible, however, to calculate the net thickness of interbedded clay from the data supplied. To portray the two net thickness values on the cross sections provided at the end of this report, we calculated a surface equal to the top of the Sandstone Aquifer minus the net thickness of the Sandstone Aquifer. This surface was displayed on the cross-sections for illustrative purposes only.

Thickness of Basal Peace River Clay: Thickness values from the WRS database were interpolated to the geologic model grid. There were no corresponding measurements in the DBHYDRO database. The interpolated values were then corrected by setting the aquitard thickness to zero if the kriged value was less than 0.

Top of the Mid-Hawthorn aquifer: Picks from both the WRS and DBHYDRO databases were interpolated to the geologic model grid. The WRS database contained two picks, one for the top of the Arcadia Formation and one for the top of the first limestone unit in the Arcadia Formation. In most cases these were identical, although in some areas, a clay unit underlying the basal Peace River confining unit was identified. For simplicity, we included this lower clay in with the basal Peace River confining unit and interpolated the top of the first limestone unit in the Arcadia Formation picks. Well LM-5864, with a pick noted as > 222 ft deep, was excluded because it acted as a "pull-up" point rather than a "push-down" point. Two other WRS wells were excluded because their data was replicated by other DBHYDRO wells. The WRS data were supplemented by an additional 7 of 44 unique picks from the DBHYDRO database based on a query for the top of the Mid-Hawthorne Aquifer and 66 of 160 unique picks based on a query for the top of Arcadia Formation. These datasets were then combined and kriged together to generate the surface for the top of the Mid-Hawthorn aquifer.

Top of Basal Peace River Clay: The top of the basal Peace River confining unit was calculated as the top of the Mid-Hawthorn aquifer plus the thickness of the basal Peace River clay. The surface was corrected if the top of basal Peace River confining unit exceeded the base of the Sandstone Aquifer by setting the top of basal Peace River Confining unit equal to the base of the Sandstone Aquifer and re-calculating the top of the Mid-Hawthorn aquifer.

Thickness of Interbedded Clays in the Sandstone Aquifer: The net thickness of the interbedded clays in the Sandstone Aquifer was calculated as the base of the Sandstone Aquifer minus the top of the basal Peace River clay. Net thickness of the interbedded clay was displayed as a gap between the Sandstone Aquifer and the top of the basal Peace River confining unit. This unit was displayed on the cross-sections for illustrative purposes only.

4. Quality Assurance, Quality Control and Outliers

It is likely that both the WRS and DBHYDRO databases contain some erroneous entries. These could be a result of transcription and data entry errors as well as incorrect interpretation of the geologic information. The Earth*f*x/BEM team conducted a number of quality control/quality assurance (QA/QC) procedures to spot obvious errors in the data. Statistical checks and geostatistical analyses were then used to identify possible outliers. We did not re-pick any of the geologic units or add new picks at this time. We recommend that that, as time permits, the points identified as possible outliers should be re-examined and new picks should be made.

The Earth*f*x/BEM team first checked for errors in the assigned ground surface elevations by comparing against the DEM. Where elevations differed by more than 10 ft, the wells were checked for possible location errors. If the well appeared to be in the proper location, the DEM value was used in place of the original elevation.

Many wells in the WRS database were assigned elevations relative to the kelly bar or to the derrick floor (signified by "KB" or "DF" in the original elevation field). It appears that WRS estimated land surface elevation at these points in preparing the database, but these estimates were not recorded. In our analyses, land surface elevations were assigned to these wells based on the new SFWMD DEM. Of the 1864 wells in Database 2, 38 wells had no assigned elevations. Of these, 15 were assigned elevations based on the DEM; the remaining 23 were excluded because they were located outside the coverage of the DEM. An additional 44 wells were excluded because they had no geologic data at all and 2 were excluded because their locations were obviously incorrect.

Several procedures were developed to search for outliers in the data. Standard methods that test for extreme values in a data set (such as in a record of water levels or concentrations at a well) are not applicable here because we need to identify values that are outliers with respect to neighboring wells. For example, depth to the top of the Ochopee Limestone ranged from 0 to 155 ft. A well with a depth of 48 ft would not be considered an extreme value, except in a situation where all the surrounding wells have much shallower depths.

Two general procedures were used to test for outliers in the WRS data. The first involved testing each data point and the nearest 32 data points. Rosner's test for multiple outliers was then applied to the 33 sample values. Rosner's test, which is a generalization of the extreme Studentized deviate (ESD or Grubbs' test (Grubbs, 1969)), can be used to sequentially evaluate up to 10 outliers for samples sizes greater or equal to 25. The test statistic is defined by:

$$R = \frac{x_{out} - \bar{x}'}{S'}$$

where $\bar{x}'$ and S' are the mean and standard deviation of the remaining samples after the first *m* outliers are removed from the data set, that is:

$$\bar{x}' = \frac{\sum_{i=1}^{n-m} x_i}{n-m}$$

$$S' = \sqrt{\frac{\sum_{\imath=1}^{n-m} (x_i - \bar{x}')^2}{n-m}}$$

The R statistic can be compared against tabulated values for different initial sample sizes and confidence intervals. In our analysis, the data point was flagged as a "possible outlier" in the database if the point was selected as either one of the first two statistical outliers (m = 2). A 95%

confidence level was specified so there was less than a 5% chance of a false-positive selection. Visual analysis of the possible outliers was done to confirm that the anomalous value was not simply indicative of a localized erosional or depositional feature.

A second method for spotting outliers was to conduct a cross-validation after the surfaces were interpolated from the WRS data. In this process, the kriging algorithm was used to estimate the value at the data point using all data except the observed value. As an example, 649 WRS wells were used in interpolating the top of Ochopee Limestone. To check the accuracy of the interpolation at the location of Well CH-372, for example, the kriged value was calculated using the nearest 32 of the remaining 648 wells. The residual was calculated by subtracting the kriged value from the reported value of 17 ft. All residuals were checked using Rosner's method to detect whether the 10 largest residual values should be considered outliers. Wells exceeding the Rosner criteria were flagged in the database as possible outliers and were confirmed by visual inspection.

Non-duplicate data points in the DBHYDRO database were then added to the data set. Because there were fewer data points, it was easier to visually screen the DBHYDRO data for possible outliers. Surfaces were then re-kriged without the outliers.

5. Variance Analysis and Interpolated Surfaces

The semivariance (i.e., one half of the variance) for a pair of data points located at $\mathbf{x}_i,\mathbf{x}_j$ is given by:

$$\gamma(xi, xj) = \tfrac{1}{2}\left[z(x_i) - z(x_j)\right]^2$$

where $z(\mathbf{x}_i)$ is the observed value at point i. The average semivariance of all pairs of data points separated by a given distance interval (lag distance) was calculated and an experimental variogram (Figure 2) was generated by plotting the average semivariance for all lag distances. Theoretical variograms were then fit to the data to best match the experimental variogram by specifying a variogram type (e.g., linear, spherical, exponential or Gaussian), and variogram parameters (i.e., nugget and slope for linear variograms or nugget, sill and range for the other shapes).

The available data tended to be fairly noisy even after removing the most likely outliers. Average distances between boreholes tended to be large. For example, the average separation distance for data points used to define the thickness of Holocene sand was equal to 30 miles. Separation distances were even greater for sparser data sets.

Variogram fitting was done using a non-linear least-squares fitting routine and visually inspected for goodness of fit. The exponential model produced the best fit for most surfaces. For stratigraphic data, we tended to select fits that minimized the nugget since there were few pairs of data points at the smaller lag distances on which to base the size of the nugget and because, while a large nugget effect would produce smoother surfaces, it could lead to more crossovers.

6. Inspection and Correction of Surfaces

Table 1 provides as summary of the results of the variance analysis and presents the variogram properties used in the interpolation. After the initial interpolation of the surfaces, they were inspected using the VIEWLOG array data processor to check for minimum thickness. Where the interpolated aquifer or aquitard layer thickness was negative, the thickness value was set to zero.

Figures 3 through 20 show the final interpolated and calculated surfaces. Figures 12 through 18 require some additional explanation. As noted earlier, the Peace River formation is comprised of interbedded sandstones and clays. From the WRS data it is possible to distinguish an upper clay bed and a basal clay bed. The thickness of the upper confining bed (Figure 14) was calculated by subtracting the interpolated top of the Sandstone aquifer (Figure 13) from the interpolated top of the Peace River Formation (Figure 12). The tops and bottoms of additional clay beds between the upper and basal confining units were not provided in the WRS database although these beds appear on the cross-sections presented by WRS. Instead, the WRS database contains information on the net thickness of sandstone layers between the upper and lower confining units and it is possible to calculate the net thickness of clay beds from this information. Figure 15 shows the net thickness of sandstone in the Peace River Formation and Figure 16 shows the calculated net thickness of the intervening clay beds. It was not possible, however, to illustrate on cross-section the true stratigraphy of the intervening clay units without having the data on the tops and bottoms of the individual clay units. Therefore, we have chosen to illustrate the net thickness of the clay beds as a gap between the sandstone aquifer and the basal confining unit.

Figure 19 shows the top of the Arcadia Formation and the top of the Lower Hawthorn aquifer which were generated in a similar manner as the other kriged surfaces. It is provided here since it is used as a bounding surface in the geologic cross-section although it will not be used in the numerical model.

Figure 20 shows the locations of geologic sections lines, similar to those drawn by WRS and DHI. Figures 21 though 29 show cross sections taken through the study area. The interpolated surfaces have been provided to SFWMD in a VIEWLOG project file so that any number of additional cross-sections can be easily generated. Surfaces were also provided to SFWMD in Arc/Info Grid format and the MS-Access database with the corrected WRS data and additional information has been provided as well.

7. Summary and Conclusion

A geologic model of the area covered by the South West Florida Feasibility Study was developed in which surfaces representing the hydrostratigraphy of the region. Layers in the model represent three major aquifers and three aquitards. The definition of the layers differs from the historical definition of aquifers in the study area, but was done to create hydrostratigraphic layers that would be more amenable to numerical modeling.

To accomplish the task of building a geologic model, an extensive review of all available sources of information was conducted. The first step involved reformatting the data provided by WRS into a more useful relational database. QA/QC procedures and statistical analyses were carried out on the borehole data to eliminate obvious outliers from the data. We did not, however, re-pick any of the geologic units or add new picks at this time.

Kriging, a well-recognized geostatistical method, was used to interpolate the data to a single model grid with a uniform 750 x 750 m cell size. An analysis of variance was first conducted on the data using the geostatistics module in VIEWLOG to determine the best shapes and properties of variograms used in the interpolations. Surfaces were corrected to provide a minimum thickness for aquifer layers and zero thickness for aquitards where the units pinch out. The minimum aquifer thickness is a requirement of the numerical model.

Figures showing the interpolated surfaces and cross sections have been provided in this report. Digital forms of the surfaces were provided as to SFWMD as ARC/INFO grid files and as a VIEWLOG project file along with the database containing the geologic data used in this study.

8. References

Grubbs, F.E., 1969, Procedures for detecting outlying observations in samples: Techonometrics, v.14, p. 847-854

Rosner, B., 1983, Percentage points for a generalized ESD many-outlier procedure: Techonometrics, v.25, p. 165-172

Report prepared by:

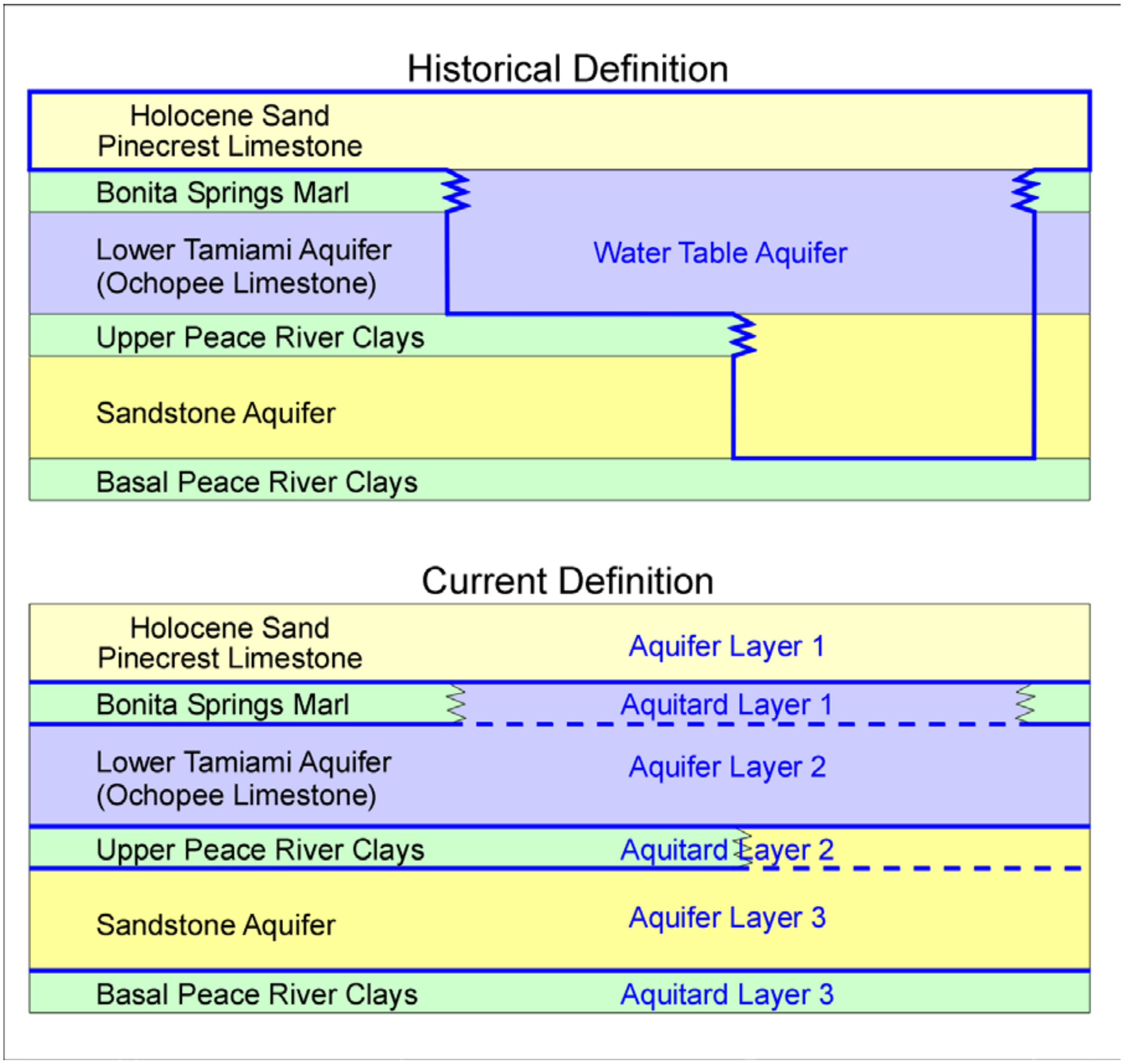
Eliezer J. Wexler

E.J. Wexler
Director of Modelling Services
Earth*f*x Incorporated

Table 1: Results of variance analysis and variogram properties

Surface	No of Data Points	No. of Possible Outliers	Duplicates	Variogram Type	Nugget	Sill	Rang e
Thickness of Holocene/Pleistocene Sands and Pliocene Limestone (WRS)	984	7	20	Exponential	0	16246	16246
Thickness of Bonita Springs Marl (WRS)	970	10	21	Exponential	0	73150	73150
Top of Ochopee Limestone (WRS & WILMA)	999	2	21	Exponential	0	44217	44217
Top of Peace River Formation (WRS & WILMA)	1060	26	6	Exponential	0	12000	12000
Thickness of upper PR Confining (WRS)	853	14	19	Exponential	0	7000	7000
Net Thickness of the Sandstone Aquifer (WRS)	821	3	5	Exponential	0	800	6500
Thickness of basal PR Confining Unit (WRS)	627	9	10	Exponential	0	1630	35000
Top of 1st Limestone in Arcadia (WRS & WILMA)	793	0	23	Exponential	0	7800	93000

Figure 1: (a) Historical definition of aquifers in the SWFFS area, and b) current definition of aquifers for modeling purposes



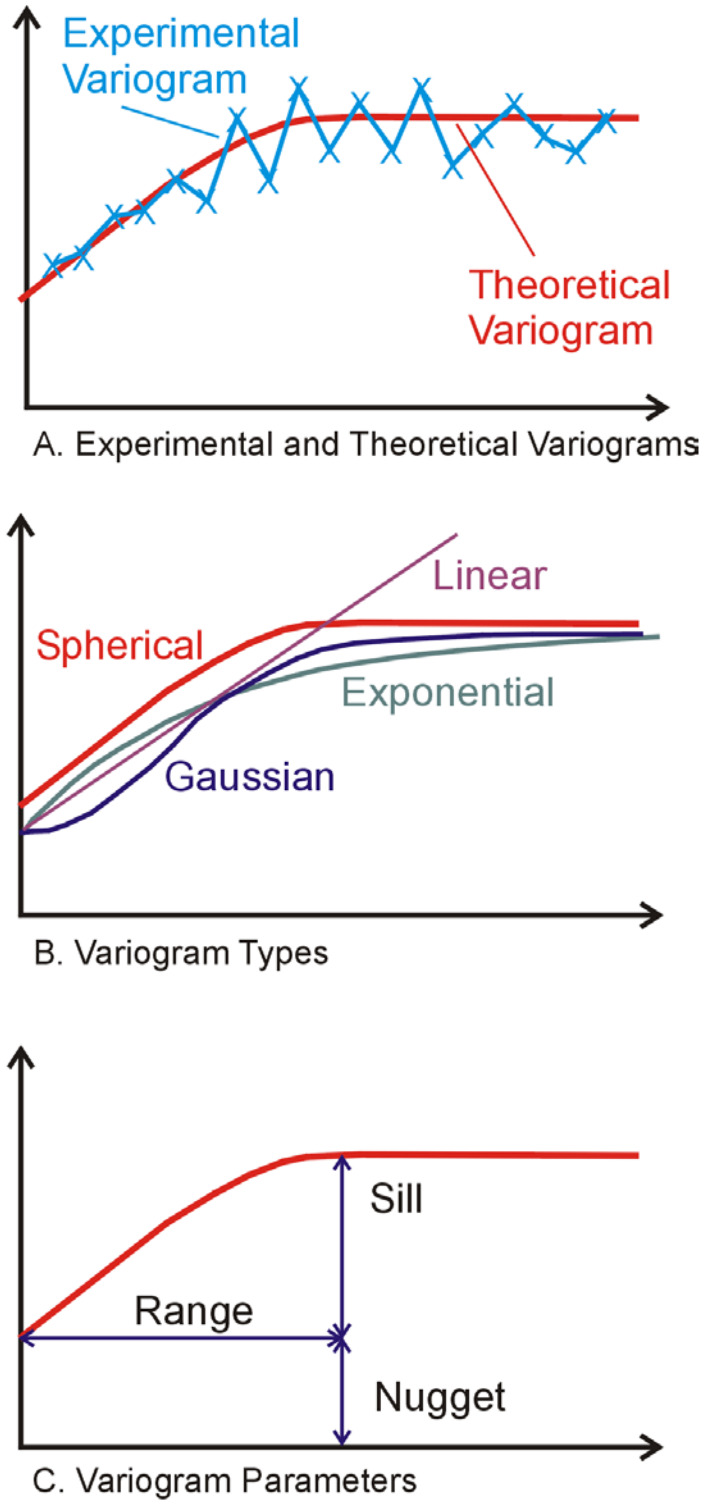


Figure 2. Variogram Properties

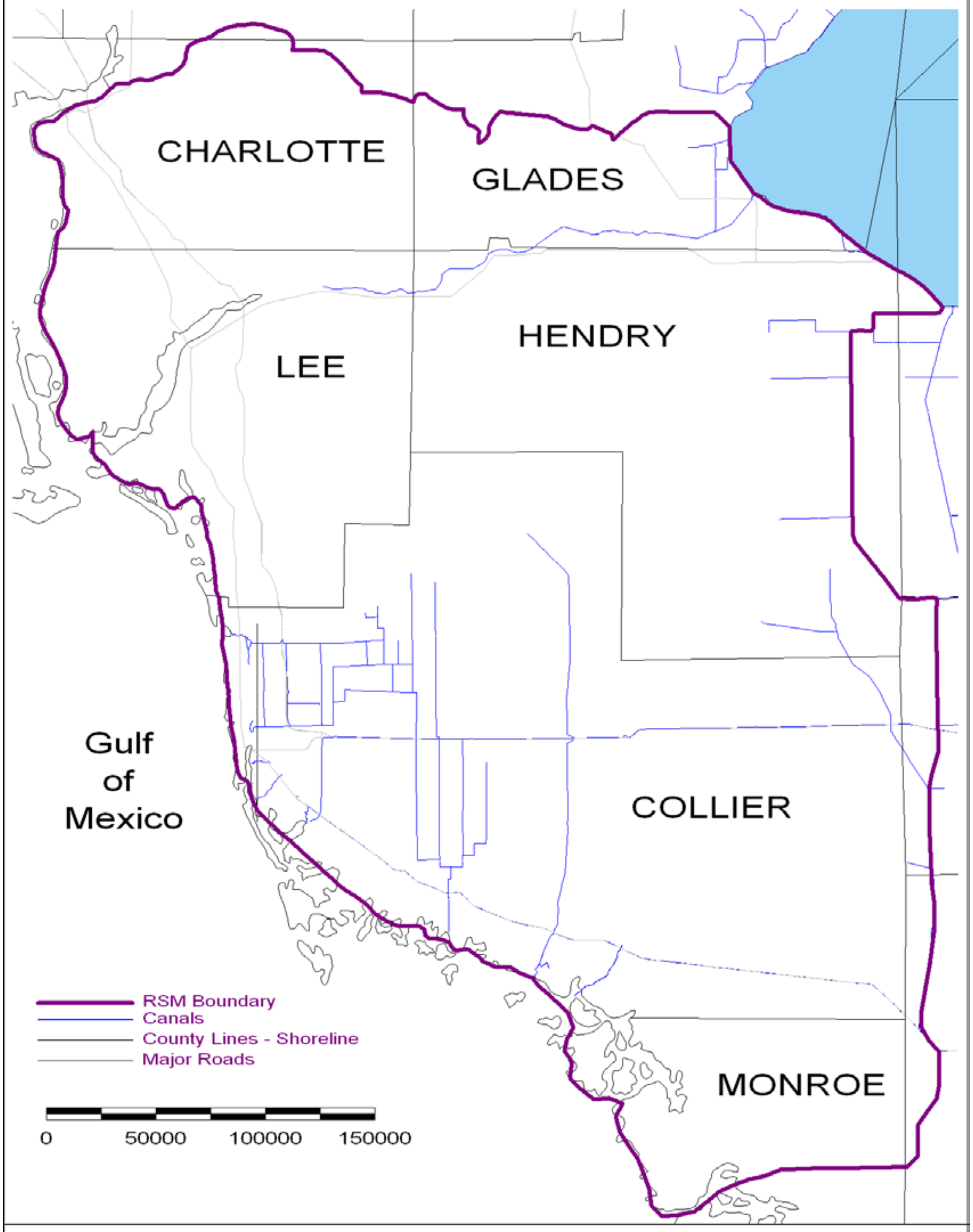


Figure 3. Region Simulation Model (RSM) Study Area

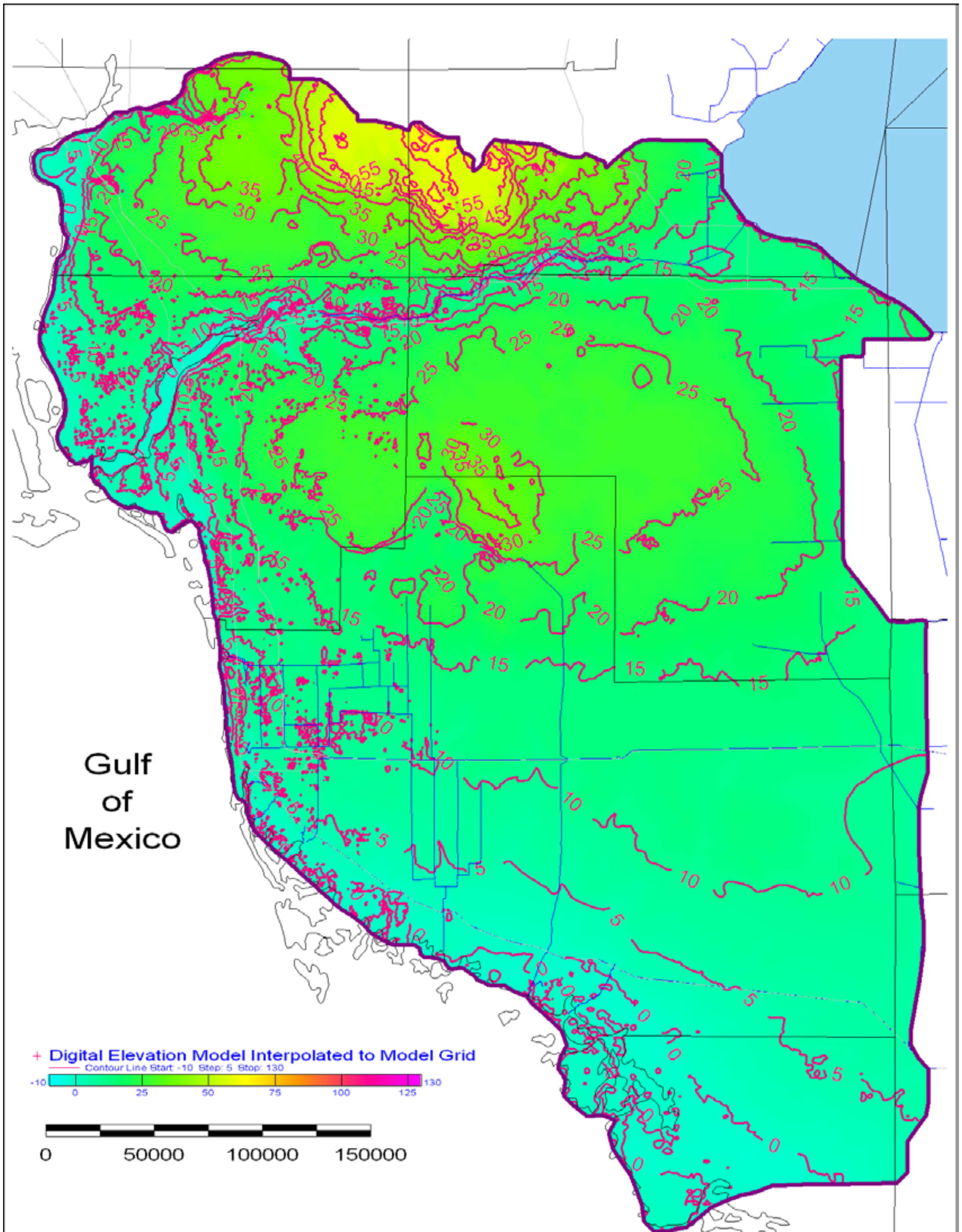


Figure 4. Land Surface Topography

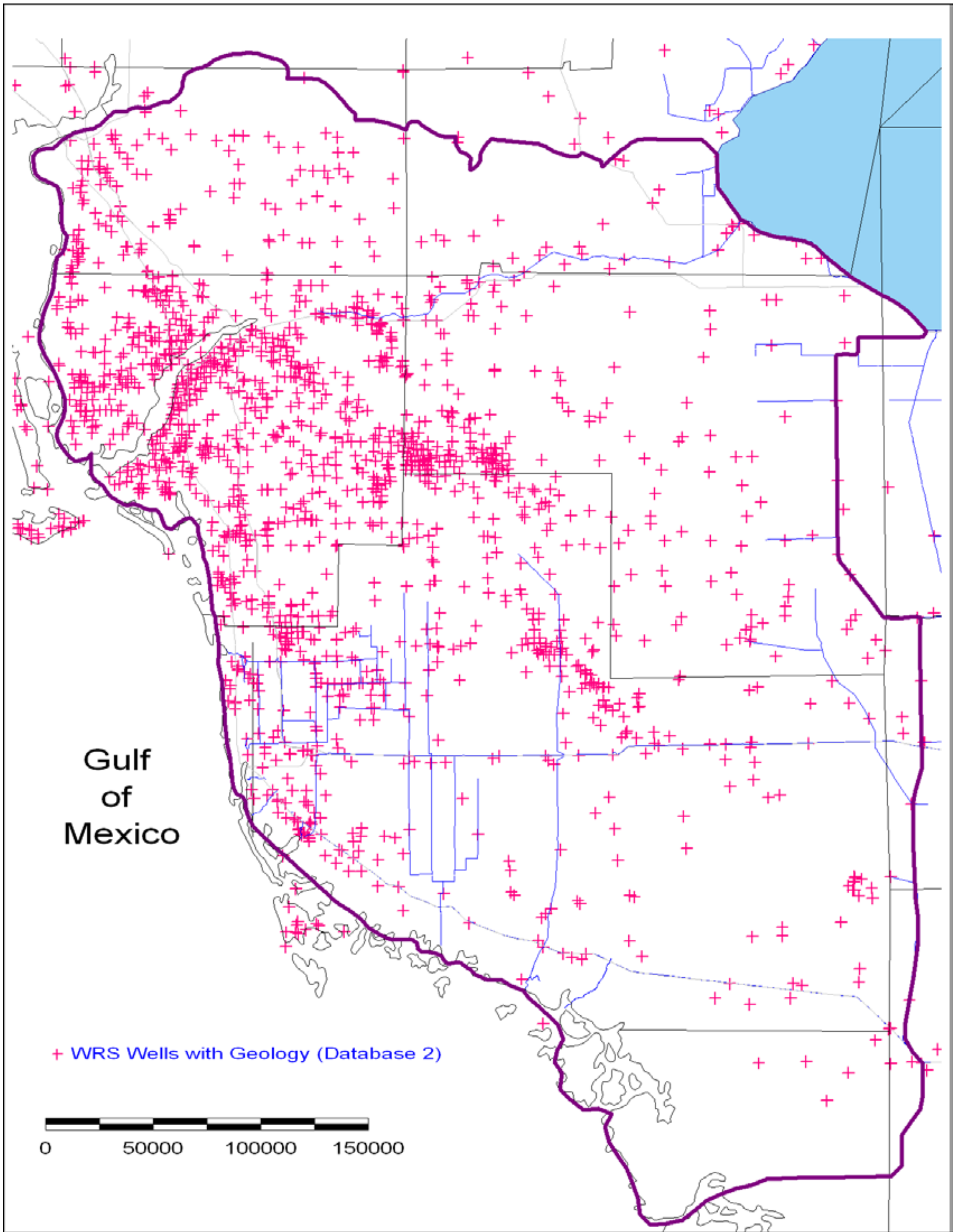


Figure 5. WRS Wells with Stratigraphic Data

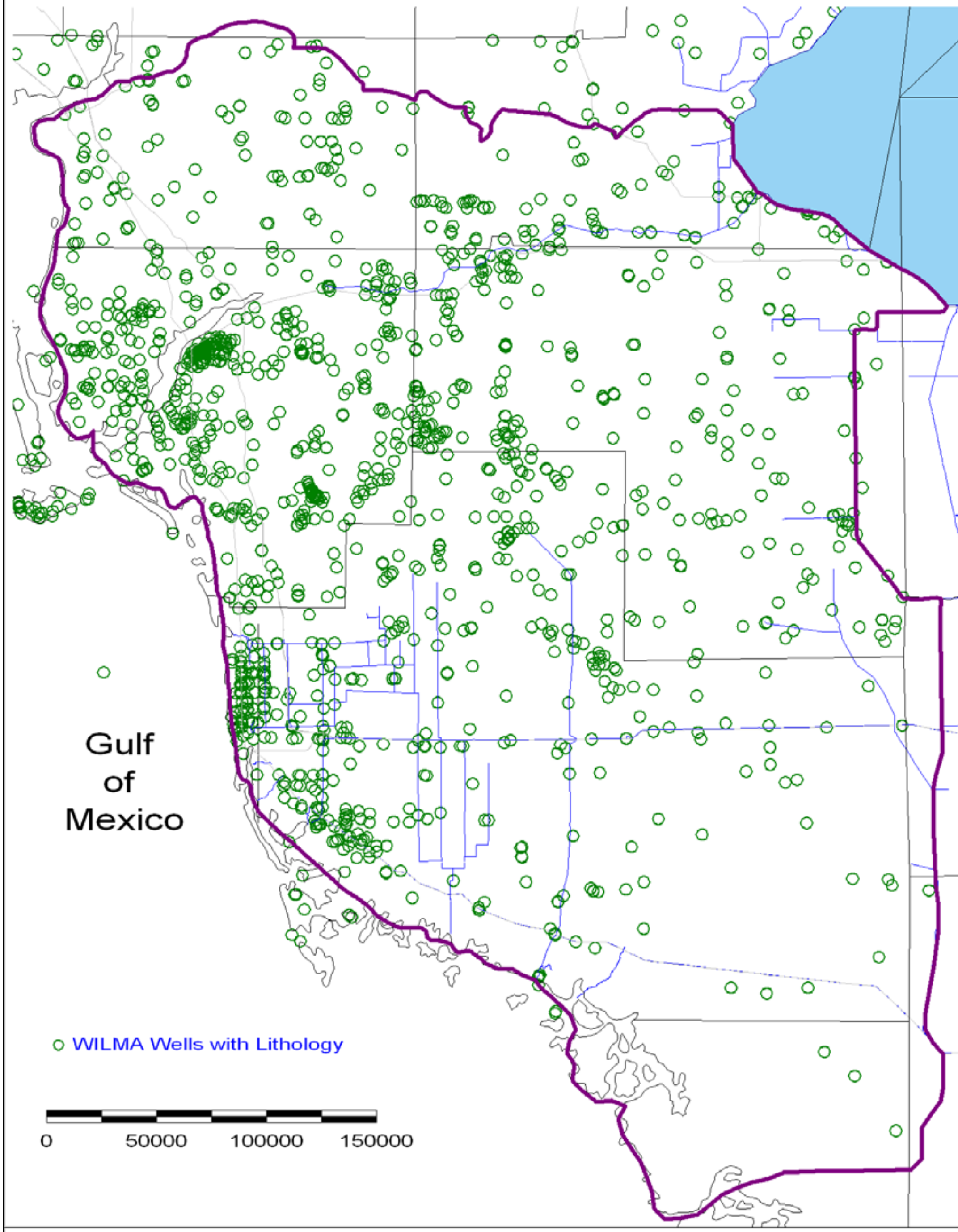


Figure 6. WILMA Wells with Stratigraphic Data

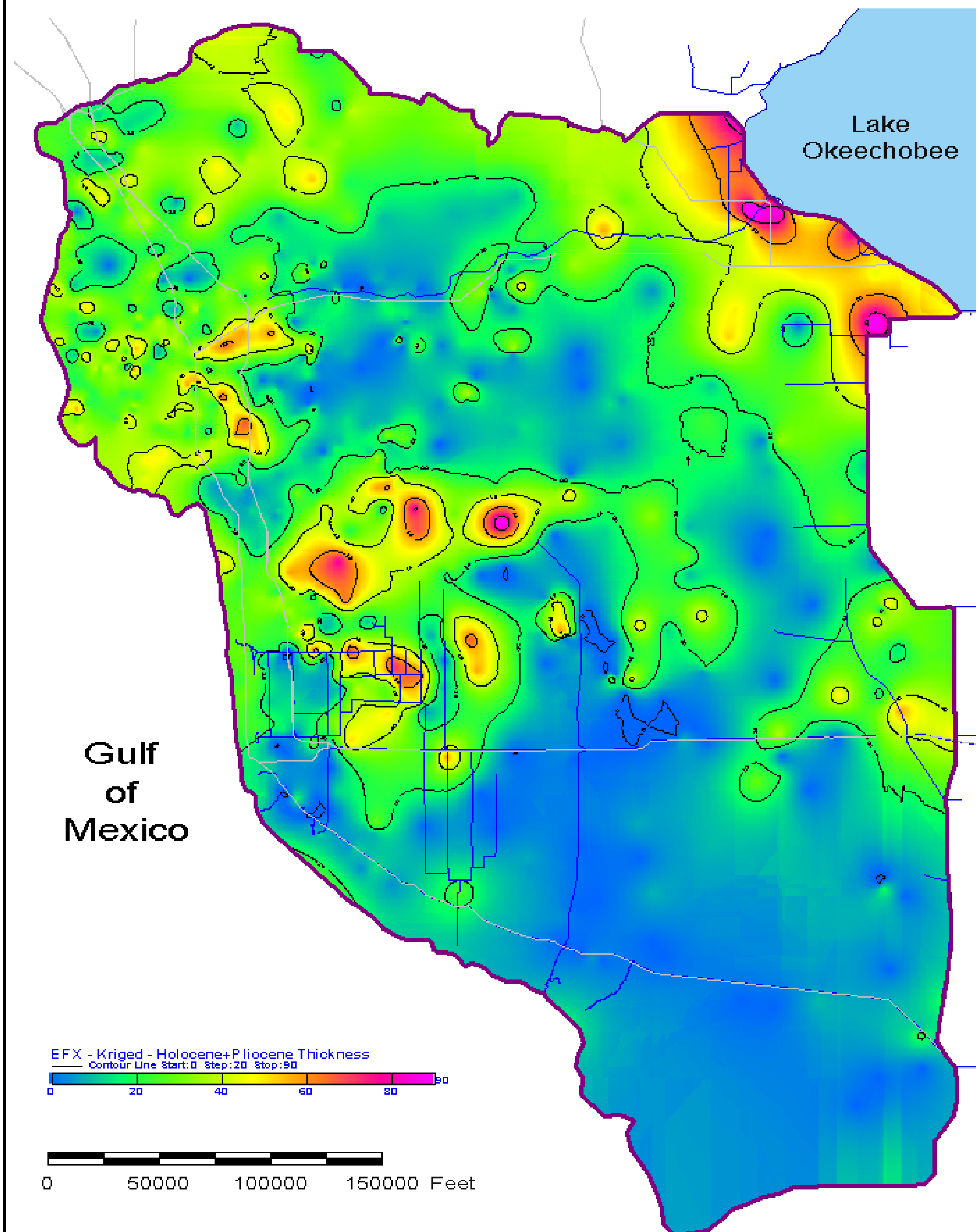


Figure 7. Thickness of the Holocene-Pliocene Units (Aquifer 1)

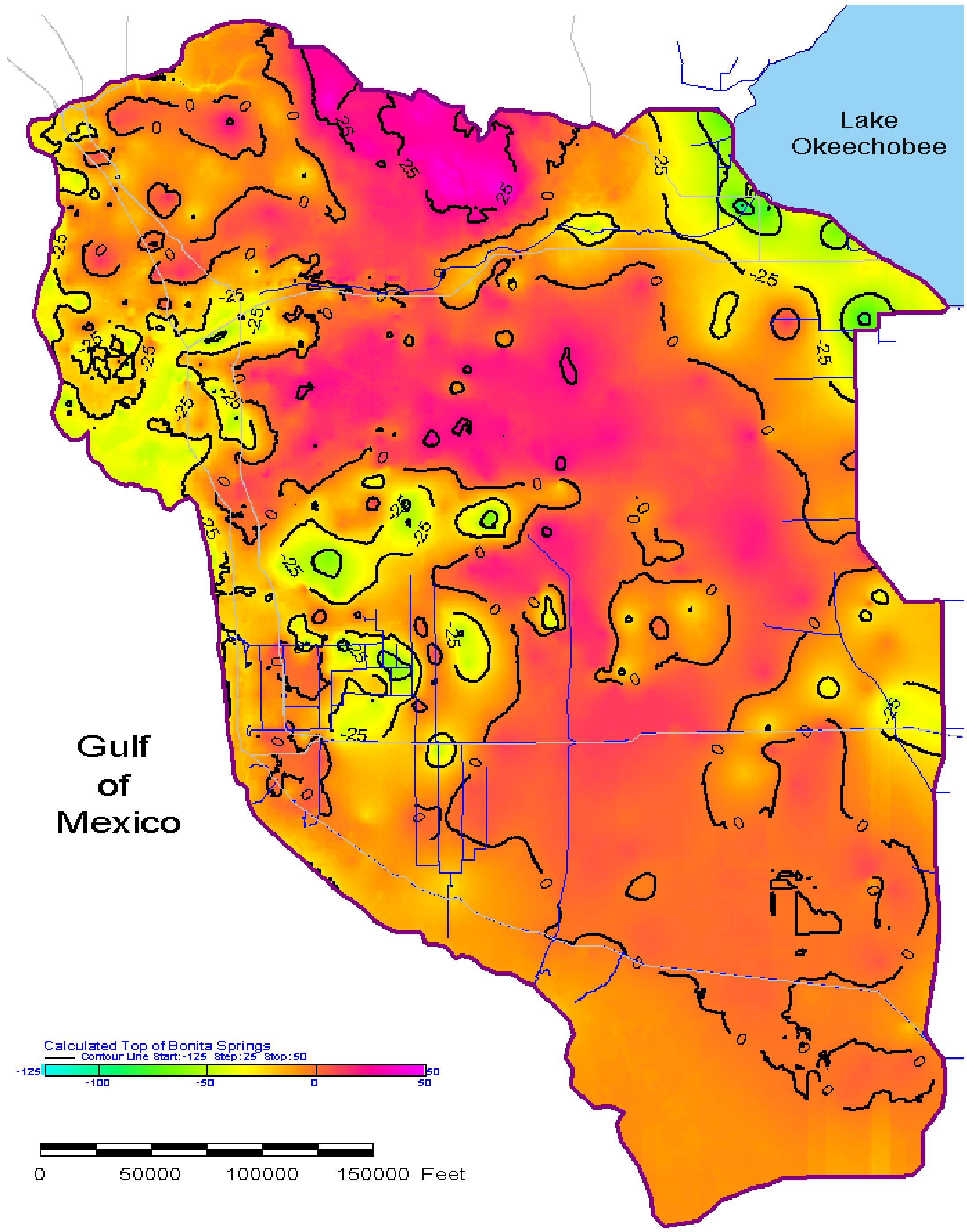


Figure 8. Calculated Top of the Bonita Springs Marl (Aquitard 1)

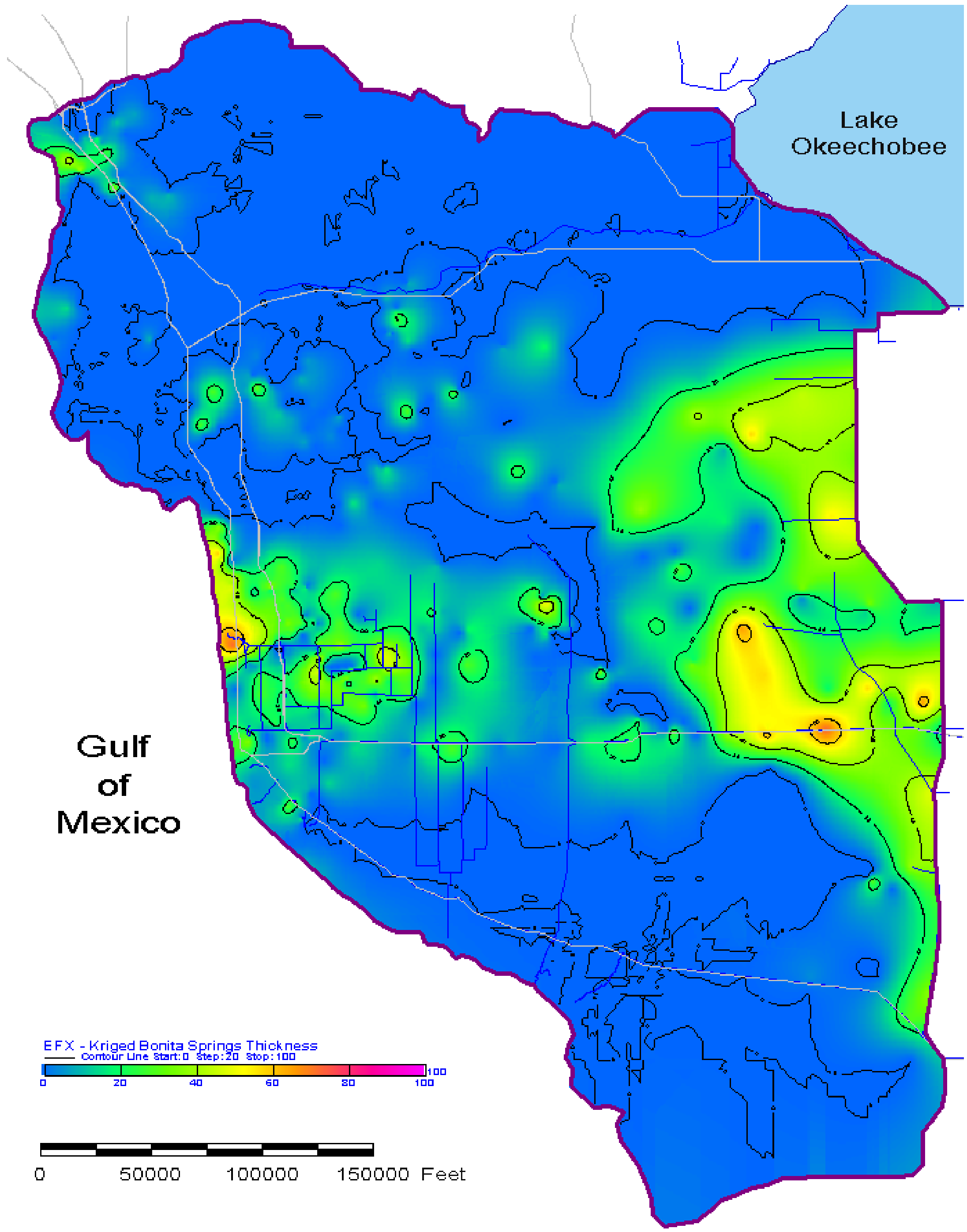


Figure 9. Thickness of the Bonita Springs Marl (Aquitard 1)

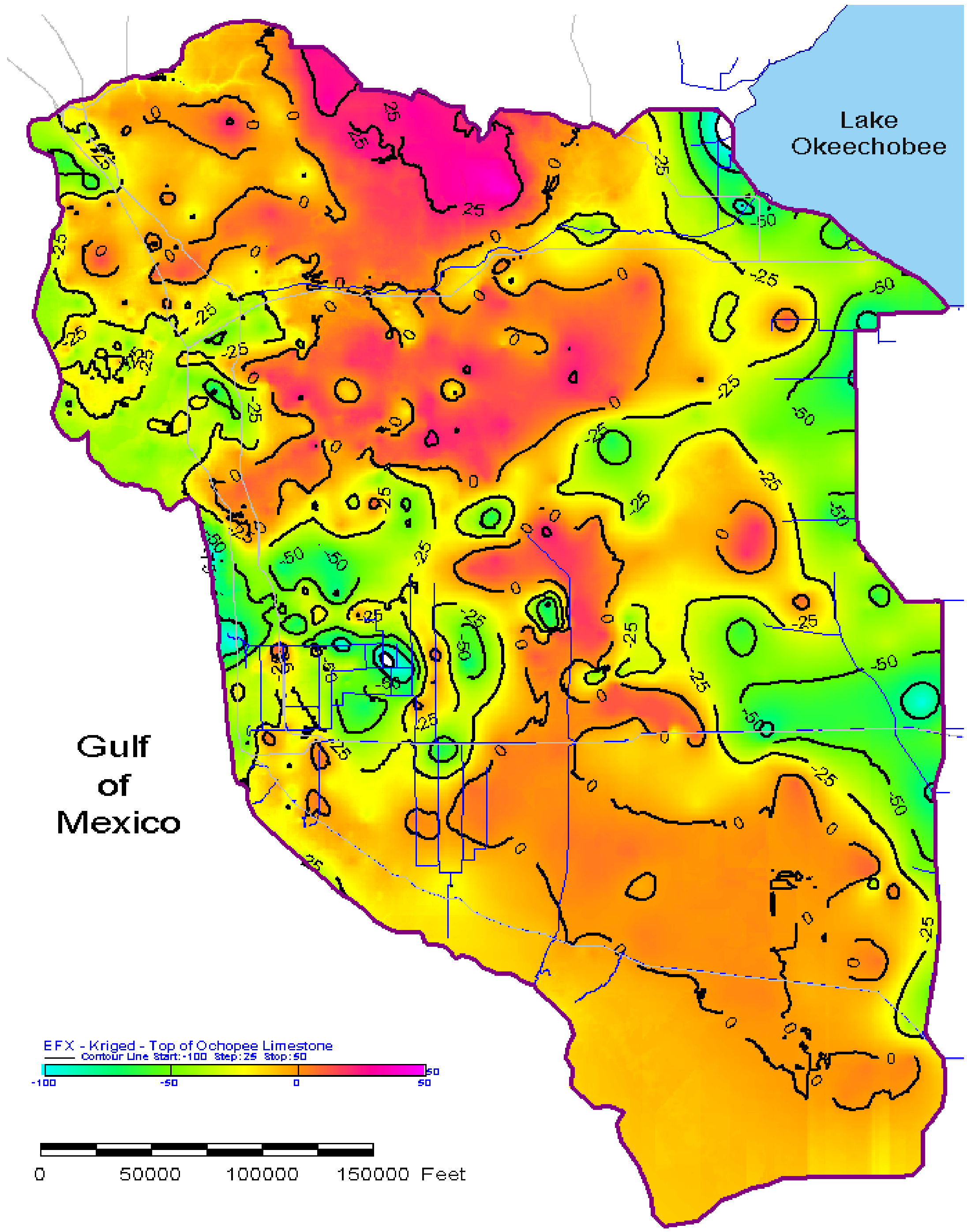


Figure 10. Top of the Ochopee Limestone (Aquifer 2)

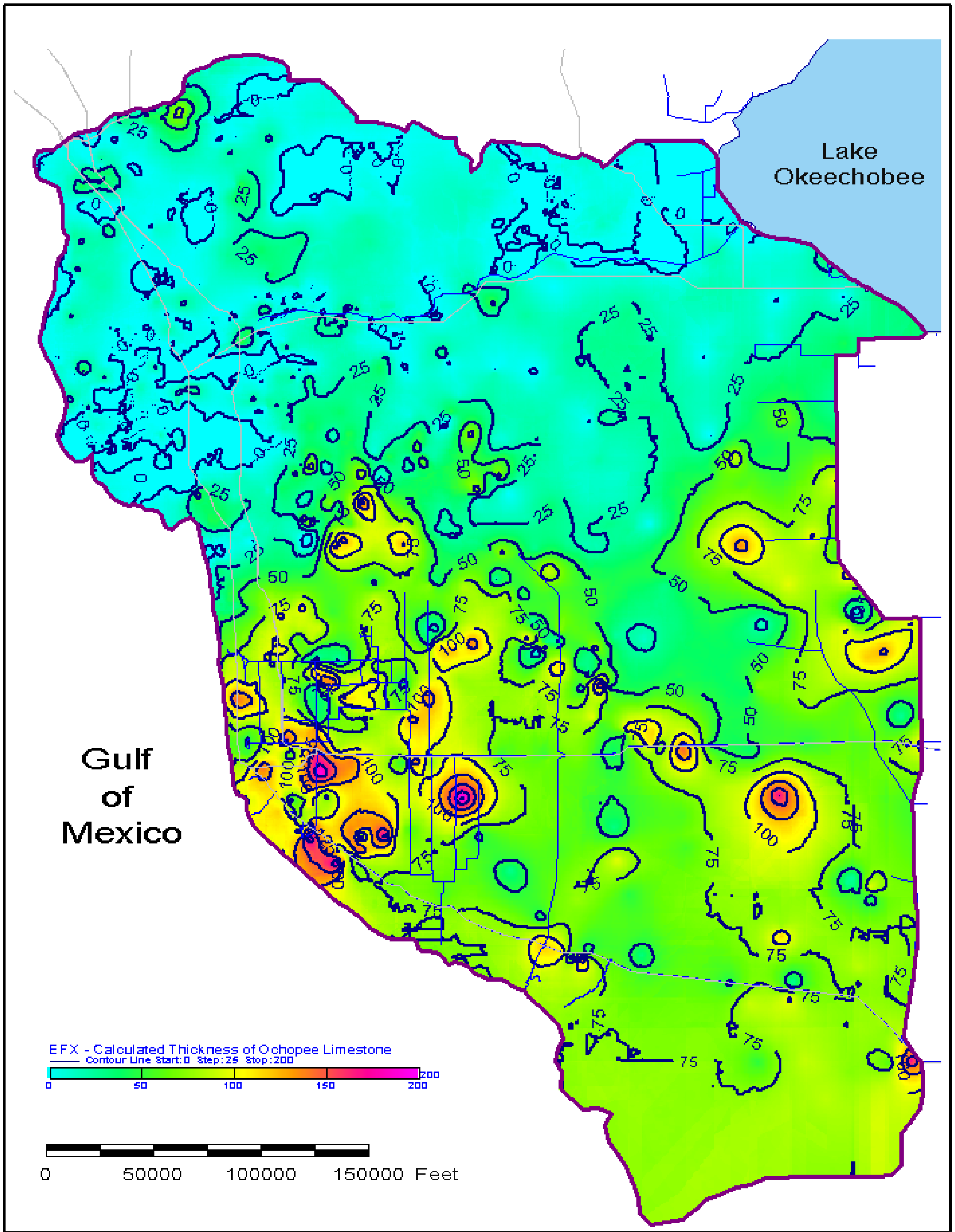


Figure 11. Thickness of the Ochopee Limestone (Aquifer 2)

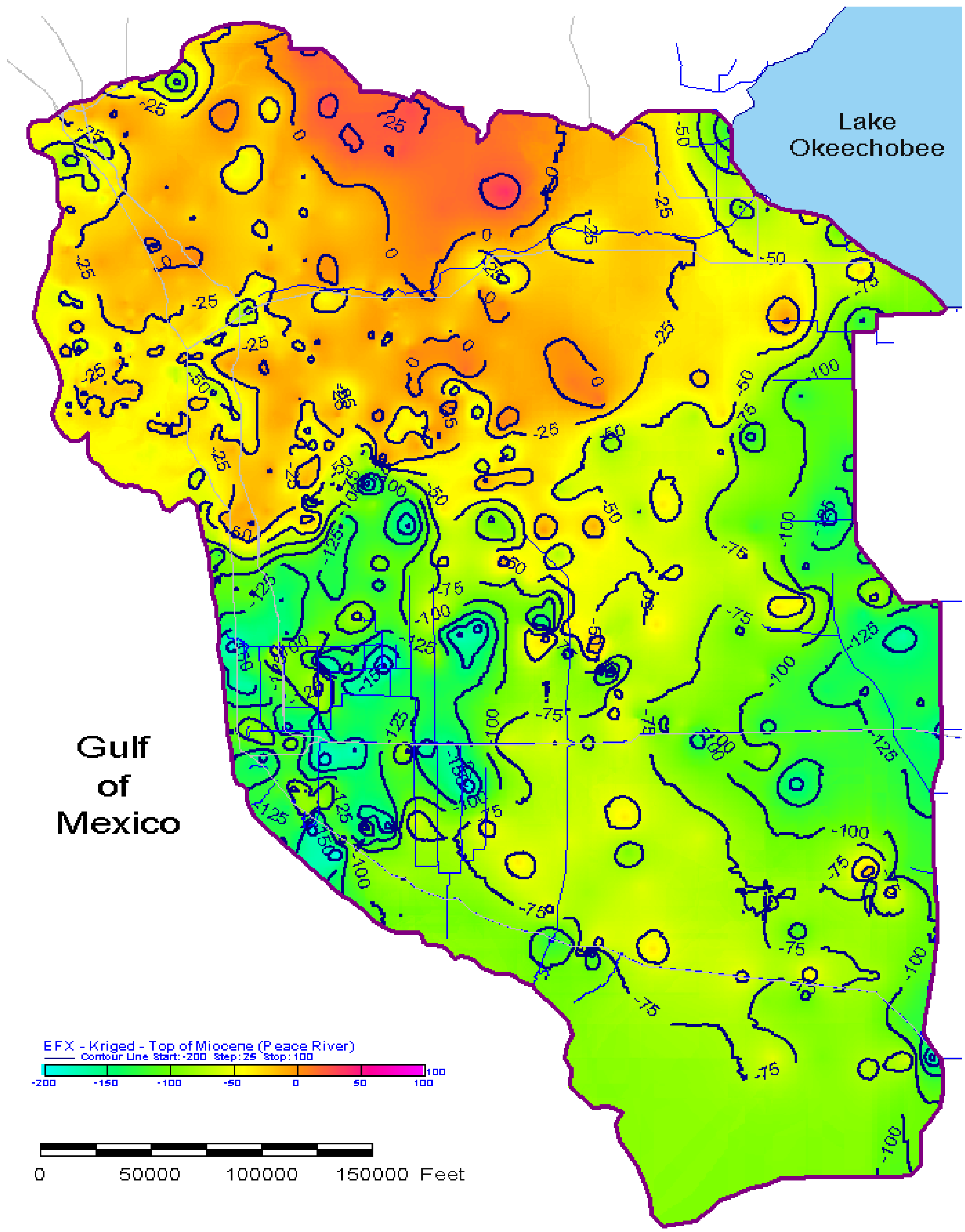


Figure 12. Top of the Peace River Formation (Aquitard 2)

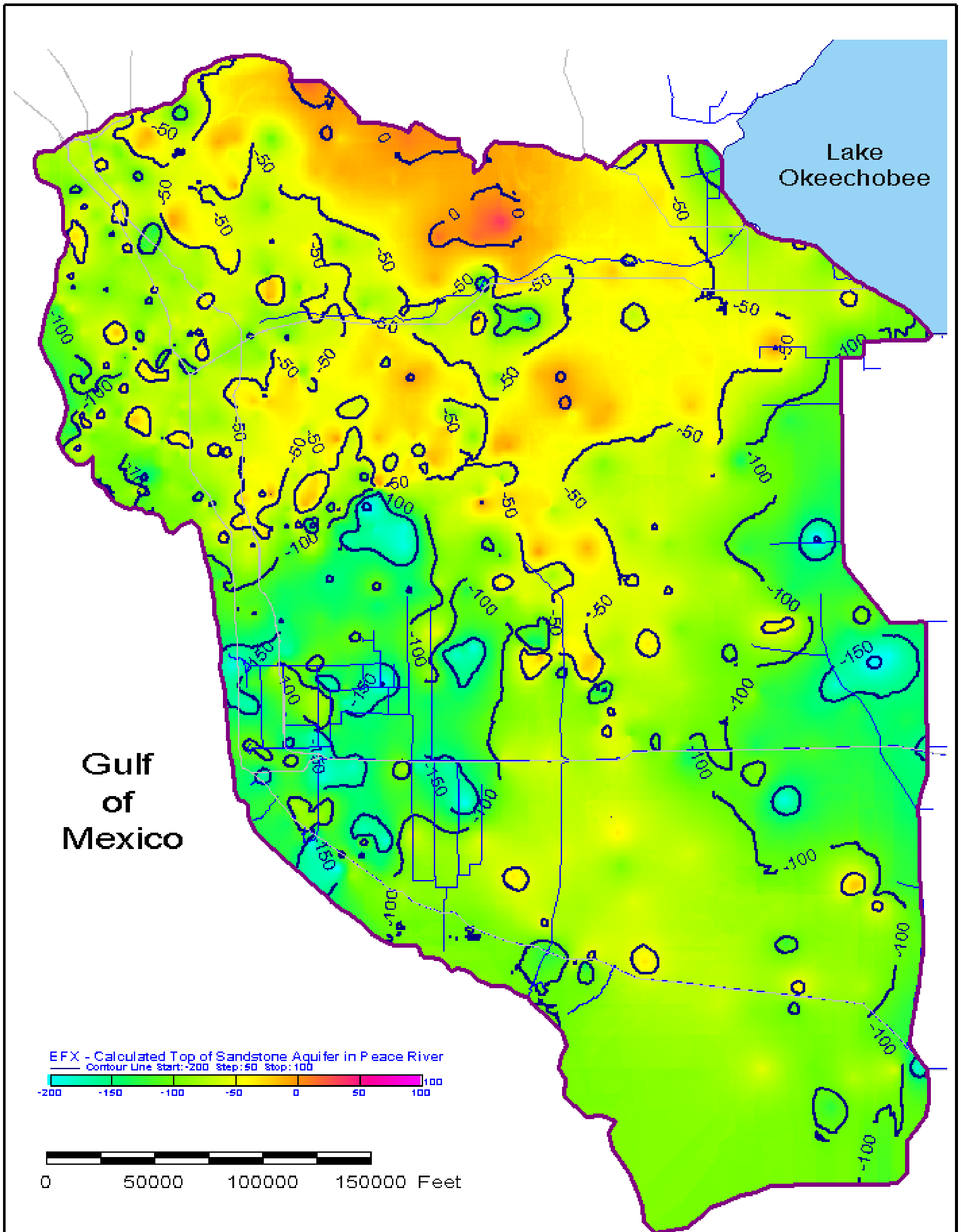


Figure 13. Top of the Sandstone Aquifer (Aquifer 3)

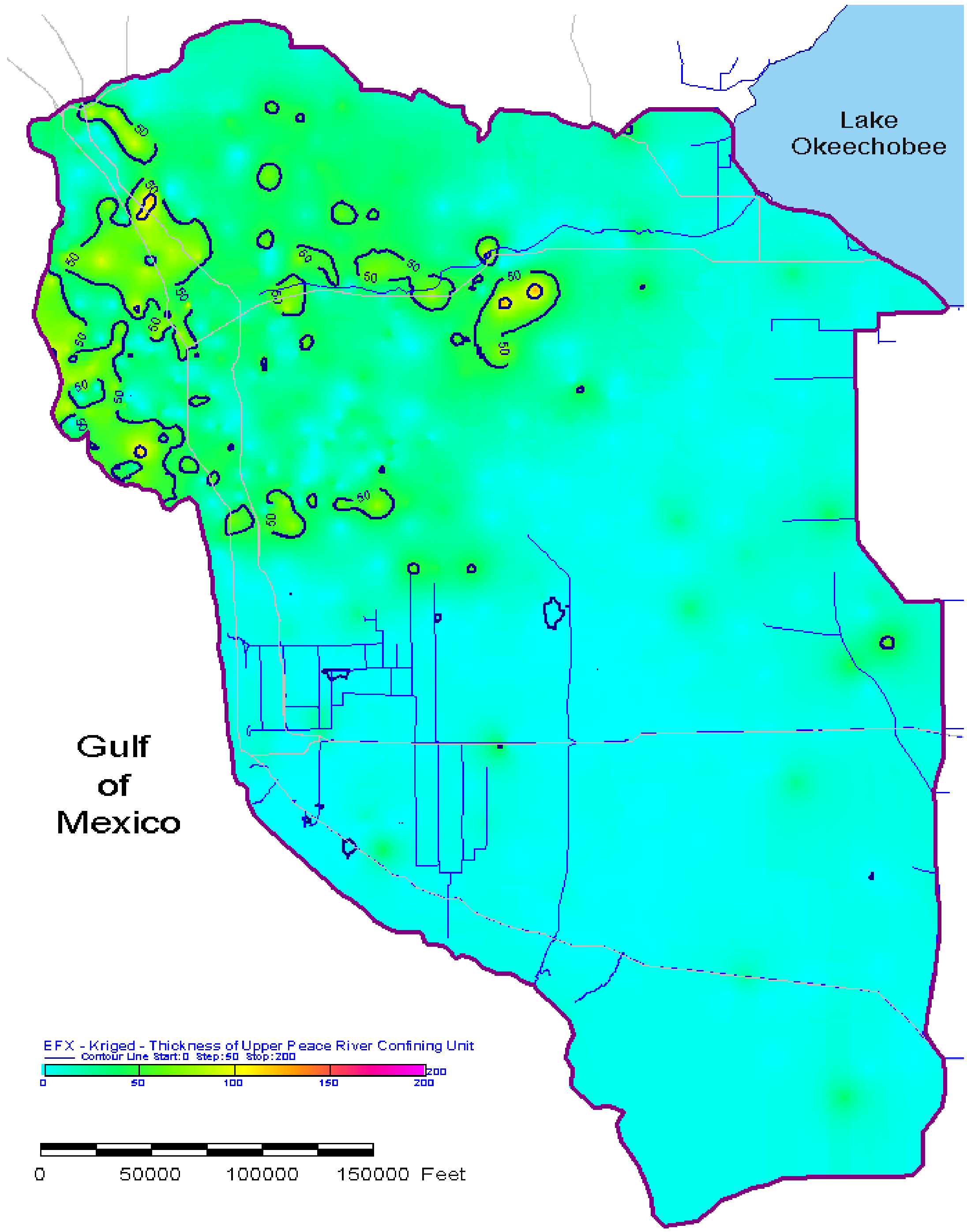


Figure 14. Thickness of Upper Peace River Clay (Aquitard 2)

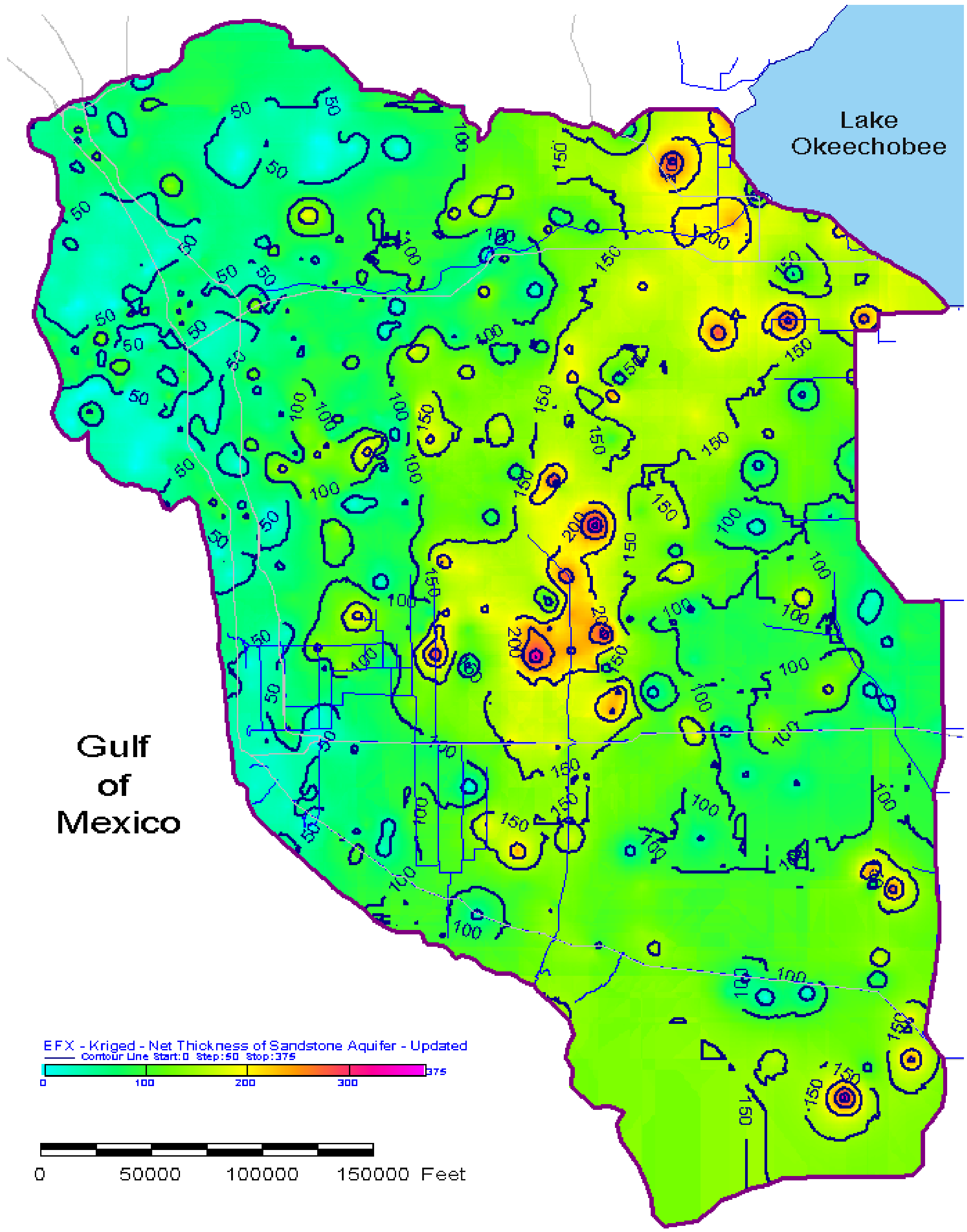


Figure 15. Net Thickness of the Sanstone Aquifer (Aquifer 3)

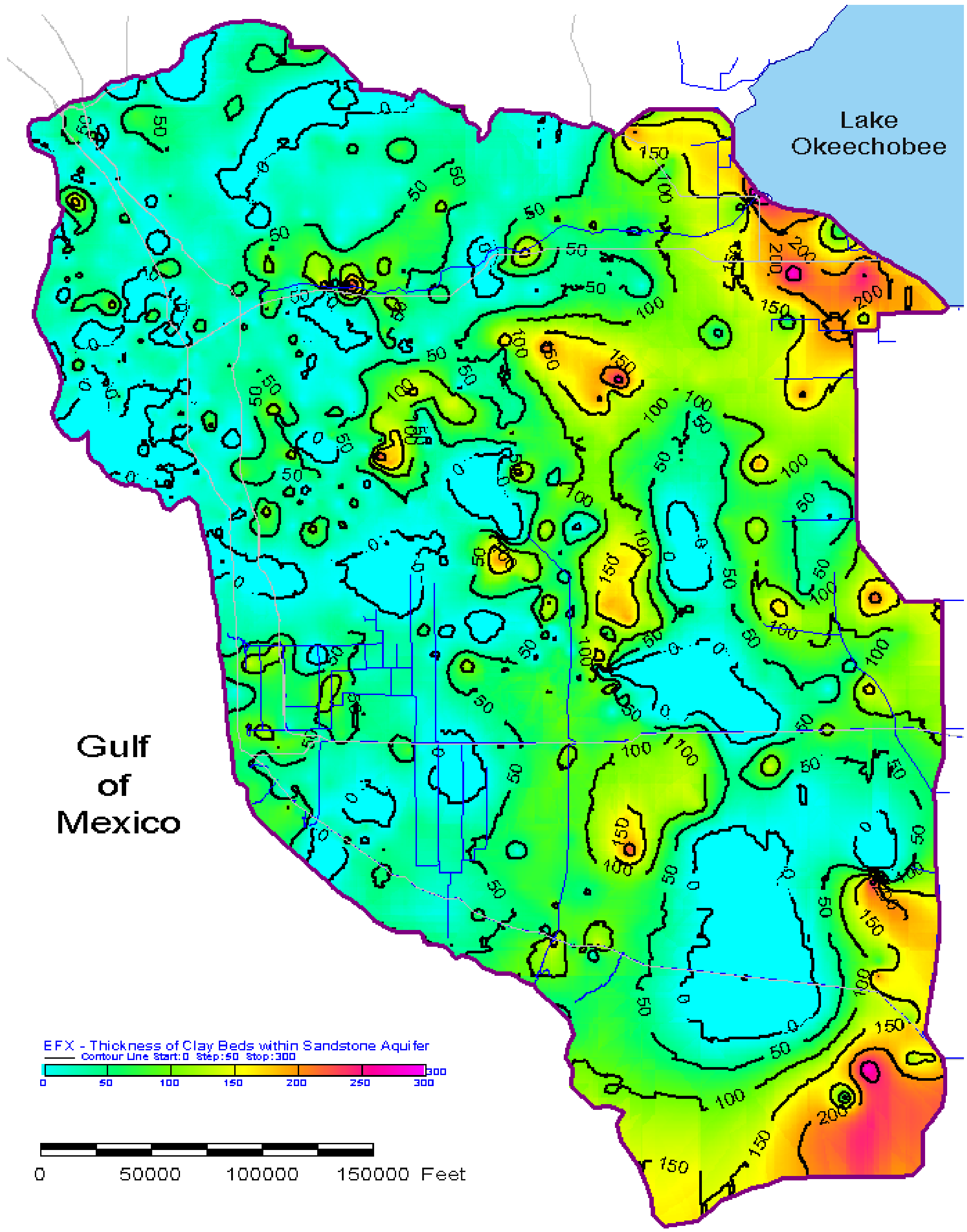


Figure 16. Calculated Thickness of Clay within Sandstone Aquifer

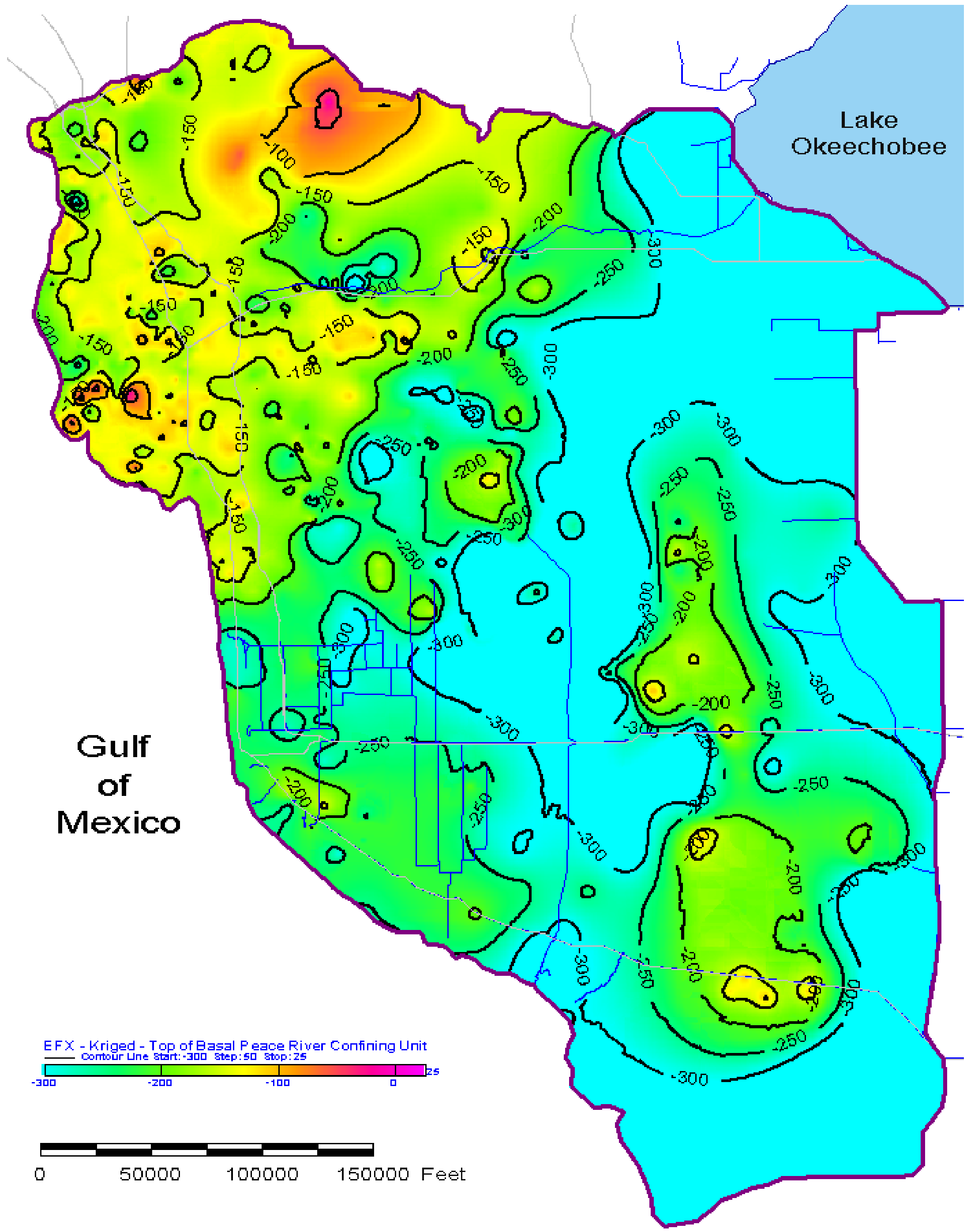


Figure 17. Top of the Basal Peace River Clay (Aquitard 3)

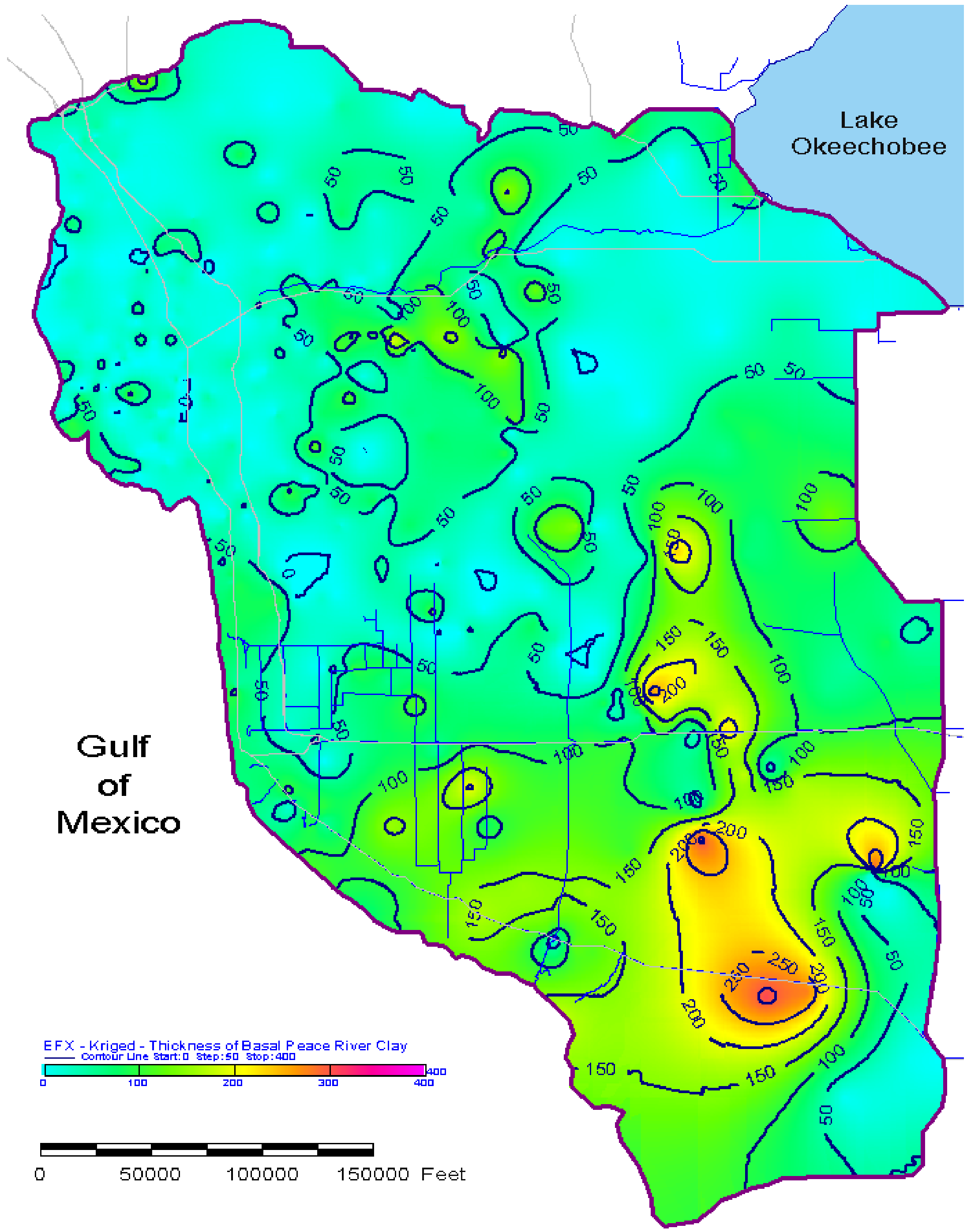


Figure 18. Kriged Thickness of the Basal Peace River Clay

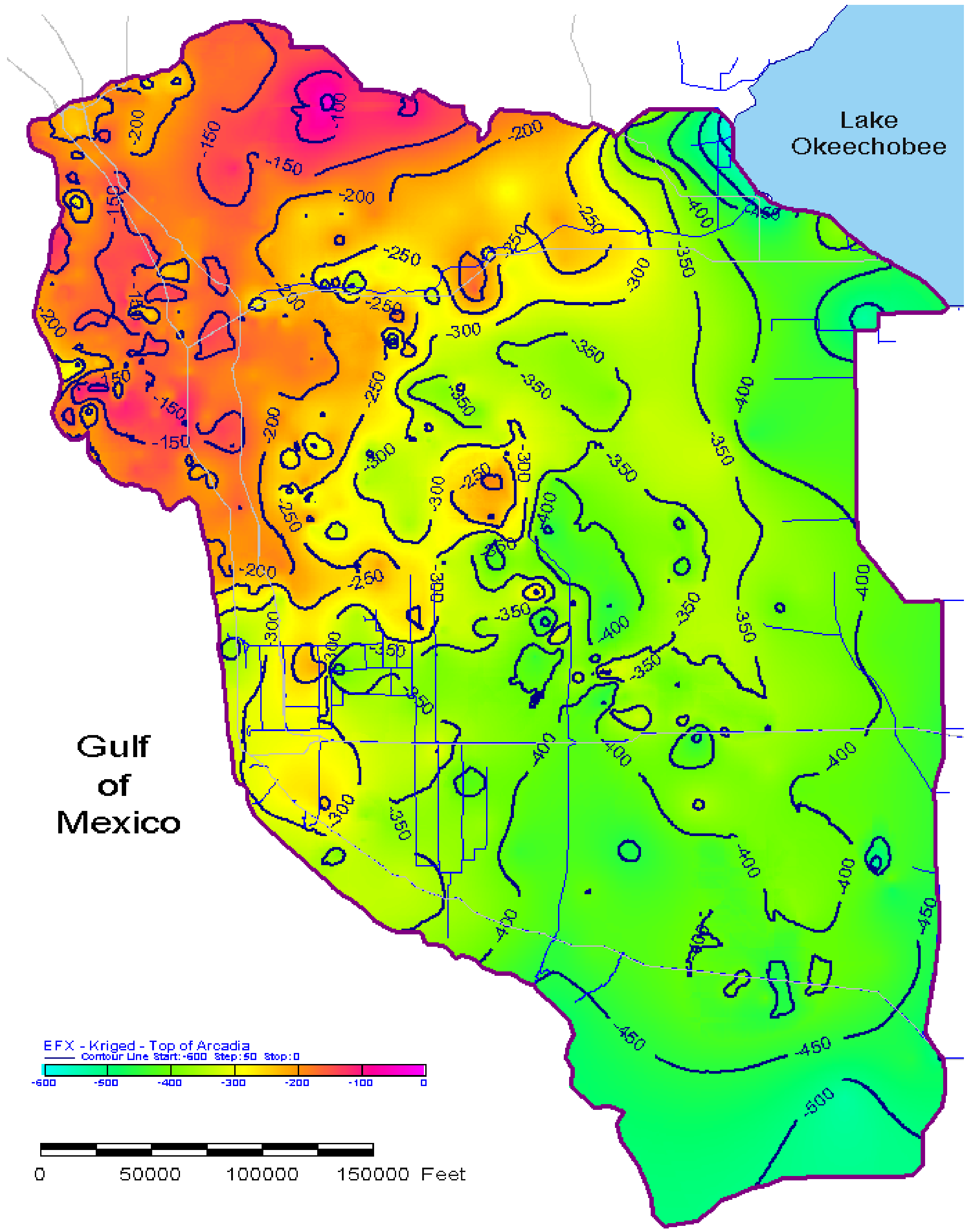


Figure 19. Top of the Arcadia Formation

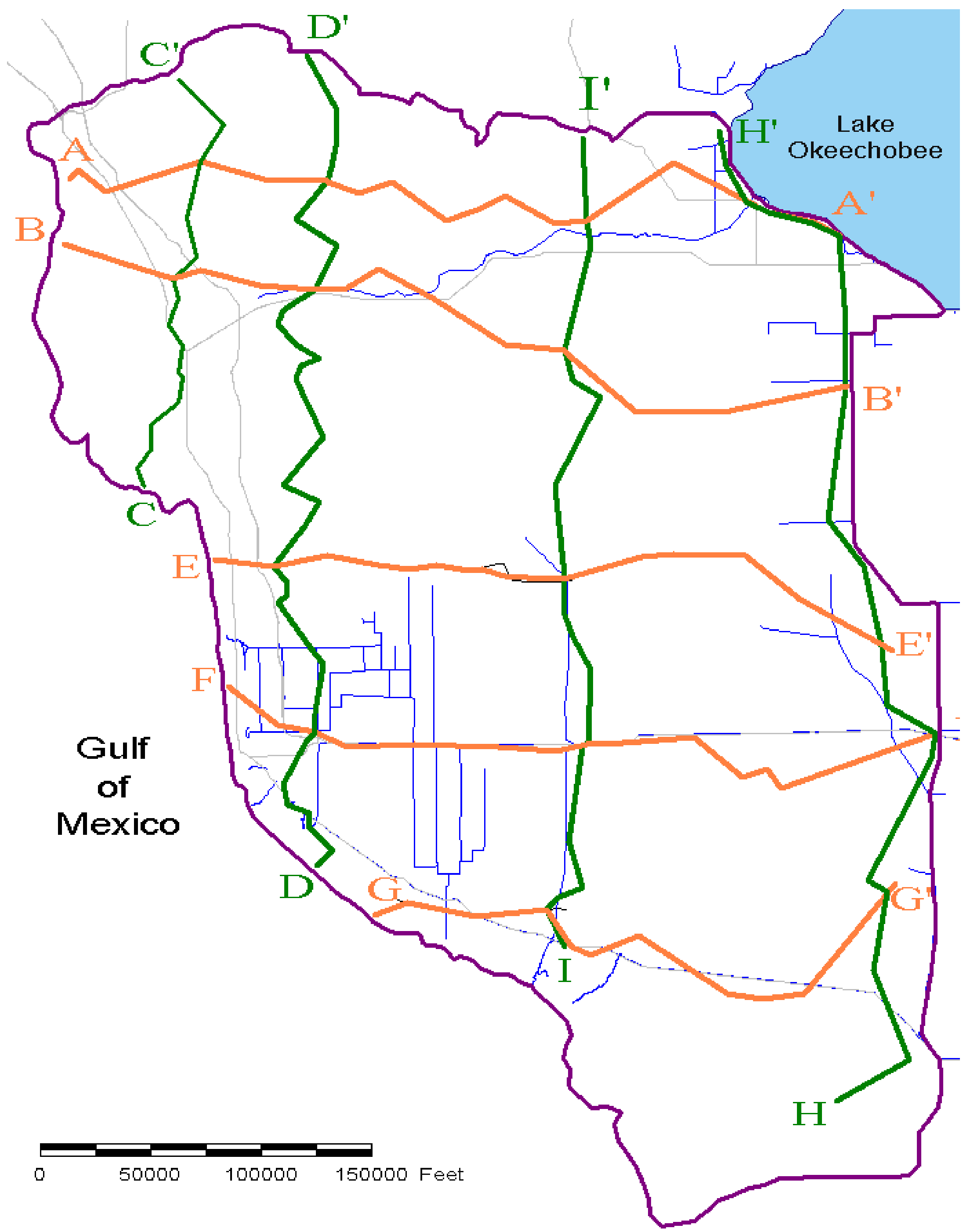


Figure 20. Location of WRS Section Lines

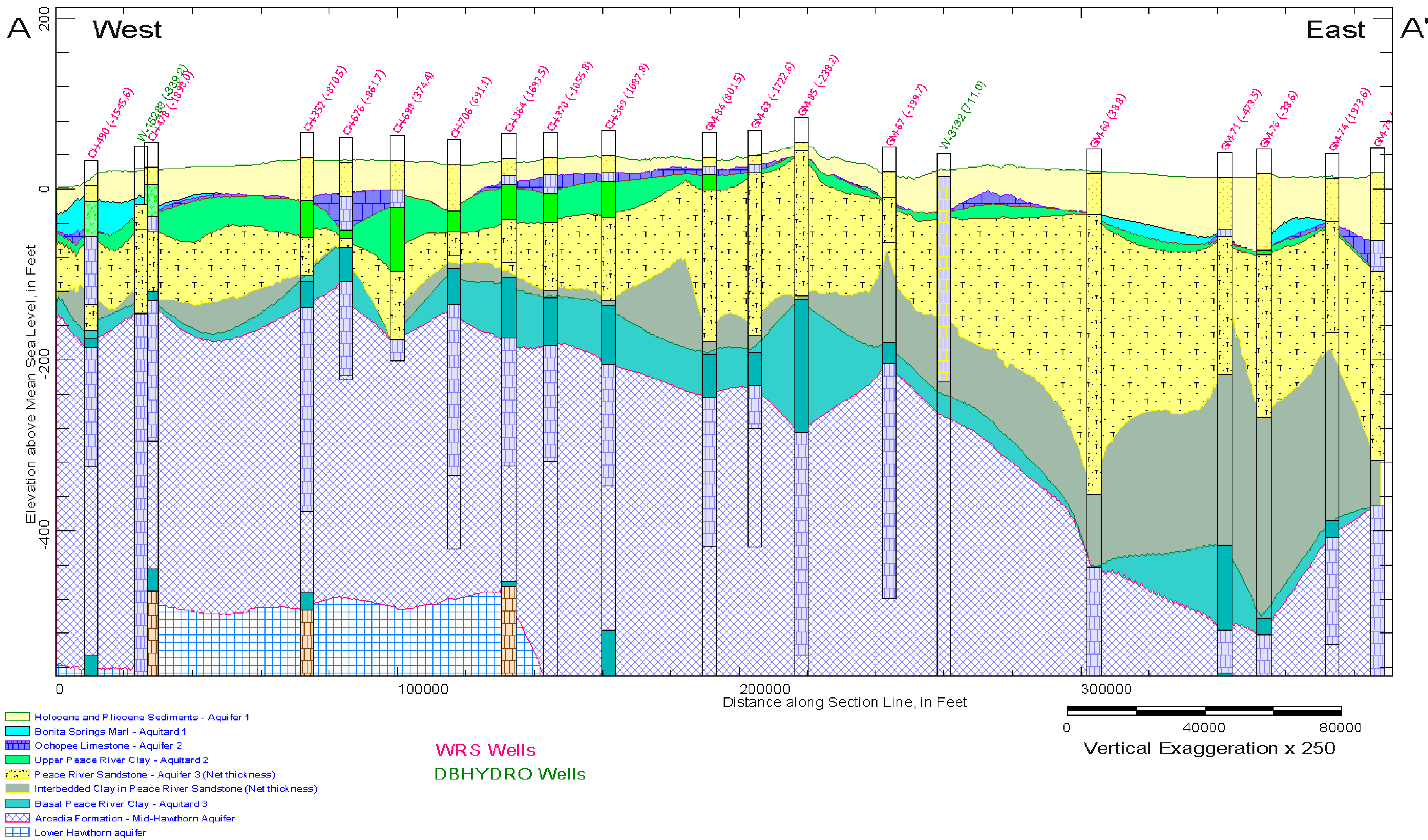


FIGURE 21: North-South Section A-A'

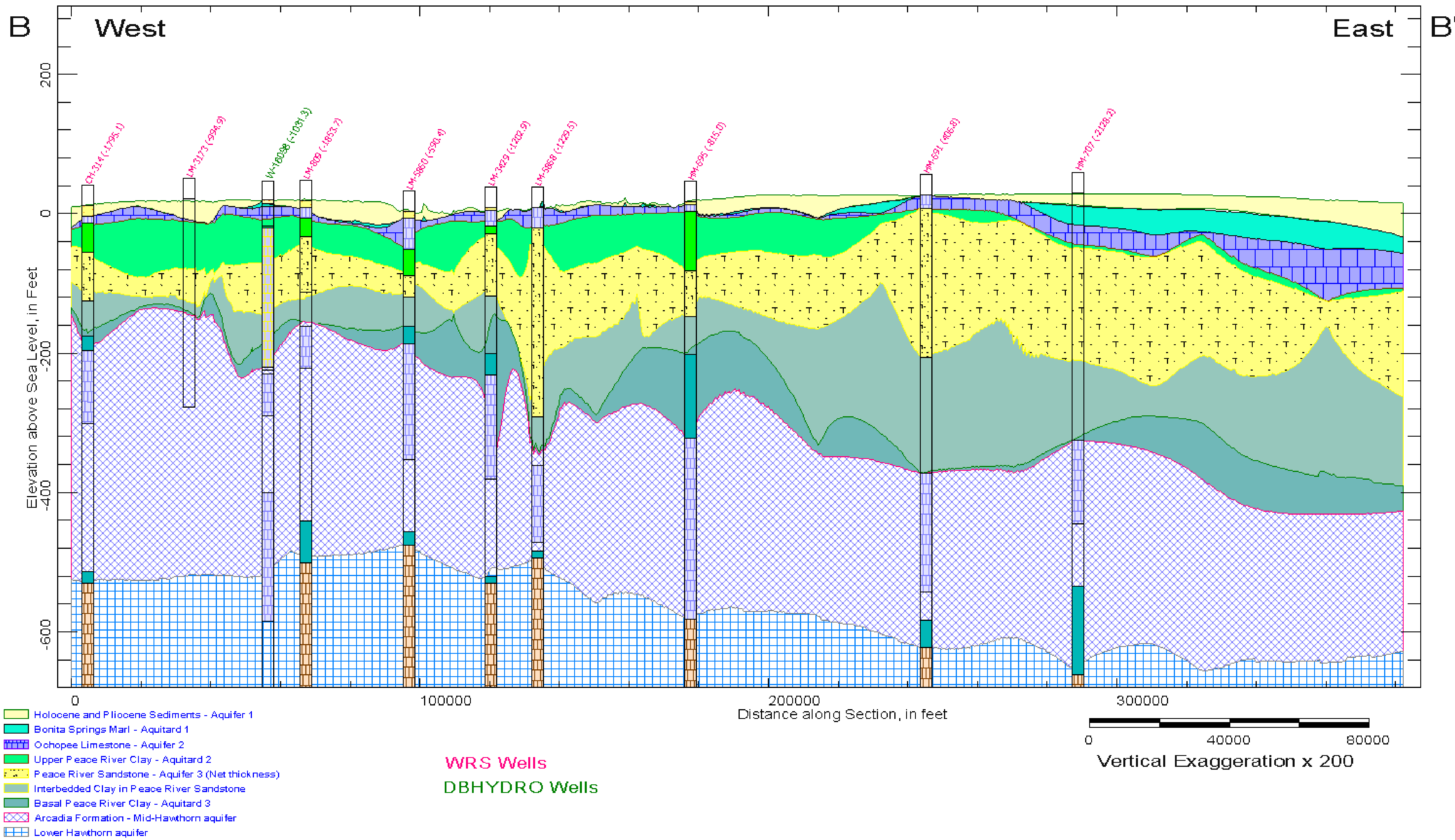


Figure 22: East-West Cross Section B-B'

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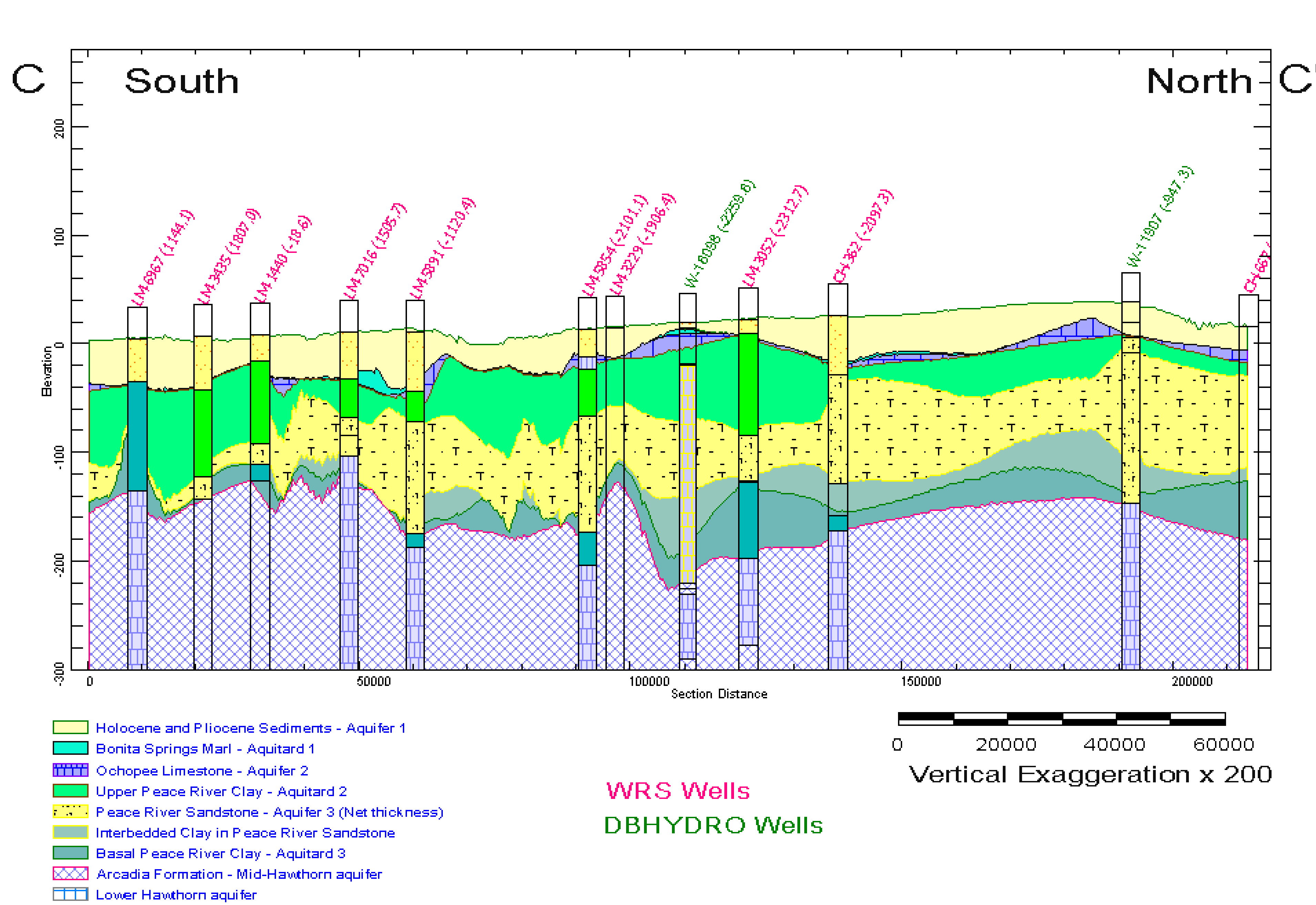

Figure 23: North-South Section C-C'

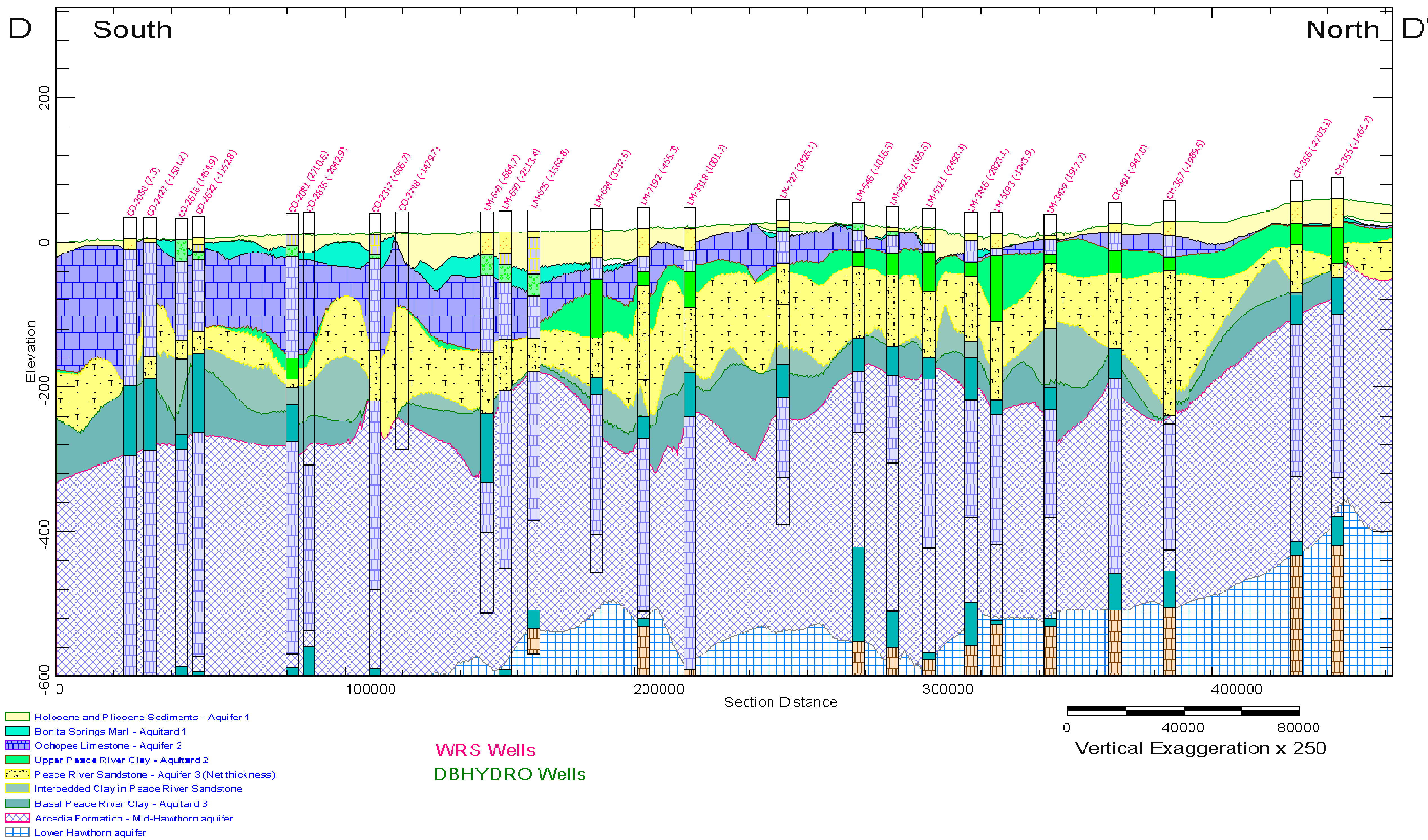

Figure 24: North-South Section D-D'

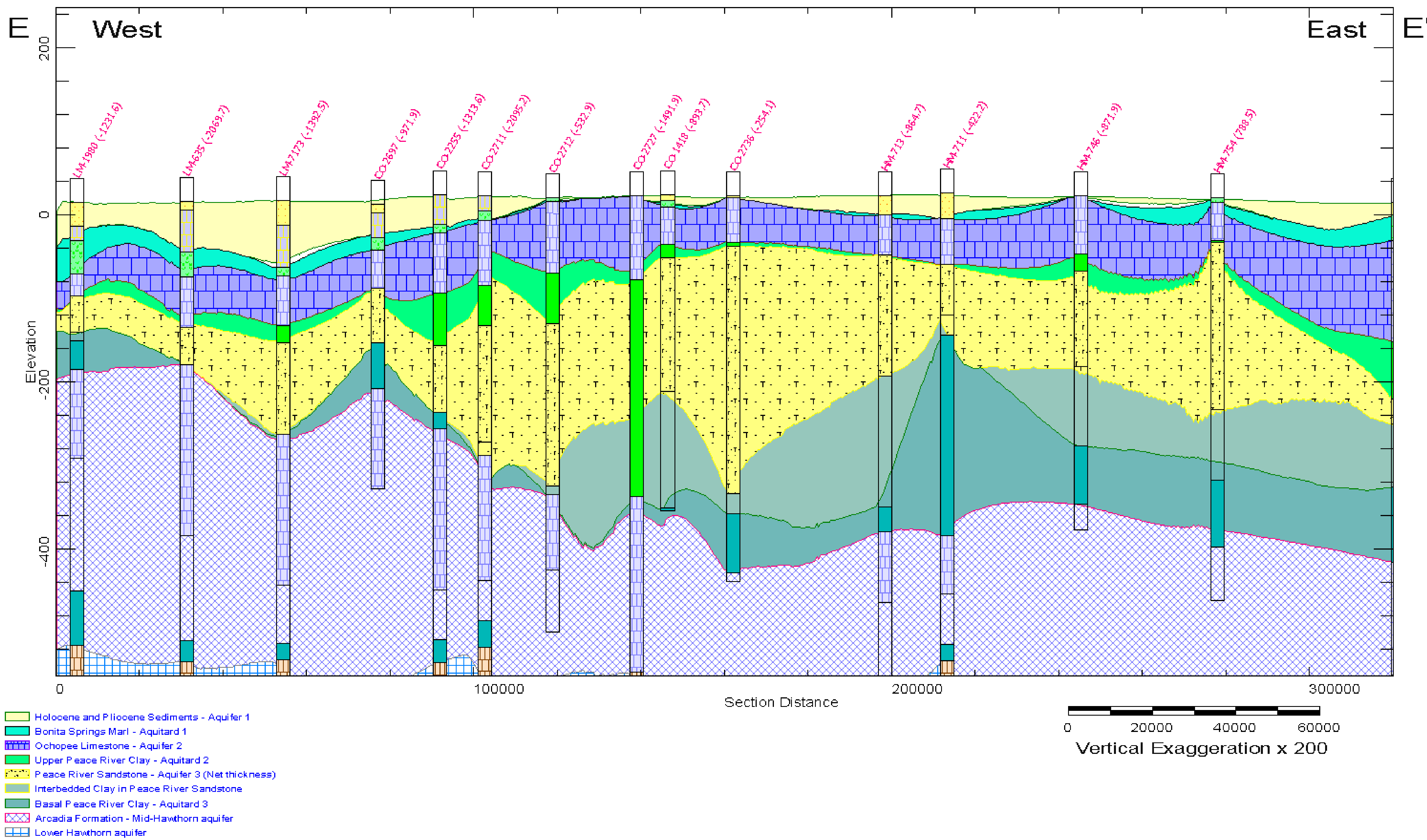

Figure 25: East-West Section E-E'

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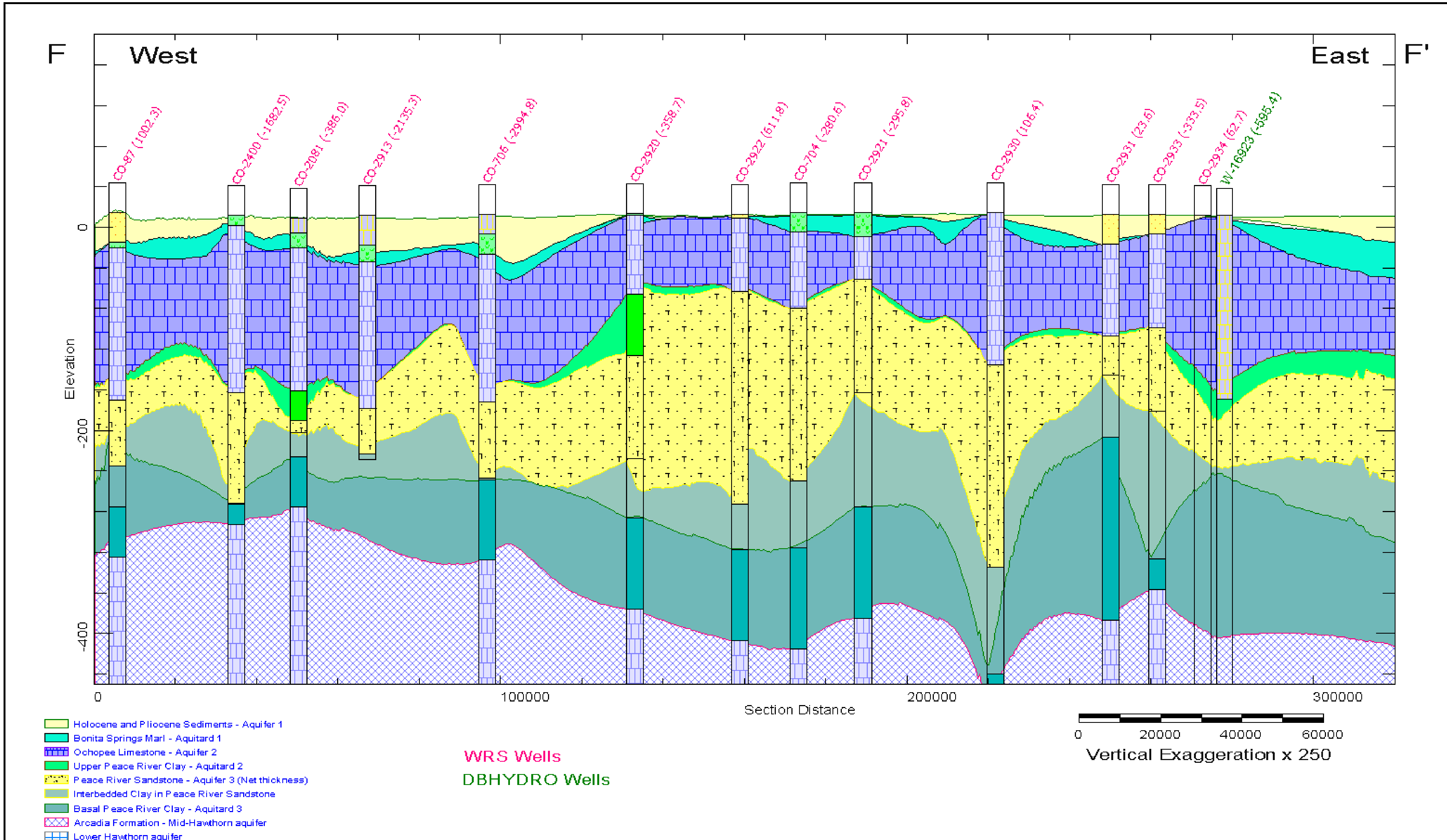

Figure 26: East-West Secion F-F'

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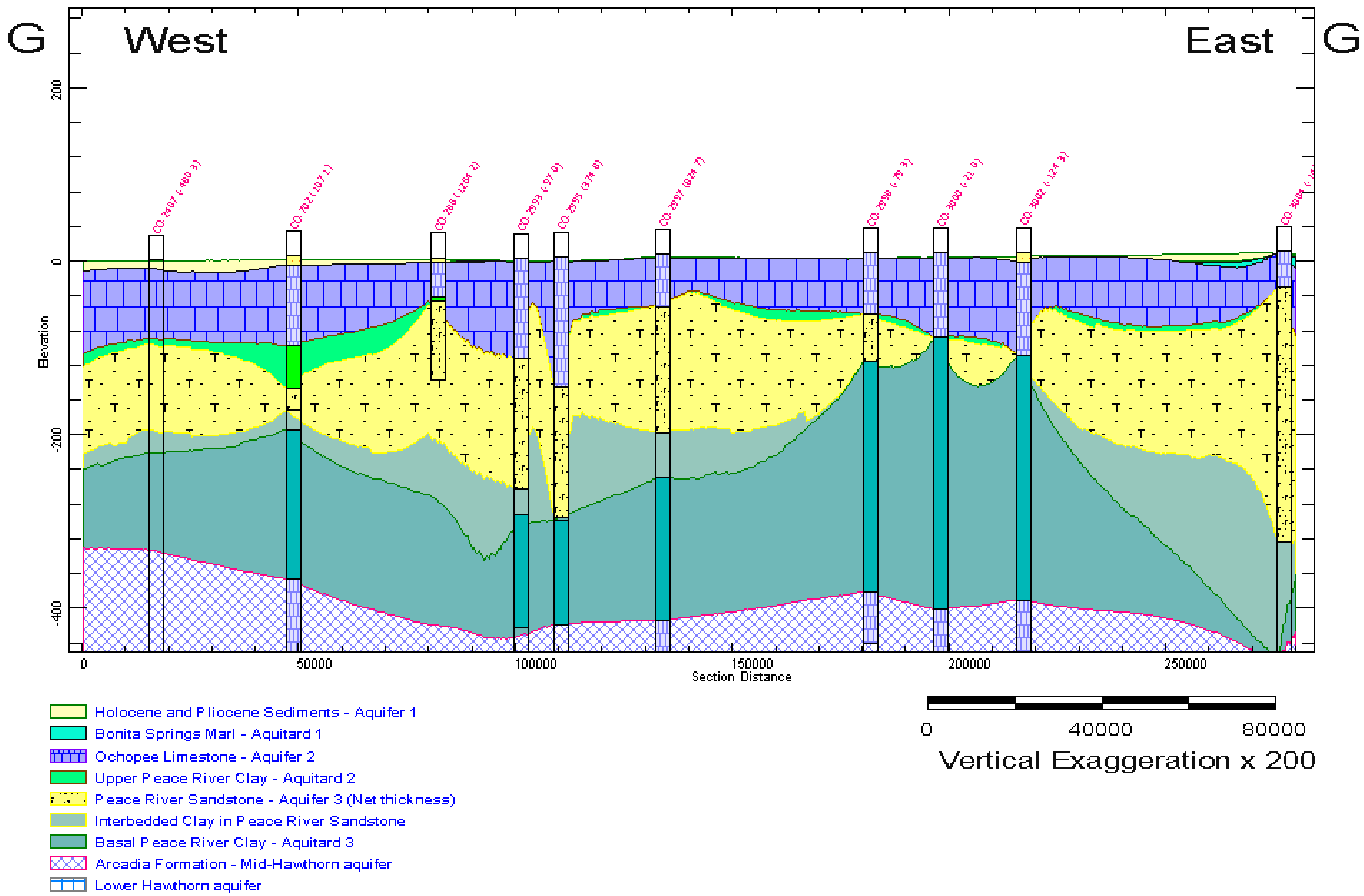

Figure 27: East-West Section G-G'

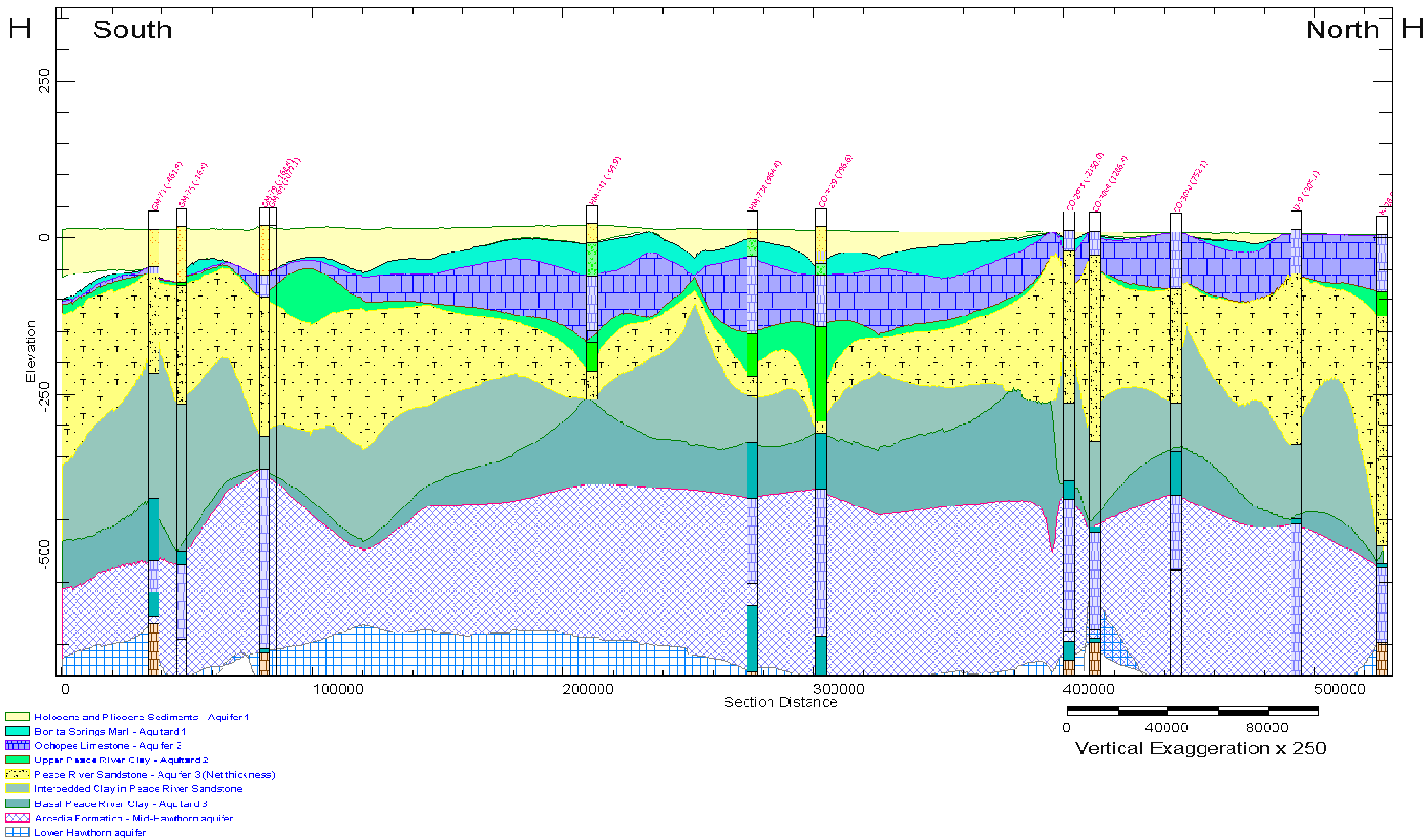

Figure 28: North-South Section H-H'

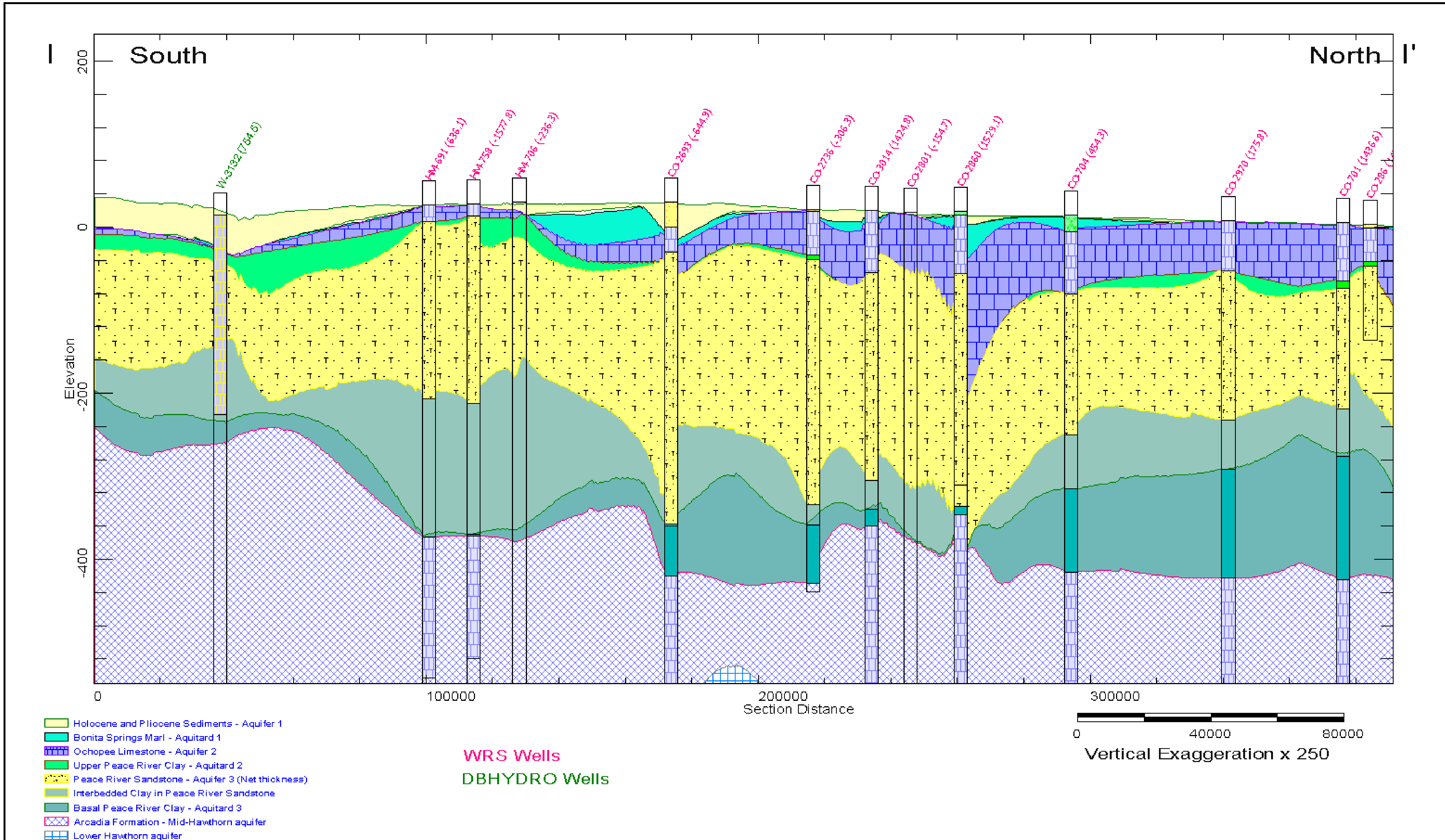

Figure 29: North-South Section I-I'