Changes in the Water Table: A Case Study of Elkhorn, Wisconsin

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Abstract

Southeastern Wisconsin is an area being affected by high capacity well pumps. Although several studies have been conducted in the surrounding area, none of the studies cover the area near Elkhorn, Wisconsin. Elkhorn has a growing population and development plans in place through 2030. This project was developed to examine known well water elevations surrounding Elkhorn and provide insight to changes in the water table. Well logs were used to establish water elevation points. Various descriptive statistics were used to interpret the data. A single factor, multi-sample analysis of variance and the Kruskal-Wallis tests were utilized to evaluate the data set. Using the universal kriging method, grids were created to predict the water table near Elkhorn between 1989 and 2008.

Introduction

The city of Elkhorn is located in Walworth County in the southeastern corner of Wisconsin. There have been discussions in the surrounding area for the past decade concerning the water table. While looking for information in the region, a shortage of data analysis around Elkhorn was discovered. This study compares static water levels found in wells surrounding Elkhorn between 1989 and 2008. The purpose was to explore private well logs to determine if they could be utilized to depict changes in the water table.

In an educational series provided by the Wisconsin Geological Natural History Survey (WGNHS), observation wells were used across Wisconsin to report on groundwater levels statewide (Zaporozec, 1999). The summaries included four wells in Walworth County. Figure 1 displays the location of the study area and each well. Each well varied in observational water table elevation levels between 1994 and 1999.

Other studies have been completed by WGNHS and the Southeastern Wisconsin Regional Planning Commission. Technical reports 37 and 41 include a vast amount of information about trends seen in southeastern Wisconsin. Both reports used commercial or city wells in analyses (Feinstein, Eaton, Hart, Krokelski, and Bradbury, 2005; Zaporozec, Eaton, and Hennings, 2002). Both studies have shown a cone of depression in the Milwaukee-Waukesha area that is slowly spreading to other areas.

Water controversies in East Troy and Lake Geneva, Wisconsin also call attention to the area around Elkhorn. In East Troy, an additional high capacity well was installed to ensure citizens maintained a water supply (Hoyer, 2007). For East Troy and Lake Geneva the major concern was linked to the

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possible decrease in the surface elevations of nearby lakes.

In these studies, there was no information that could be directly interpreted for the area around Elkhorn. This project was created to see if the effects of the cone of depression in the Milwaukee, Wisconsin area could be seen near Elkhorn. With plans for further development in Elkhorn, analysis of the area would provide insight for the community.

Figure 1 displays a map of Walworth County. The controversial areas of Lake Geneva and East Troy have been labeled on the map. Observation wells used in previous studies and noted in the WGNHS annual summaries are represented by orange circles. The study area is outlined by a pink box.

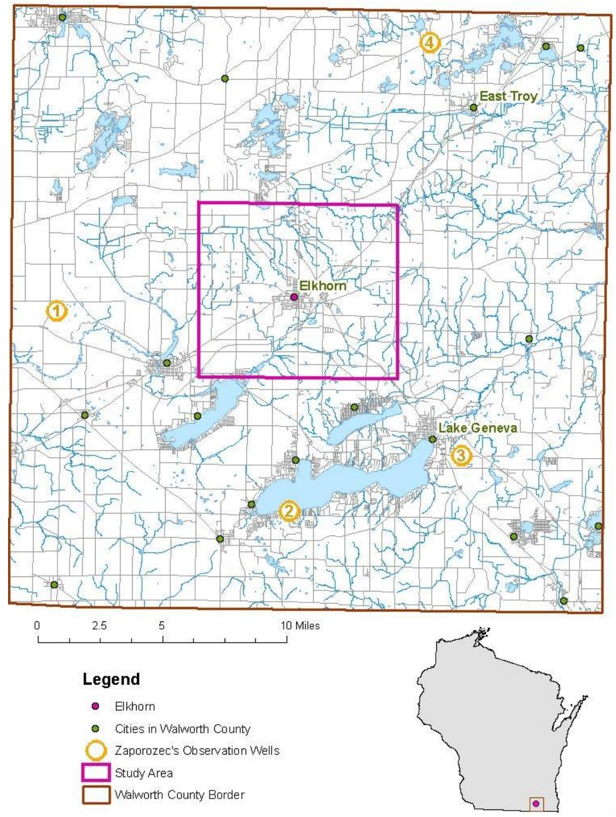

Figure 1. Map of the study area in Walworth County, Wisconsin.

Climate

The climate of the area has been consistent during the last fifteen years. Records from the Wisconsin State Climatology Office did not list any measurements for a specific year or an updated trend that would indicate a changing pattern. Figure 2 displays the drought statistics for Southeastern Wisconsin from 1985 to September 2009. As shown in Figure 2 since 1980 there have been more years of abundant moisture than drought years. The Palmer Drought Severity Index was created by using both precipitation and temperature data.

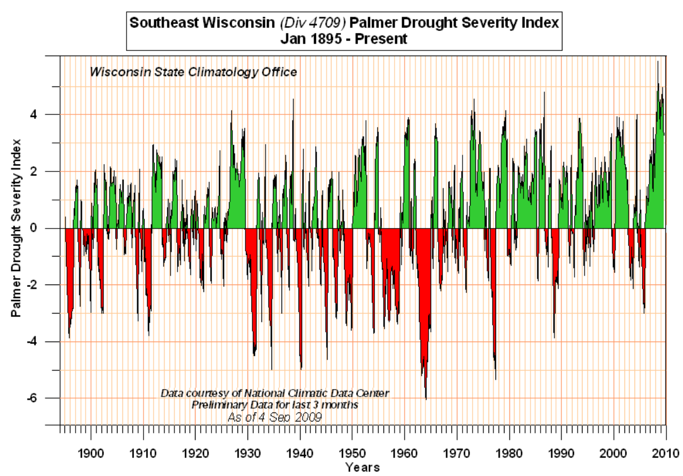

Figure 2. Drought levels from 1895 to 2009. Data was provided by the National Climatic Data Center. The graph was developed by the Wisconsin State Climatology Office (Wisconsin State Climatology Office, 2009).

Population

Since the establishment of Elkhorn in the 1900's, the population has been steadily increasing. Population estimates and census data were retrieved from the State of Wisconsin Department of Administration Division of Intergovernmental Relations (Wisconsin Department of Administration, 2008).

Two graphs were created from the population data. Figure 3 displays the population for each year between 1970 and 2008 and shows consistent growth trends. Figure 4 contains the total population change per year between 1989 and 2008 for the city of Elkhorn.

When organizing the well log data into groups, the large increase of population in 1999 was taken into consideration. The data were split into four groups with the middle division between 1998 and 1999. The first group was from January 1988 to December 1993. The second group was from January 1994 to December 1998. The third group was from January 1999 to December 2003. The fourth group was from January 2004 to December 2008.

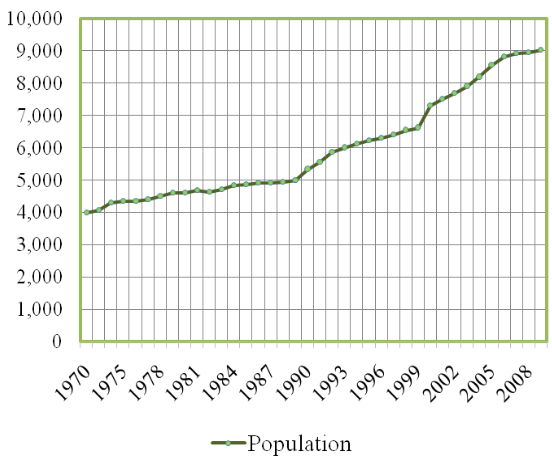

Figure 3. Population levels from 1970 to 2008. The data was a mixture of census data and estimates. The census data was for 1970, 1980, 1990, and 2000.

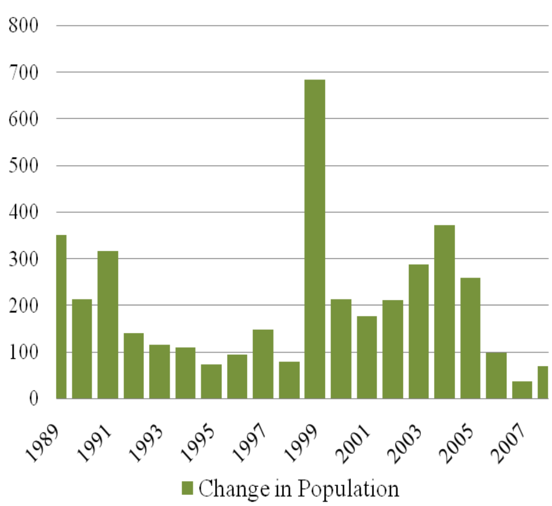

Figure 4. Population change per year from 1989 to 2008 for the city of Elkhorn.

Methods

Well Data Entry

Data was requested from the Wisconsin Department of Natural Resources (WIDNR). The data included Public Land Survey System (PLSS) information, address, owner information, date created, well depth, and static water levels at the time of drilling. PLSS information was only accurate to the quarter-quarter section. The wells ranged in creation time and only a handful of wells were created before 1985. The file was current through December 2008. The file requested from the Wisconsin DNR included private and public wells for Walworth County.

PLSS sections were chosen to surround Elkhorn, but not to include any major lakes. Major lakes were omitted from the study area due to potential open surface water biasing the results. The PLSS sections chosen were: T3 R17 sections 15-22, 27-34; T3 R16 sections 13-16, 21-28, 33-36; T2 R16 sections 1-4, 9-16; T2 R17 sections 3-10, 15-18. Once the appropriate townships/ranges and sections were queried, 311 wells were identified.

After starting to plot the wells, the data revealed inaccuracies in three area subdivisions. A total of 187 wells were noted to exist in these subdivisions. From that total, 41 wells were missing house numbers, accurate road names, and/or accurate owner names. In most cases, instead of an owner name, a construction company was listed.

Examples of this scenario were wells listed with an address of Pebble Drive. The wells on this road were established before properties were bought by individual owners. The area surrounding the road is hilly with changes in elevation up to 30 feet and contains a golf course. In the subdivision, roads wind through the hills and the different holes of the golf course. Although the wells could have been placed in a general area, not knowing where each was located made it impossible to locate the correct elevation near the property.

Also in the case of each subdivision, other wells existed with similar values and creation dates for the wells that were omitted. The exclusion of wells such as just noted brought the total to 270. The excluded wells were all created after January 1, 2000.

Information for each well record was verified by public record search tools accessed through the Walworth County, Wisconsin website. The two databases are called Recorded Documents and Tax Bill Information (Public Records, 2002). The recorded documents are organized in an internet application known as LandShark. The application publicizes documents for the Register of Deeds in Walworth County. Both databases allowed searches under owner names if the address was recorded incompletely.

Bing Maps was used to locate the addresses. Bing Maps was selected since it offered the most updated data that was freely available. The service included satellite imagery which meant images did not have to be purchased.

To map each point in ArcGIS, a PLSS shapefile was used to get a general location. Digital raster graphs (DRG) and road files were used to help locate the specific area. By utilizing the different tools, locations could be cross referenced and accurately placed in ArcGIS.

Fields were created to hold data from the well logs spreadsheet. Data was then transferred from Excel into the appropriate fields in the new shapefile. The ID field provided with the shapefile was used to link the row information in the Excel spreadsheet. This provided an additional assurance that points were not duplicated.

A few wells were not included when analyzing statistics or creating grids. The seven wells not included were listed in Table 1. Most of these wells were created earlier than the rest of the data set. Therefore, these wells did not fit into a group for analyzing. One well was ruled out since it was a deep well and received water from a different source. Data that were not used to generate statistics or grids were still plotted.

Table 1. This table shows the year the well was created and the water level at that time. These wells were not included in analysis. The well from 1995 was a deep aquifer well.

Creation Date	Water Elevation (feet)
1/1932	735
7/1950	913
1/1962	808
9/1975	898
11/1982	830
8/1987	889
3/1995	666

Elevation

Elevations were determined using a DRG for reference. Statistics for the ground elevations were generated. To calculate the estimated water table elevation, the elevations above mean sea level (NAVD 88) values were subtracted from the static water level values. This allowed grids to be created from the water elevation values to represent a simulated water table.

Statistics

Basic statistics were generated for the well logs using the water elevation data. Figure 5 displays the number of wells per year. Unfortunately, the wells were not uniform in number. The number of wells could reflect the number of new homes created in the area. With population increases in Elkhorn, an increase in the number of wells per year would make sense.

The number of wells per group, minimum, maximum, and mean was listed in Table 2. Figure 6 includes histograms containing the frequencies of wells at each elevation. As shown in Figure 6, most of the values were close to the mean and creating a pattern similar to a bell-shaped curve. In theory, a bell-shaped curve would have a normal distribution pattern. The normal distribution pattern is characterized by 68% of values being within one standard deviation, 95% within two standard deviations, and 99% within three standard deviations (Zar, 1999). Table 2 displays the percentage of wells observed within the data set for each standard deviation.

Although the wells did not fit a normal distribution, no wells were eliminated if the values were outside three standard deviations. Wells were only removed from the study if the location of the well could not be determined or the well was using a

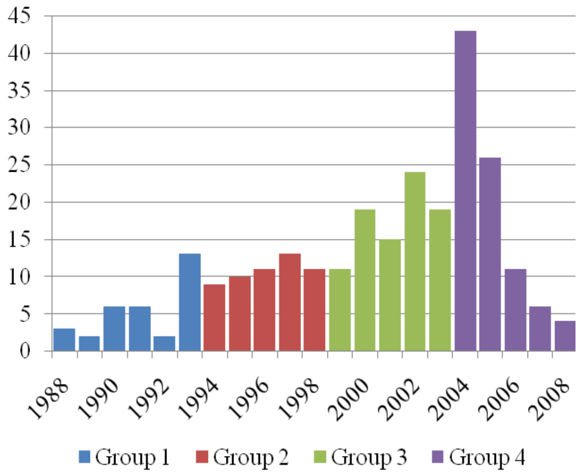

Figure 5. A graph displaying the number of wells per year. The graph was color coded to display the year groups.

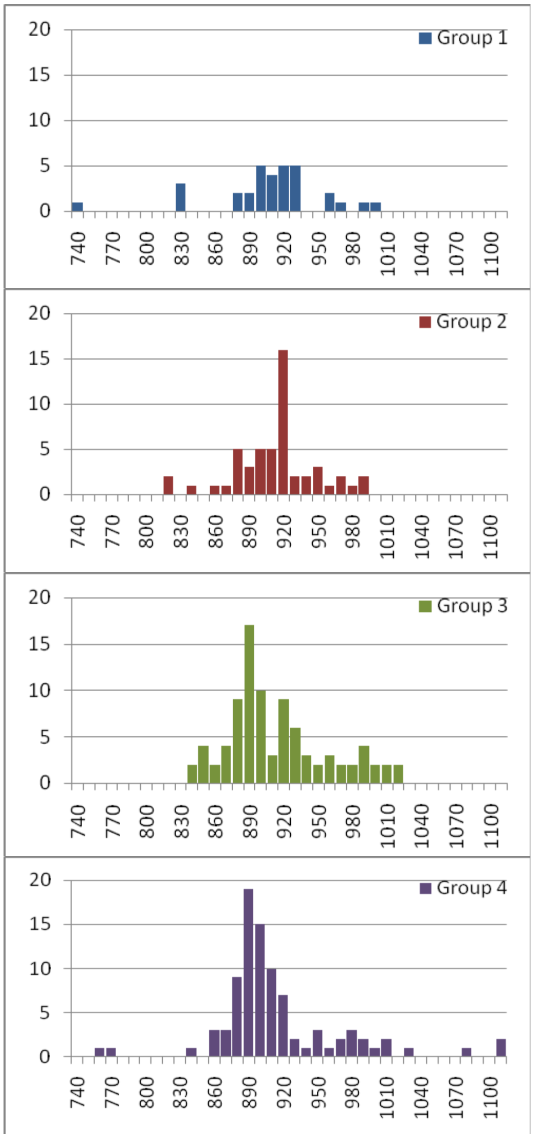

Figure 6. The four graphs above were histograms showing the frequency of wells at each elevation above sea level.

Table 2. Descriptive statistics for the well logs. The statistics were generated using the water elevations in feet (NAVD 88). In this table, "N" equals the number of wells in each group. Percents are listed for the number of values within each standard deviation of the mean.

	Group 1: 88-93	Group 2: 94-98	Group 3: 99-03	Group 4: 04-08
N	32	53	88	90
Minimum	740	815	840	764
Maximum	1002	999	1027	1115
Mean	913.22	915.40	918.25	918.02
Std. Deviation	47.62	39.29	43.98	54.94
1 Std Dev	75.00%	75.47%	70.45%	82.22%
2 Std Dev	96.88%	90.57%	94.32%	93.33%
3 Std Dev	96.88%	100%	100%	96.67%

deeper aquifer. Three explanations for an abnormal distribution were: (a) the study area varies in elevation, (b) the study area also contains two sub-watersheds, and (c) water tables can fluctuate throughout the year. Since the percentages are close to normal, the data set was accepted.

A single factor, multi-sample, analysis of variance (ANOVA) test was performed using the four groups of data. Although the test did not require equal groups, when the numbers were close to equal the test became more powerful (Zar, 1999). The outcome of the test showed that there was no statistical difference between groups (P = 0.1). The data was also analyzed with the Kruskal-Wallis test. The Kruskal Wallis non-parametric test compared the ranked values across all groups. That test also showed no statistical difference in the data (P = 0.15).

Grids

Grids were created to visualize a predicted water table surface. Using the geostatistical analyst toolbar in ArcMap, different interpolation techniques were explored. A universal kriging prediction map was chosen to convert the well points into a predicted water table surface grid. Kriging was chosen since the wells were scattered across the study area and a method was needed to calculate the unknown points. The universal form of kriging was chosen to auto correlate any random errors that occurred.

The Geostatistical Wizard allowed manipulation of certain variables. Using the wizard, the data was plotted and compared to different semivariogram options and an exponential semivariogram was chosen. By using the exponential semivariogram, all of the data points in a group were included in the creation of each grid. A circle with eight angular sections was used for search neighborhoods. Limiting the neighborhood search to smaller sections helped eliminate points being biased from points too distant. The prediction maps were exported to grid format.

Each grid showed predicted values of what the water table could have been during that period of time. Figure 7 displays the simulated water table for group 1. Figure 8 shows the water table for group 2. Figure 9 displays the simulated water table for group 3. Figure 10 represents the water table for group 4. Values were assigned to classes to standardize each grid. Each class held a range of twenty feet. The range of values was from 740 to 1060 feet.

Figures 7-10 also display the placement of wells. There were two concentrations of wells shown in each figure. Both of those areas represented large subdivisions that were growing

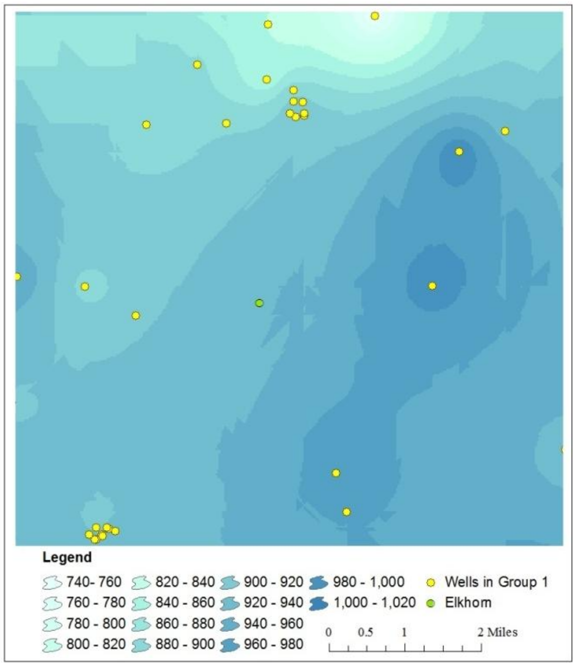

Figure 7. Grid model estimates for wells in the first group (1988-1993). The predicted values range from 740-1000 feet. Also shown are wells.

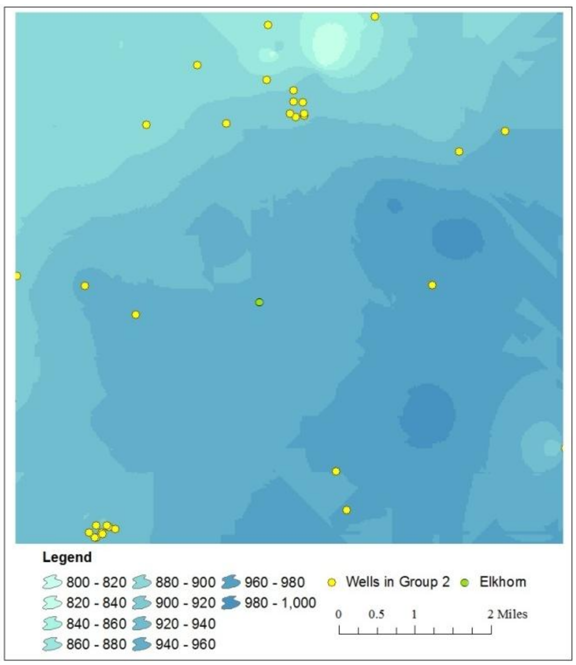

Figure 8. Grid model estimates for wells in the second group (1994-1998). The predicted values range from 800-1000 feet. Also shown are wells.

throughout the study period.

One subdivision was located in the southeast area. That subdivision was near a lake that was outside the study

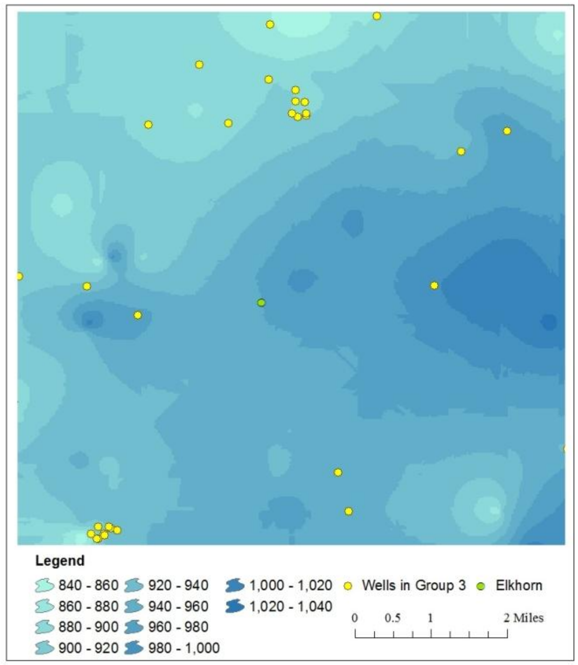

Figure 9. Grid model estimates for wells in the third group (1999-2003). The predicted values range from 840-1040 feet. Also shown are wells.

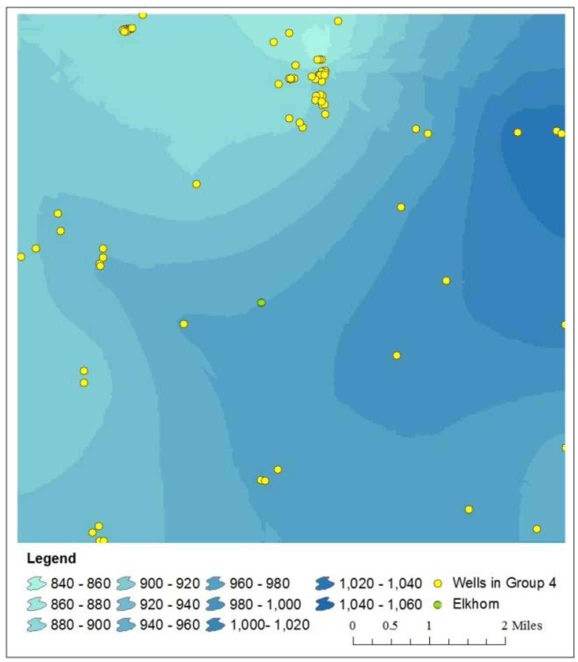

Figure 10. Grid model estimates for wells in the fourth group (2004-2008). The predicted values range from 840-1060 feet. Also shown are wells.

area. For 36 wells, over a period of 20years the elevation ranged from 910 to 930 feet. The surface elevation of the nearby lake is less than 930 feet.

Therefore the water in the wells could not have a lower elevation unless the nearby lake did likewise. This is why the 36 wells are similar in water table elevation values. Without a major change effecting rivers, lakes, and groundwater in the area the water elevation seen in wells will not vary by much.

The other area was located in the northern central region of the study area. This area contained a cluster of subdivisions and covered a much larger area. The cluster of wells covered two, one mile square sections. Although the area was hilly and had many streams, no large bodies of water were close to it. A total of 72 wells occurred here ranging from 760 to 920 feet in water elevation. There was not a discernable pattern that emerged from the water elevations.

The only other concentration of wells was found in group 4 in the northwest portion of the study area. Between 2004 and 2008, 38 wells were drilled. The wells ranged in value from 885 to 910 feet in this area. The increase of wells and potential residents in four years demonstrates the ability the region has for population growth in a small time period.

To gain a better understanding of the data, each grid was exported into points. The water elevation was then taken from each point for additional analysis. Each grid held 101,400 points. Descriptive statistics for each group were determined and presented in Table 3. The predicted statistics in Table 3 were slightly different than the values in Table 2. Although the minimum and maximum values were within two feet for the first three groups, the fourth group's data were quite different. The difference could be attributed to the nature of the grid predicted estimated elevations. Only the wells outside 3 standard deviations were affected by the grid estimates. For example, in Group 4, if the top three wells are removed, the maximum water elevation would then be 1033 feet which was close to the projected elevation.

Table 3. Descriptive statistics for water elevations that were extracted from water surface elevation grids. Each group contained 101,400 values.

Group	Minimum	Maximum	Mean
1: 88-93	740.39	1001.12	926.56
2: 94-98	816.68	998.16	933.74
3: 99-03	841.80	1026.53	934.75
4: 04-08	853.11	1041.24	946.33

Results

Statistical tests show no significant differences. This indicates that at this time, it is not possible to demonstrate that the water table has changed. However, the tests are limited by the fact that the groups of data are very uneven in numbers. Slightly different elevation values were noted for the more recent years, but again the change was not statistically significant.

Conclusion

Using private well information segmented by when they were drilled proved to be a difficult way to make assumptions of the water table elevations. To use well log information in this fashion, it would be better to have near similar numbers of wells in each group. An equal number in each group would create a stronger set of statistics.

Idealistically, this study could be expanded using the wells already recorded. Retrieving current water levels from wells created in 1988 to 1998 would provide a more consistent sample set. Monitoring private wells for static water levels every five or ten years would help ensure a set of samples to be analyzed. Global positioning system (GPS) could be utilized to record latitude, longitude and ground elevation at each well. Both additions to the study would yield a more standardized set of points, reduce error, and provide more power to the statistical tests.

Even though the data shows no significant difference in elevation, with a growing population groundwater use can only be expected to increase. Knowing that the area around Elkhorn at present has not been adversely affected by other areas in southeastern Wisconsin can provide residents with insight for the next step. Focusing on protecting water quantity, in addition to water quality, for the area would be beneficial. Employing conservation efforts before problems arise would also benefit citizens of the future.

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