Kansas Geological Survey

Open File Report 2002-25D

Exploring Relationships Between Water Table Elevations, Reported Water Use, and Aquifer Lifetime as Parameters for Consideration in Aquifer Subunit Delineations

By

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With contributions from other authors in the report series

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KGS OFR 2002-25D. Exploring Relationships Between Water Table Elevations, Reported Water Use, and Aquifer Lifetime as Parameters for Consideration in Aquifer Subunit Delineations

Table of Contents

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KGS OFR 2002-25D.
Exploring Relationships Between Water Table Elevations, Reported Water Use, and Aquifer Lifetime as Parameters for Consideration in Aquifer Subunit Delineations
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1. Introduction

This report on exploring relationships between water table elevations, reported use, and aquifer lifetime as parameters for consideration in aquifer subunit delineations (OFR 2002-25D) is written as part of the Kansas Geological Survey's report of ongoing technical support series (OFR 2002-25) to further understand the characteristics and properties of the High Plains Aquifer. This report was developed within the framework of contracts with the Kansas Water Office (KWO) and Kansas Department of Agriculture's Division of Water Resources (KDA-DWR). Contract documents are contained in Section 4 of KGS OFR 2002-25G.

The concept of aquifer subunits is a relatively new approach for planning enhanced management activities in the Ogallala-High Plains Aquifer. The Kansas Water Authority's Ogallala Management Advisory Committee (MAC) and Technical Advisory Committee (TAC) final report, which was adopted into the FY 2004 Kansas Water Plan, recommends the delineation of aquifer subunits in which specific water use goals could be tailored to areas containing similar aquifer characteristics (Ogallala, 2001). This approach recognizes that a "one-size fits all" management policy or program is not applicable for the entire Ogallala-High Plains aquifer region. Excerpts from this recommendation are contained in Section 3, KGS OFR 2002-25G.

This report is focused on a review of possible techniques and methodologies that could be used to identify and characterize aquifer subunits within the Ogallala-High Plains aquifer (the western region of the High Plains Aquifer). The first method is based on the estimated usable life of the Ogallala-High Plains aquifer where past rates and trends in the water table are projected into the future until the saturated thickness of the aquifer reaches a certain level. These estimates provide a simple classification of the amount of time remaining until the amount of water in storage for a subunit area is projected to reach resource exhaustion and large volume ground-water pumping becomes impractical.

The second aquifer subunit delineation process evaluated in this report is the use of geo-statistical cluster processes to spatially classify similar areas of the aquifer based on a series of selected aquifer parameters, specifically, the amount of reported water use, the change in the water table, and the current saturated thickness. The geo-statistical clustering process is based on both unsupervised and supervised clustering routines similar to methods used to classify remotely-sensed satellite data images.

2. Estimated Usable Lifetime of the Ogallala-High Plains Aquifer

2.1. Methodology

In published maps of the Atlas of the Kansas High Plains Aquifer (Schloss et al., 2000), the heterogeneity of the aquifer is well documented, both in terms of resource available and water demands. The spatial distribution of the amount of water in storage, water right development, climatic features, and the changes in the water table elevations over time has been and continues to be extremely nonuniform. In addition, different methods used to estimate the usable lifetime of the Ogallala-High Plains aquifer provide very different answers to the question of whether the ground-water resource is sustainable and if not, how long until necessary transitions will occur.

Usable lifetime was estimated using the methods of Schloss et al. (2000), but incorporating more recent data on water level trends (1991-2001) and additional time classifications. The estimates were made by projecting established recent rates of water level declines into the future until a certain saturated thickness threshold was reached. Note that these are projections of recent water level trends, not predictions. Consistent with Schloss et al. (2000), a saturated thickness of thirty feet has been assumed by state agencies and local water users to be the approximate minimum thickness needed to support large volume water demands. The 30 feet saturated thickness threshold is used in this report to facilitate comparisons with the estimated usable lifetime maps originally portrayed in the Atlas of the Kansas High Plains Aquifer. Sections 2.2 and 2.3 below describe usable lifetime projections using the 30 foot threshold value and 5 and 10 year water level trend values.

However, recent results from the well yield portion of this report series (KGS OFR 2002-25C) suggest that the minimum thickness is actually substantially greater than thirty feet; these issues are addressed in section 2.4 of this report.

To calculate the recent rates of water level change, data were extracted from the KGS Water Information Storage and Retrieval Database (WIZARD). Monitoring wells selected from WIZARD were required to be screened within the geologic formations of the High Plains aquifer and to have at least one depth to water measurement during the winter months (December, January, and/or February) in a three-year time window around each year of 1991, 1996, and 2001. For example, the 1991 water level data subset represents wells measured at least once during the winters of 1990, 1991, or 1992. If more than one measurement was available, the average of all the winter measurements over the three-year time period was used. Under these selection criteria, a total of 1,115 monitoring wells in the High Plains aquifer were identified.

The rates of water level change for the periods 1991-2001 (Figure 1), 1991-1996 (Figure 2), and 1996-2001 (Figure 3) were then established for every well in the data set by dividing the total change in the water table by the number of years in the time period. For example, if the water table at a monitoring well declined by 10 feet from 1991 to 2001, the annual rate of change was calculated to be 1 foot per year. The annual rates of change were then used for spatial interpolation of the average annual rate of change across the High Plains aquifer region and assigned to section-centers. By classifying the rates of change into five year intervals of 1991 to 1996 and 1996 to 2001, comparisons can be made during conditions when the overall precipitation levels where higher (early 1990s), compared to when they were normal or lower (later 1990s). Information from WIZARD data can be access free of charge via the internet at http://www.kgs.ku.edu/Magellan/WaterLevels/index.html.

The estimated saturated thickness, defined as the vertical thickness of the aquifer in which the pore spaces are filled (saturated) with water, was calculated from the interpolated section-center values of the water table elevation from the 2001 WIZARD data subset, by subtracting the estimated elevation of the bedrock or base of the aquifer at each location. Bedrock elevation estimates were derived from Hansen and Juracek (1995); these data can be obtained free of charge from the Data Access and Support Center via the internet at http://gisdasc.kgs.ku.edu/. The estimated 2001 saturated thickness (Figure 4) was then used as the starting point from which the annual rate of change for a given time period was used to calculate the number of years until the aquifer reaches a saturated thickness of thirty feet or less.

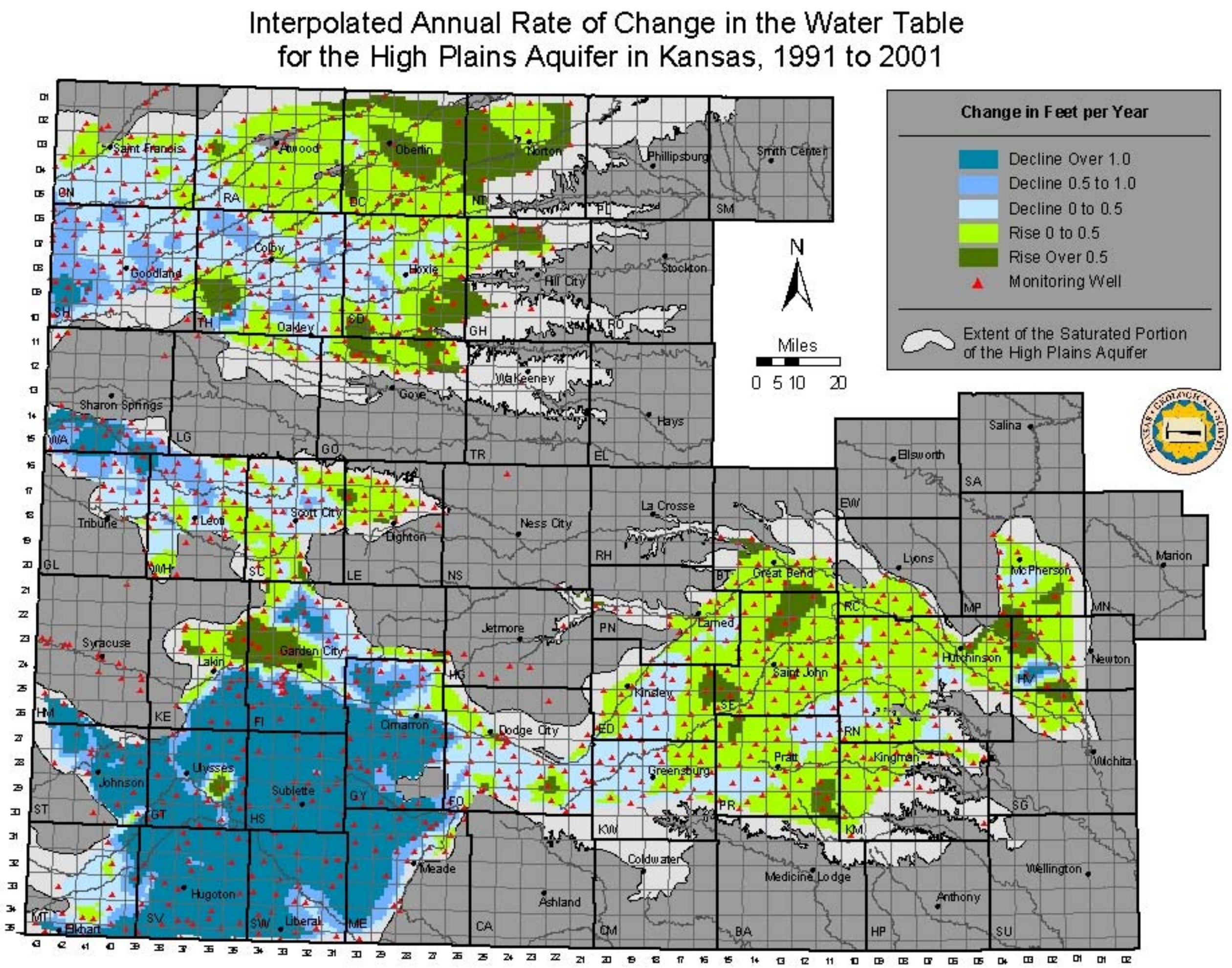


Figure 1- Interpolated annual rate of change in the water table for the High Plains aquifer in Kansas, 1991 to 2001.

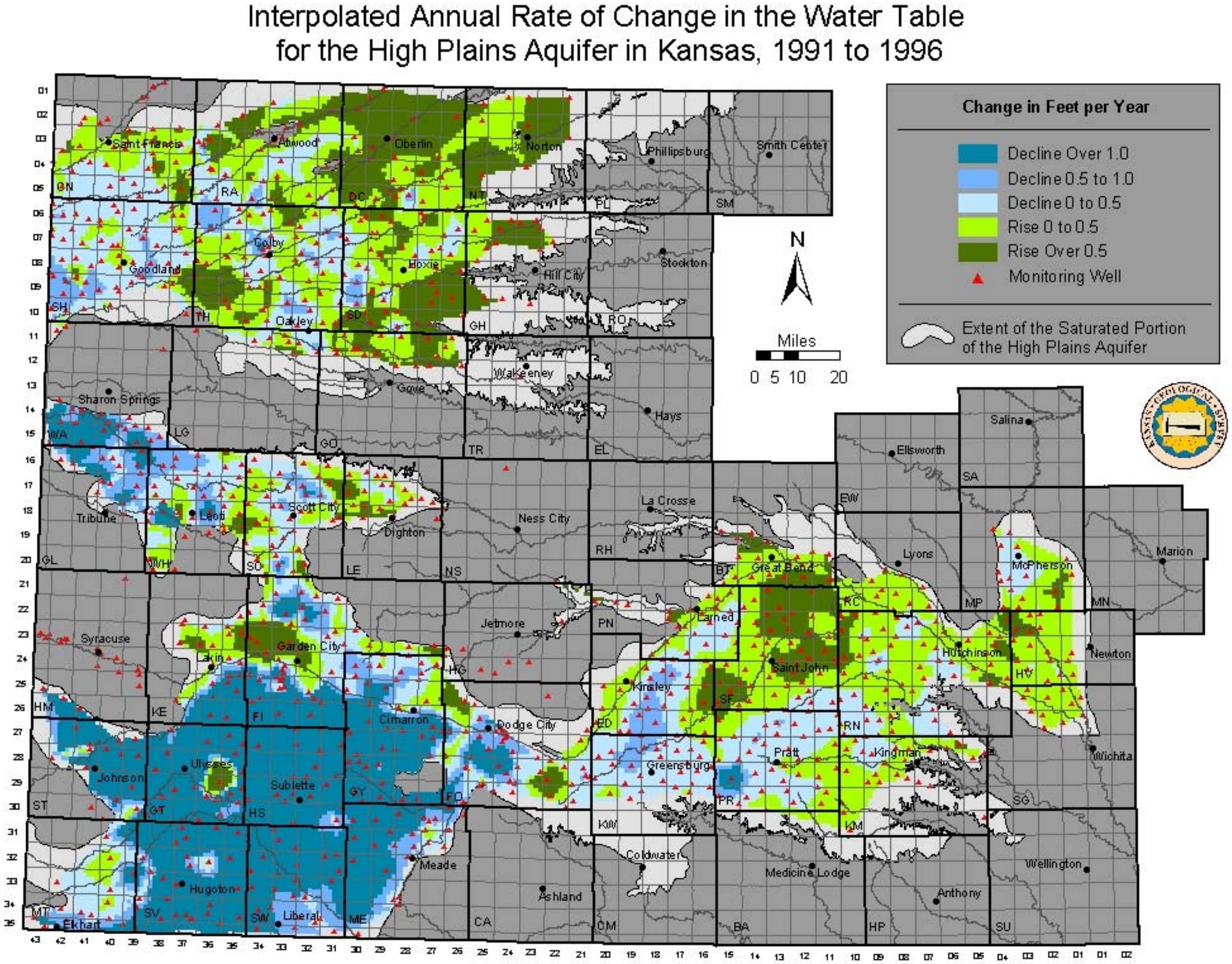


Figure 2- Interpolated annual rate of change in the water table for the High Plains aquifer in Kansas, 1991 to 1996.

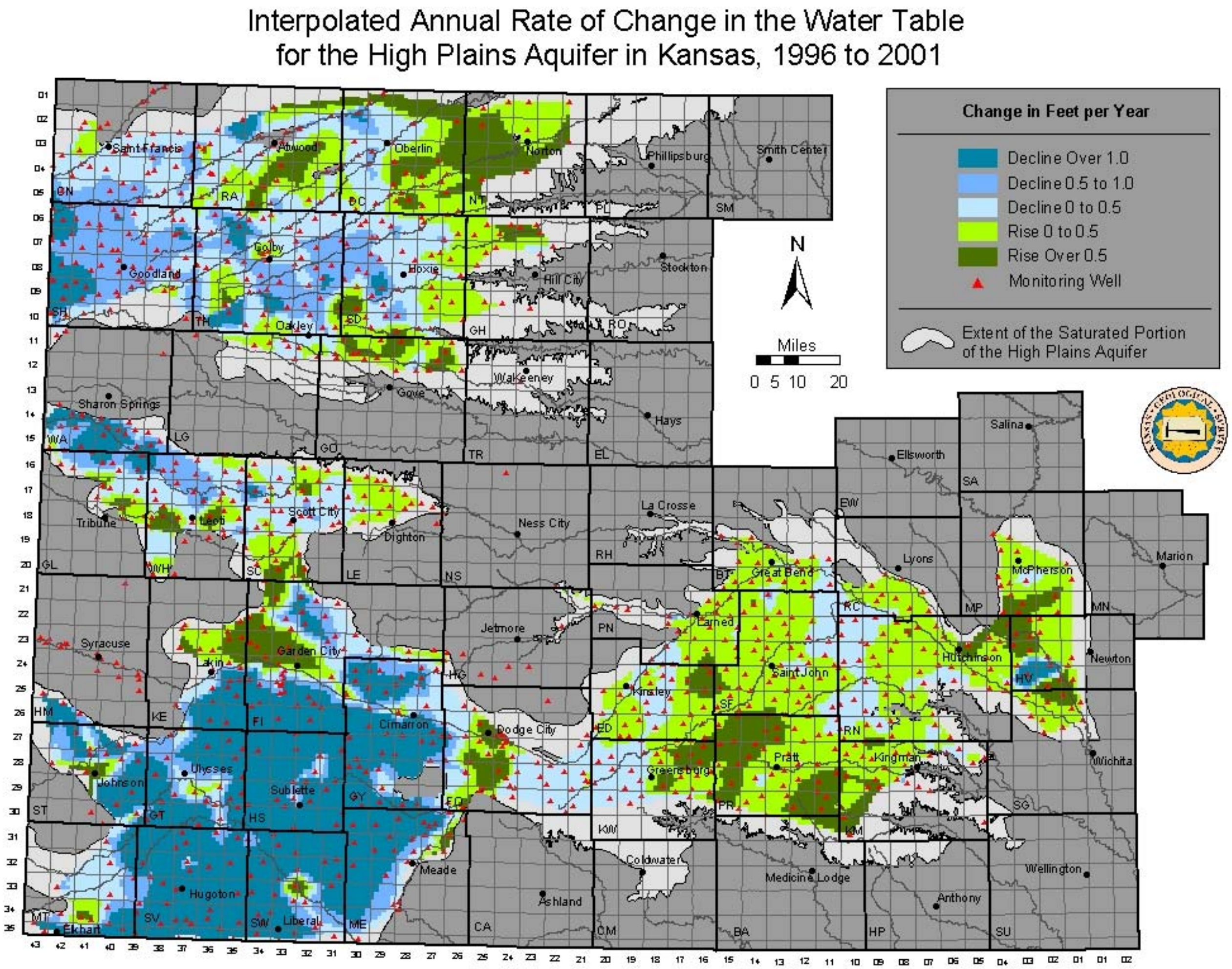


Figure 3- Interpolated annual rate of change in the water table for the High Plains aquifer in Kansas, 1996 to 2001.

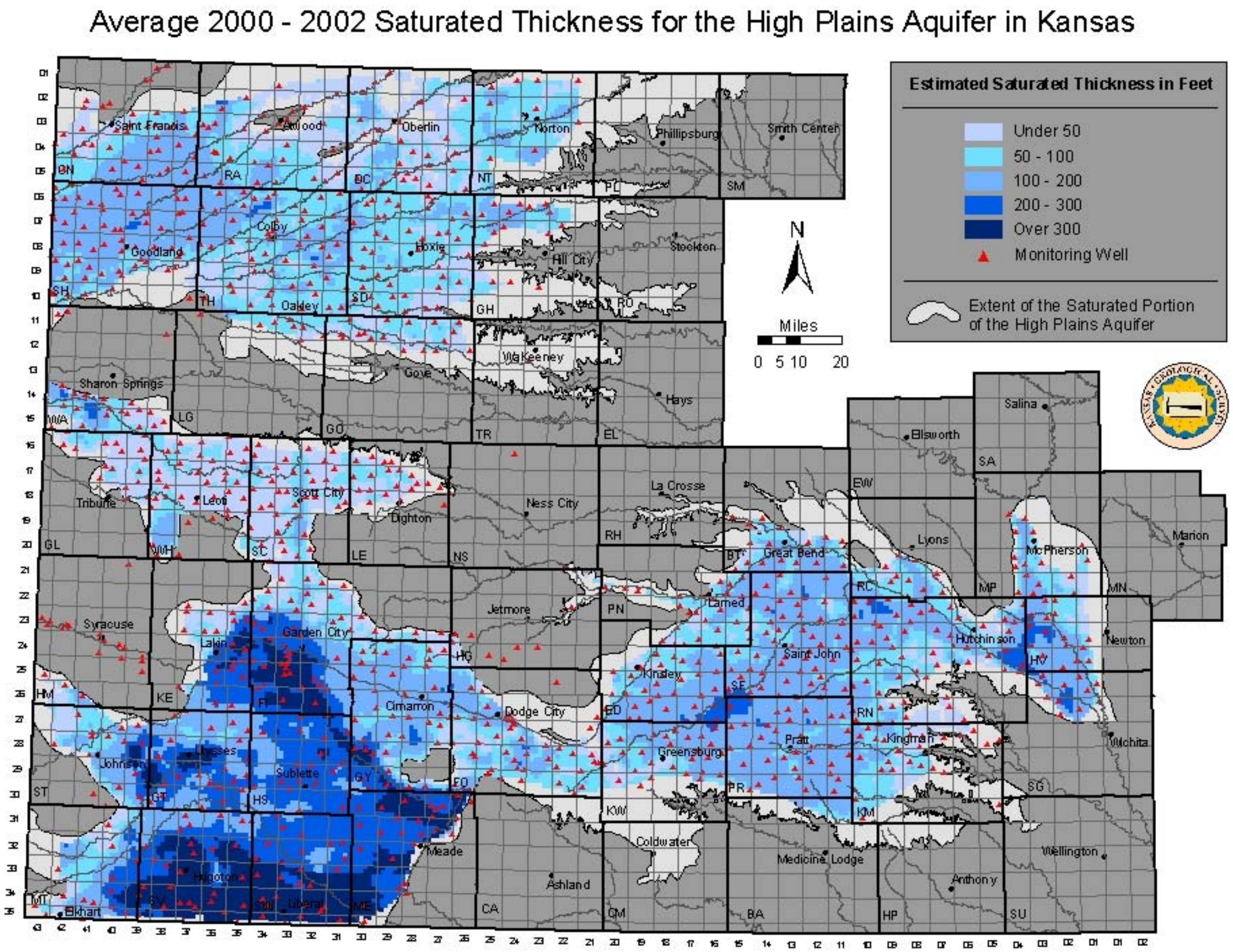


Figure 4- Estimated 2001 saturated thickness for the High Plains aquifer in Kansas. The 2001 saturated thickness is based on the difference in the average 2000-2002 water table elevation and the estimated bedrock elevation.

The usable lifetime estimates are presented in a variety of formats based on differing time intervals, classifications, and minimum required saturated thicknesses . The intervals initially used are the same intervals used in the Atlas of the Kansas High Plains Aquifer (Schloss et al., 2000): under 25, 25-50, 50-100, 100-250, and over 250 years (see section 2.2). Under the contract scope of work developed for this report, the estimated usable lifetime classification schemes were further refined to 10-year time intervals (see section 2.3). Finally, the estimated usable lifetime calculations were repeated using the Atlas classifications based on the minimum required saturated thickness thresholds for varying wells yields outlined in KGS OFR 2002-25C (see Section 2.4).

2.2. Results Using Atlas Intervals

The new estimates of the usable lifetime of the High Plains aquifer were classified for comparison purposes using the same intervals initially used in the Atlas of the Kansas High Plains Aquifer (Schloss et al., 2000). The estimated lifetime based on ground-water trends from 1991 to 2001 can be seen in Figure 5, with estimates based on trends from 1991 to 1996 and from 1996 to 2001 being shown in Figures 6 and 7, respectively.

Results from this evaluation using more recent data reveal both similar and dissimilar regional patterns when compared with the aquifer lifetime estimates in the Atlas. West-central Kansas consistently shows areas at or within 25 years of resource exhaustion, defined here as a saturated thickness of thirty feet or less. The estimates for southwest Kansas also show similar patterns, although at the township scale there is greater variability between the different time periods used. It is interesting to note the area of localized recharge occurring in Kearny and Finney counties. This is probably caused primarily by the operation of surface ditch irrigation systems where surface water is seeping back into the aquifer; the area is further discussed in OFR 2002-25B.

The area that shows the greatest variability in the usable lifetime estimates occurs in the northwest region of the aquifer. Within this region, the areas classified as being within 25 or 25 to 50 years change considerably depending on the water level change time-period used. It should be noted, however, that northwest Kansas has been subject to greater influences from climatic factors than the other regions of the Ogallala- High Plains; precipitation levels were higher than normal in 1993, and there was an untimely freeze event in 1994. Both events had notable effects on the amount of water used and resulted in decreases in the water level declines for those years.

Results from this assessment further demonstrate that there is great variability in the Ogallala-High Plains aquifer. This variability supports the idea of management approaches based on specific aquifer subunit characteristics, and illustrates one possible approach to their identification based on sub-regional lifetime classifications using the amount of and trends in the water resources for a given area.

2.3. Results Using 10-Year Intervals

Under the contract scope of work developed for this report, the estimated usable lifetime classification schemes were further refined to 10-year time intervals. Within this classification format, the estimated lifetime values for an area are portrayed in a manner more compatible with the time periods associated with short-term bank loans and some owner-tenant agreements. Figures 8, 9 and 10 show the same estimates of the usable lifetime of the aquifer, characterized by 10 year time periods, based on rates of water level change during 1991 to 2001, 1991 to 1996, and 1996 to 2001 respectively.

Although these figures further illustrate the great variability of the aquifer, in some areas it is clear that adjacent small areas with different aquifer classifications reflect the influence of water level measurements from individual monitoring wells. Given the water level measurement uncertainties discussed in OFR 2002-25F, this level of spatial resolution is not justified for establishing trends on a ten-year time interval on the basis of currently available data.

Additionally, the classification areas are too small to conform effectively to the township-scale size target for manageable subunits. However, it could be argued that a 10-year time period classification on the lifetime estimates does have application in prioritizing possible water use goals based on larger areas identified as having a short time period (10, 20 or possibly 30 years) of adequate saturated thickness remaining. Classifying the estimated usable lifetime of the aquifer to 10-year time intervals at local (e.g., section) scales exceeds the temporal resolution of data now being acquired from the existing monitoring well network, and should probably not be used as a management target at local (sub township) levels unless the monitoring data are significantly enhanced (see OFR 2002-25F).

2.4. Estimated Usable Lifetime Based on Required Saturated Thickness/Well Yield Estimates

One of the products of the well yield portion of this series (KGS OFR 2002-25C) is estimates of the minimum amount of saturated thickness required to support different well yields under a variety of pumping and hydrogeologic property scenarios. These relationships between saturated thickness and well yield indicate that the minimum saturated thickness required to support large volume water demands is substantially greater than thirty feet for most scenarios. Based on the scenario of 90 days of pumping with five wells on adjacent ¼ sections, the estimated 2001 saturated thickness (Figure 4) and the estimated hydraulic conductivity shown in Figure 11 (Cedarstrand and Becker, 1998) were used to establish a new minimum required saturated thickness threshold for the estimates of the usable lifetime of the aquifer. The estimates replace the previously used 30 feet threshold with the minimum saturated thickness needed to support well yields of 50, 400 and 1000 gpm under this scenario. The results of the estimated usable lifetime based for well yields of 50, 400, and 1000 gpm under the 90 day pumping scenario can be seen in Figures 12, 13, and 14 respectively, and are based on annual ground-water trends from 1991 to 2001.

The estimates of the usable lifetime of the aquifer for the various pumping rates illustrate that in general there are adequate water reserves to support all of the selected well yields and the associated minimum saturated thicknesses under the 90 day pumping scenario in much of southwest Kansas, and to a lesser extent in northwest Kansas (particularly Sherman county) for at least 25 years if not longer. However, by using the minimum saturated thickness thresholds for the 90 day pumping scenario, the overall lifetime estimates have shortened, and the total area and spatial distribution of areas classified as being within 25 years of, or areas already below, the minimum saturated thickness, have increased from the initial estimates based on the 30 feet threshold.

The lifetime estimates required for 50 gpm well yields (Figure 12) has characteristics most similar to the initial lifetime estimates presented in the Atlas of the High Plains Aquifer and its updated version shown in Figure 5. This should be expected since the original saturated thickness of 30 feet was chosen based on discussion with other state agencies and local water users to

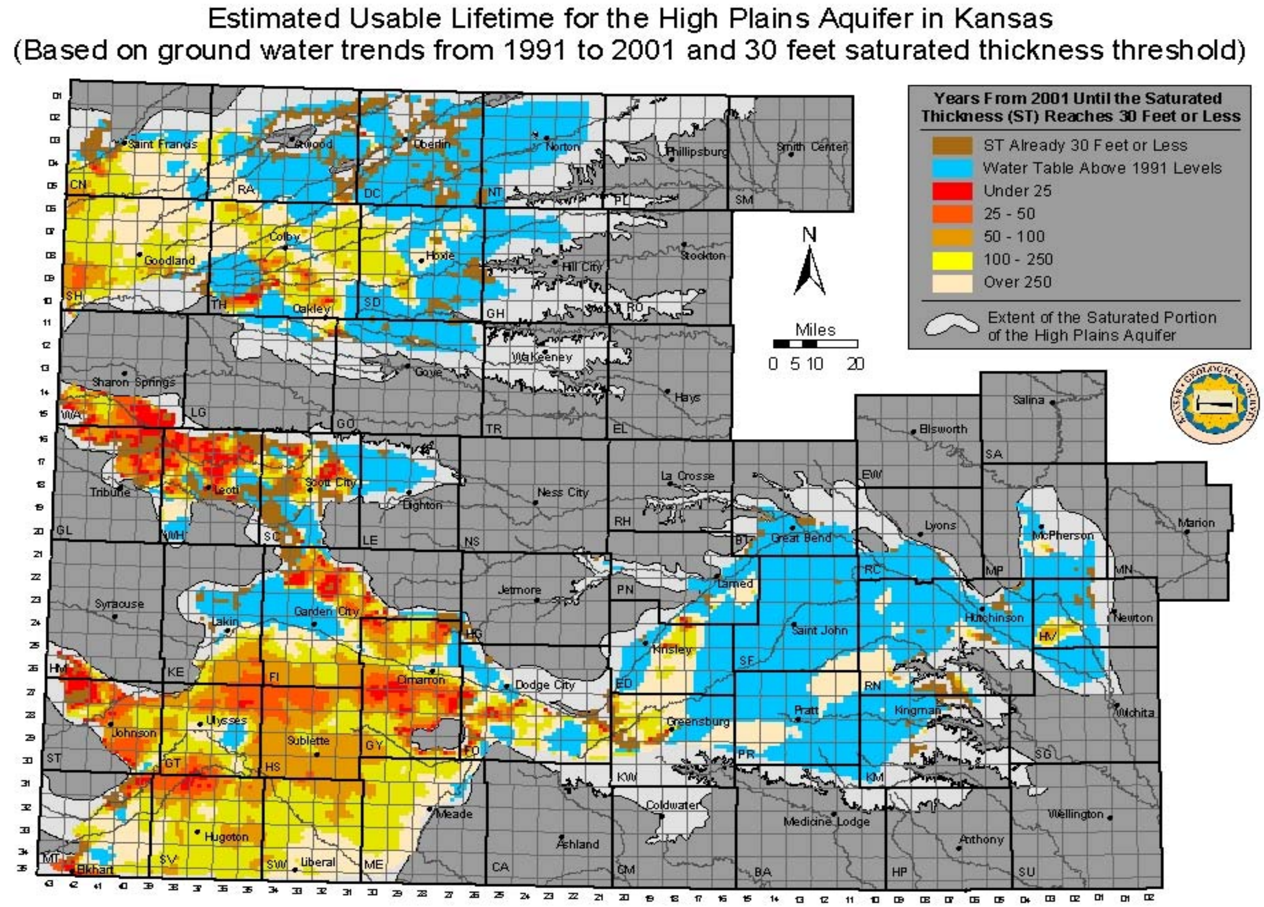


Figure 5- Estimated usable lifetime for the High Plains aquifer in Kansas based on ground-trends from 1991 to 2001 and a 30 feet saturated thickness threshold.

Estimated Usable Lifetime for the High Plains Aquifer in Kansas
(Based on ground water trends from 1991 to 1996 and 30 feet saturated thickness threshold)

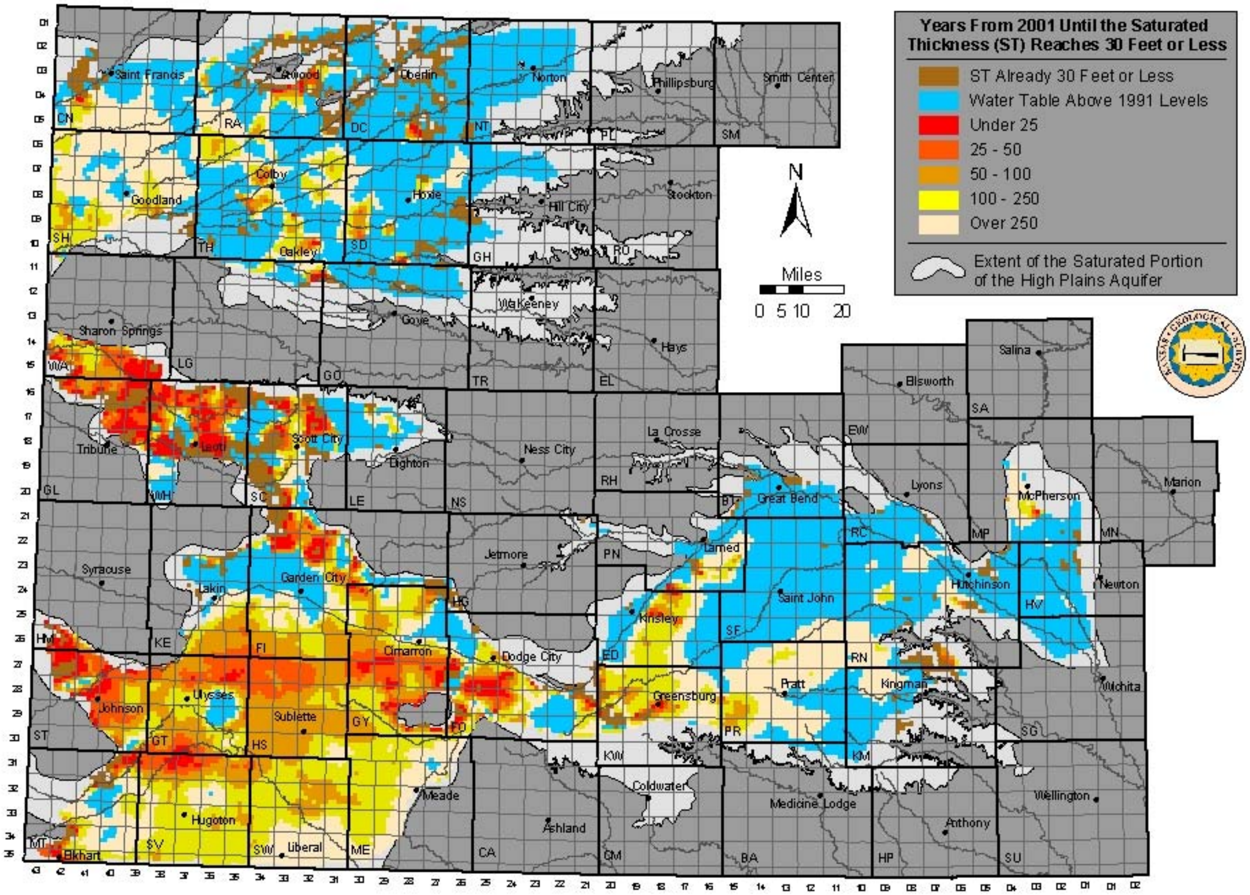


Figure 6- Estimated usable lifetime for the High Plains aquifer in Kansas based on ground-trends from 1991 to 1996 and a 30 feet saturated thickness threshold.

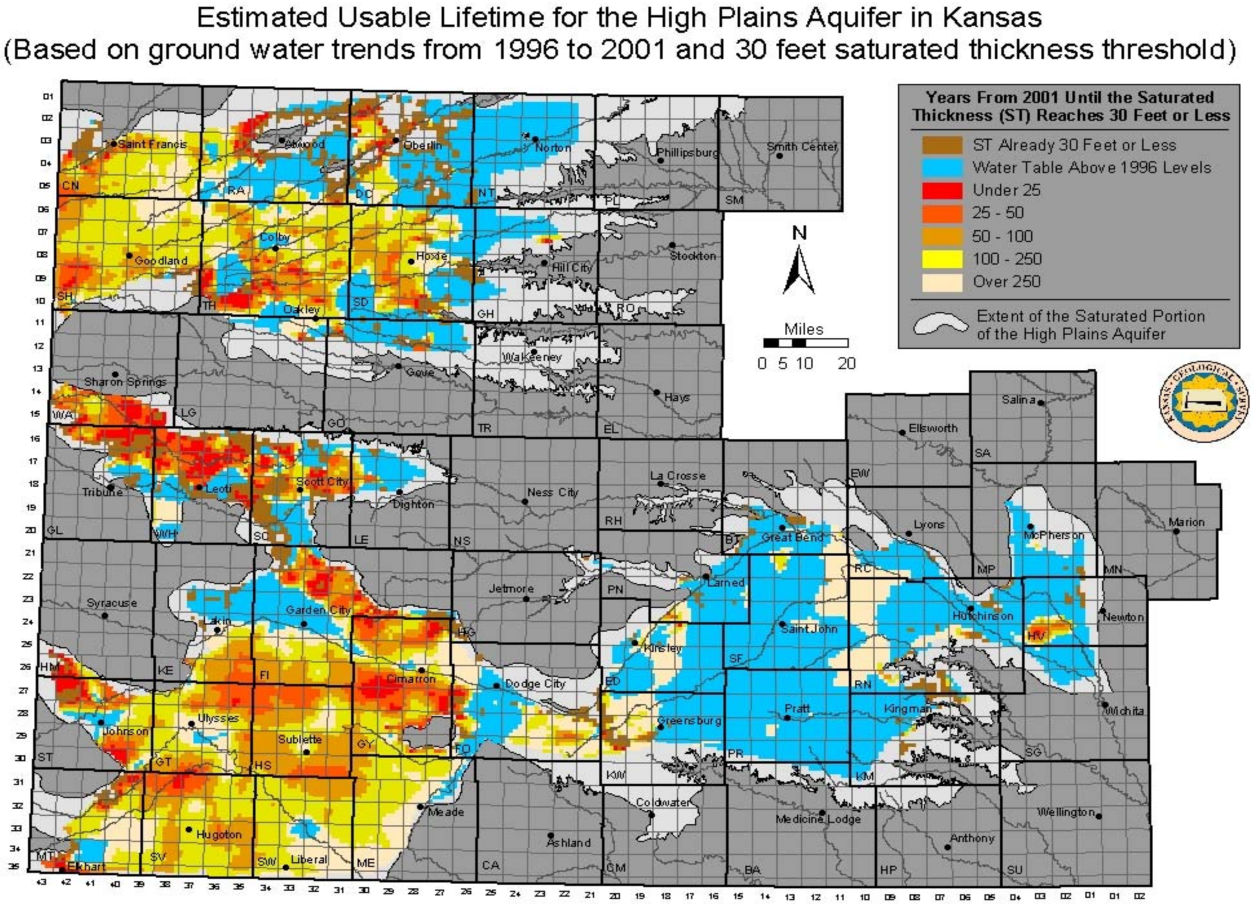


Figure 7- Estimated usable lifetime for the High Plains aquifer in Kansas based on ground-trends from 1996 to 2001 and a 30 feet saturated thickness threshold.

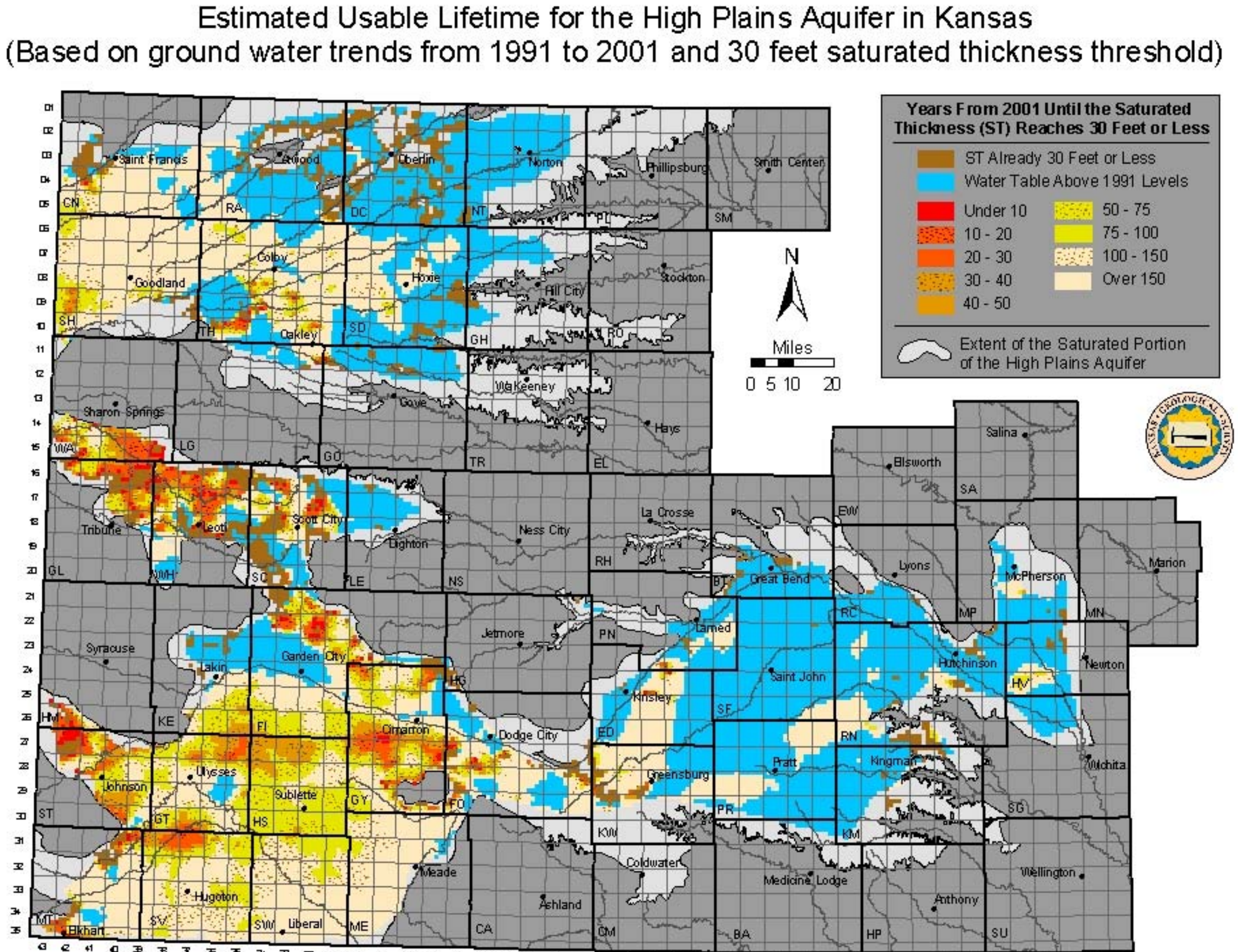


Figure 8- Estimated usable lifetime for the High Plains aquifer in Kansas based on ground-trends from 1991 to 2001 and a 30 feet saturated thickness threshold.

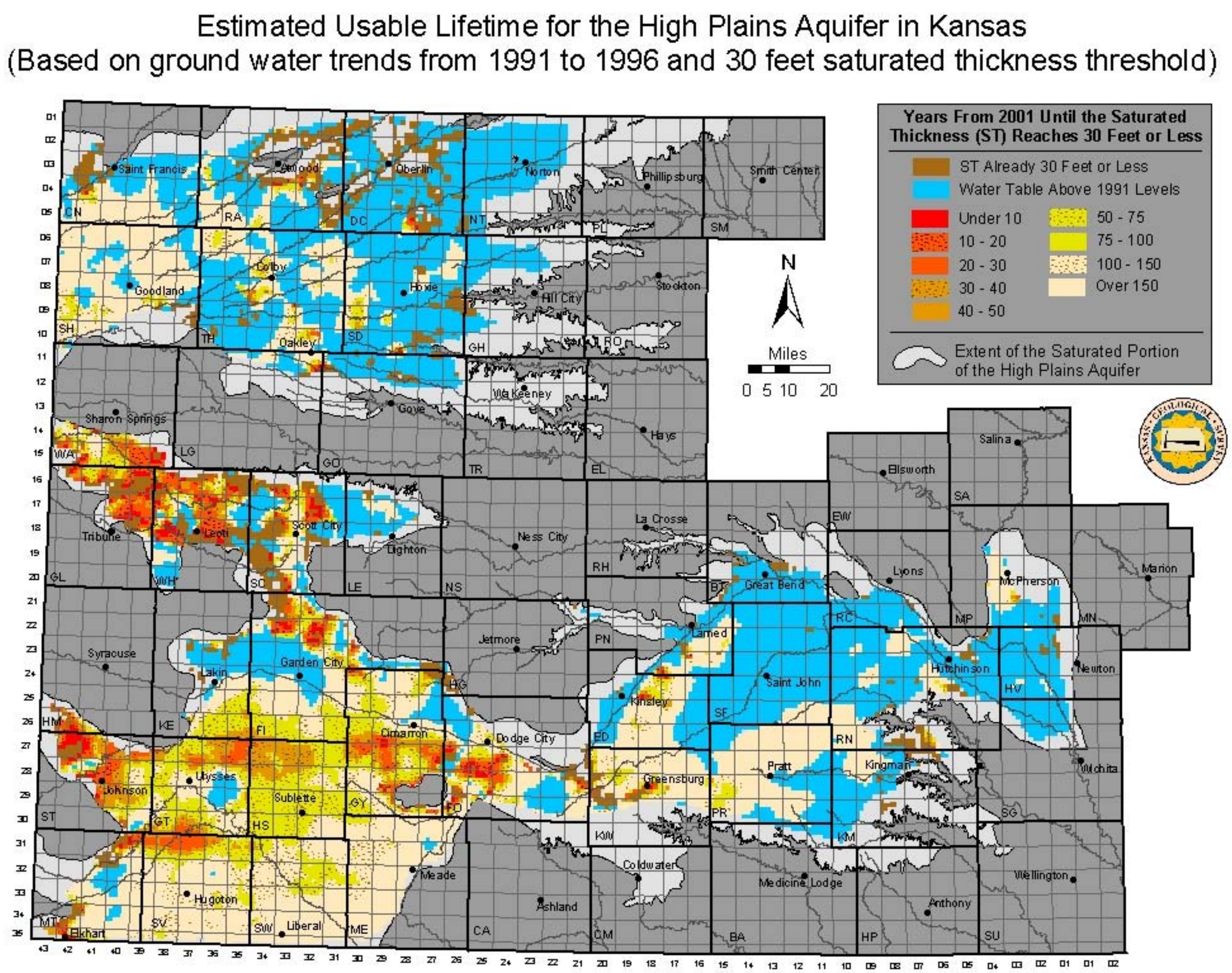


Figure 9- Estimated usable lifetime for the High Plains aquifer in Kansas based on ground-trends from 1991 to 1996 and a 30 feet saturated thickness threshold.

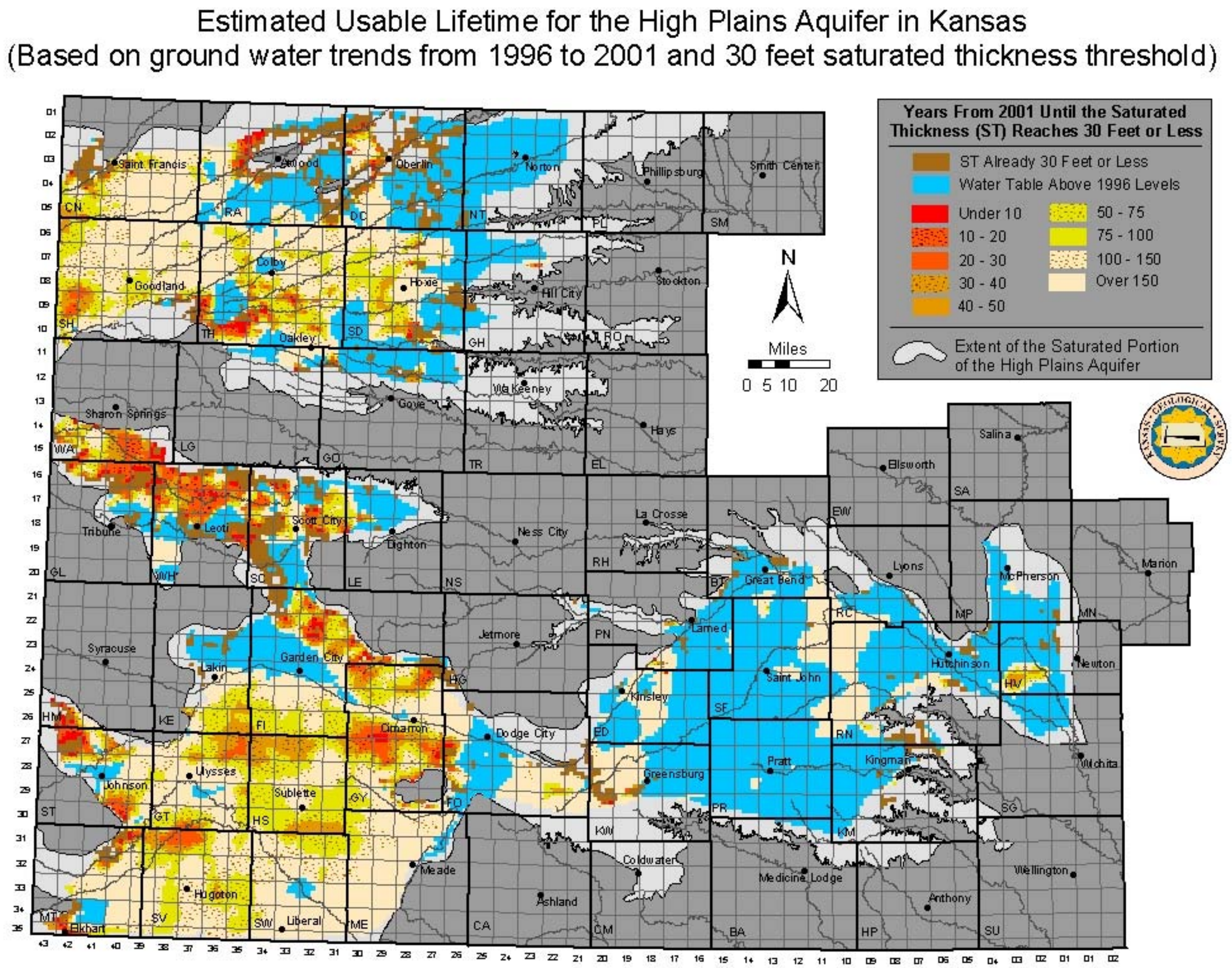


Figure 10- Estimated usable lifetime for the High Plains aquifer in Kansas based on ground-trends from 1996 to 2001 and a 30 feet saturated thickness threshold.

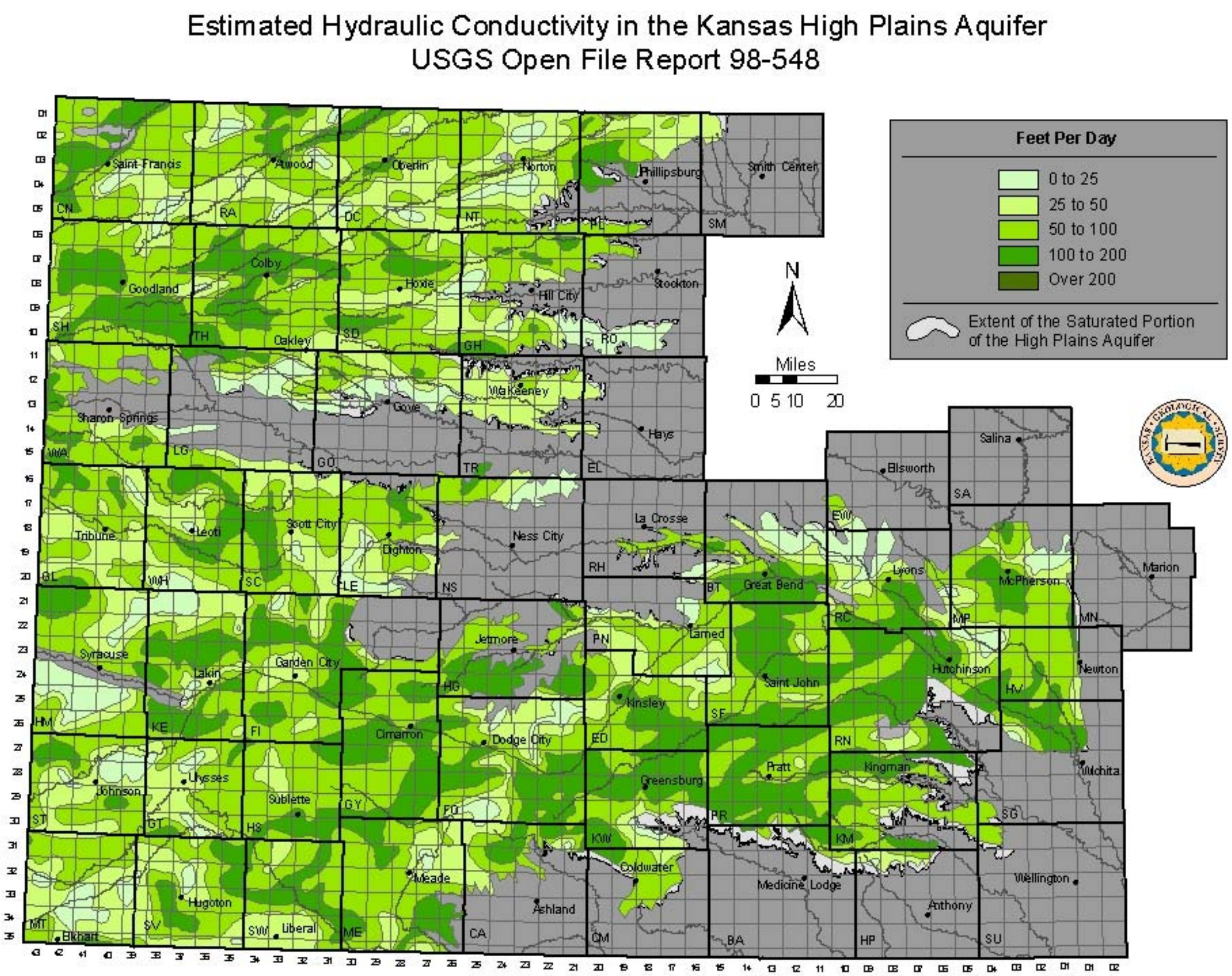


Figure 11 - Estimated hydraulic conductivity in the Kansas High Plains Aquifer. USGS Open File Report 98-548.

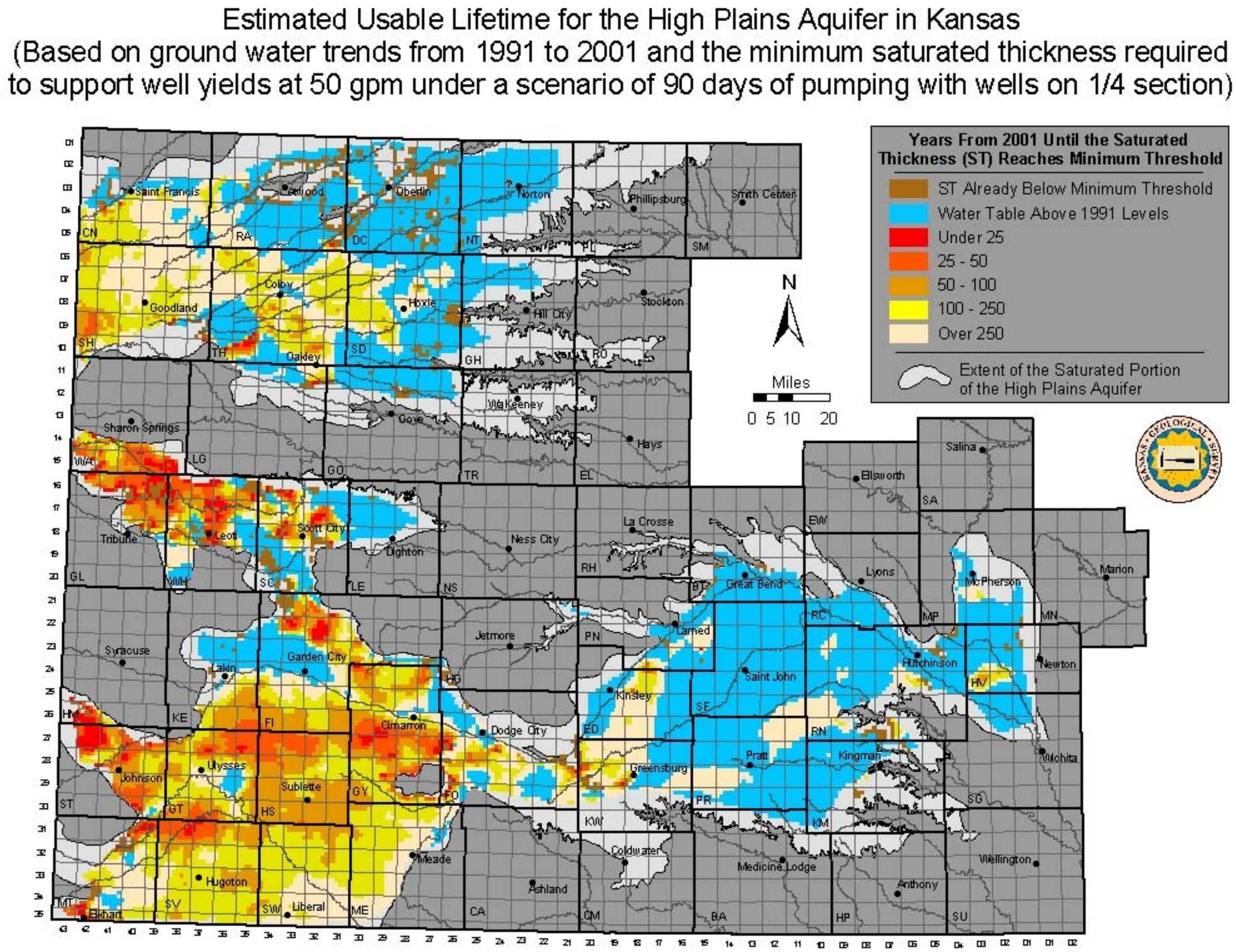


Figure 12- Estimated usable lifetime for the High Plains Aquifer in Kansas based on ground water trends from 1991 to 2001 and the minimum required saturated thickness required to support well yields at 50 gpm under a scenario of 90 days of pumping with wells on ¼ section.

Estimated Usable Lifetime for the High Plains Aquifer in Kansas
(Based on ground water trends from 1991 to 2001 and the minimum saturated thickness required to support well yields at 400 gpm under a scenario of 90 days of pumping with wells on 1/4 section)

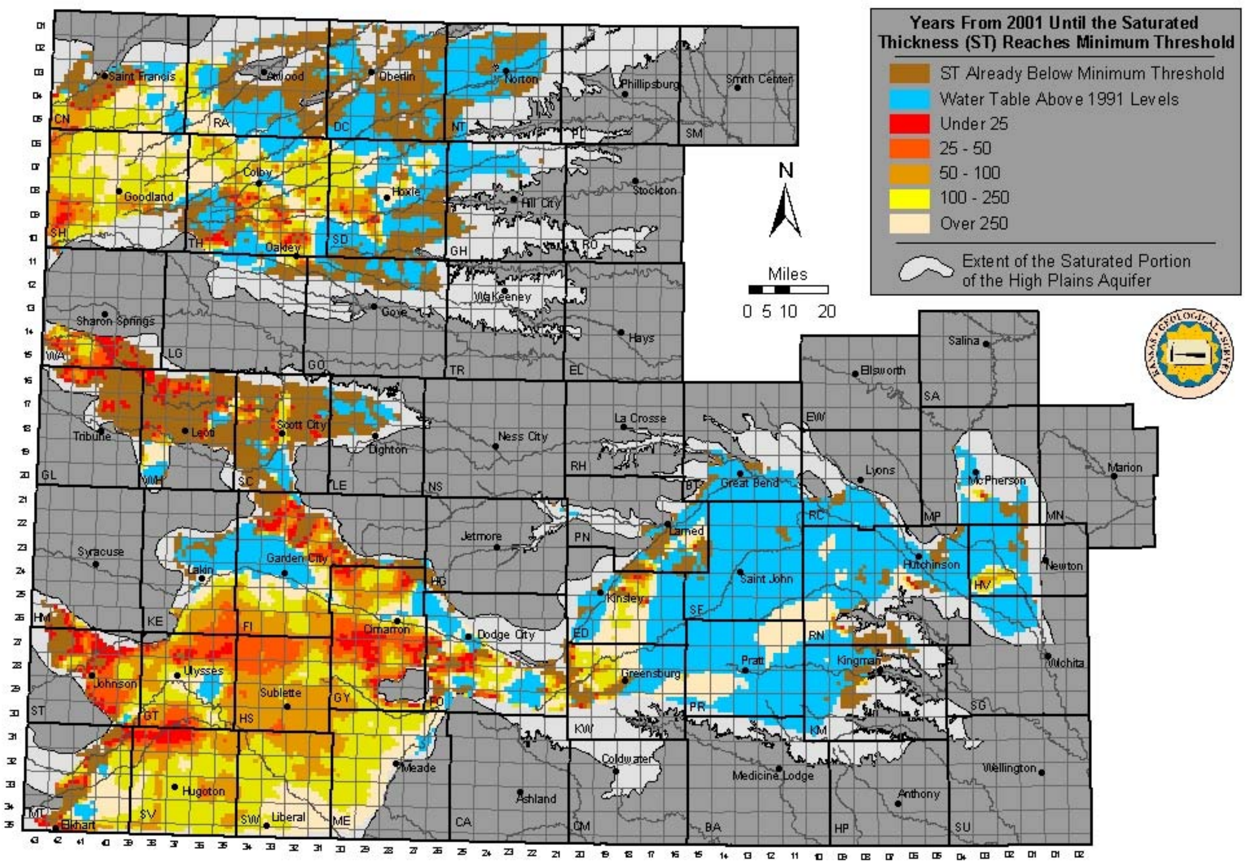


Figure 13- Estimated usable lifetime for the High Plains Aquifer in Kansas based on ground water trends from 1991 to 2001 and the minimum required saturated thickness required to support well yields at 400 gpm under a scenario of 90 days of pumping with wells on ¼ section.

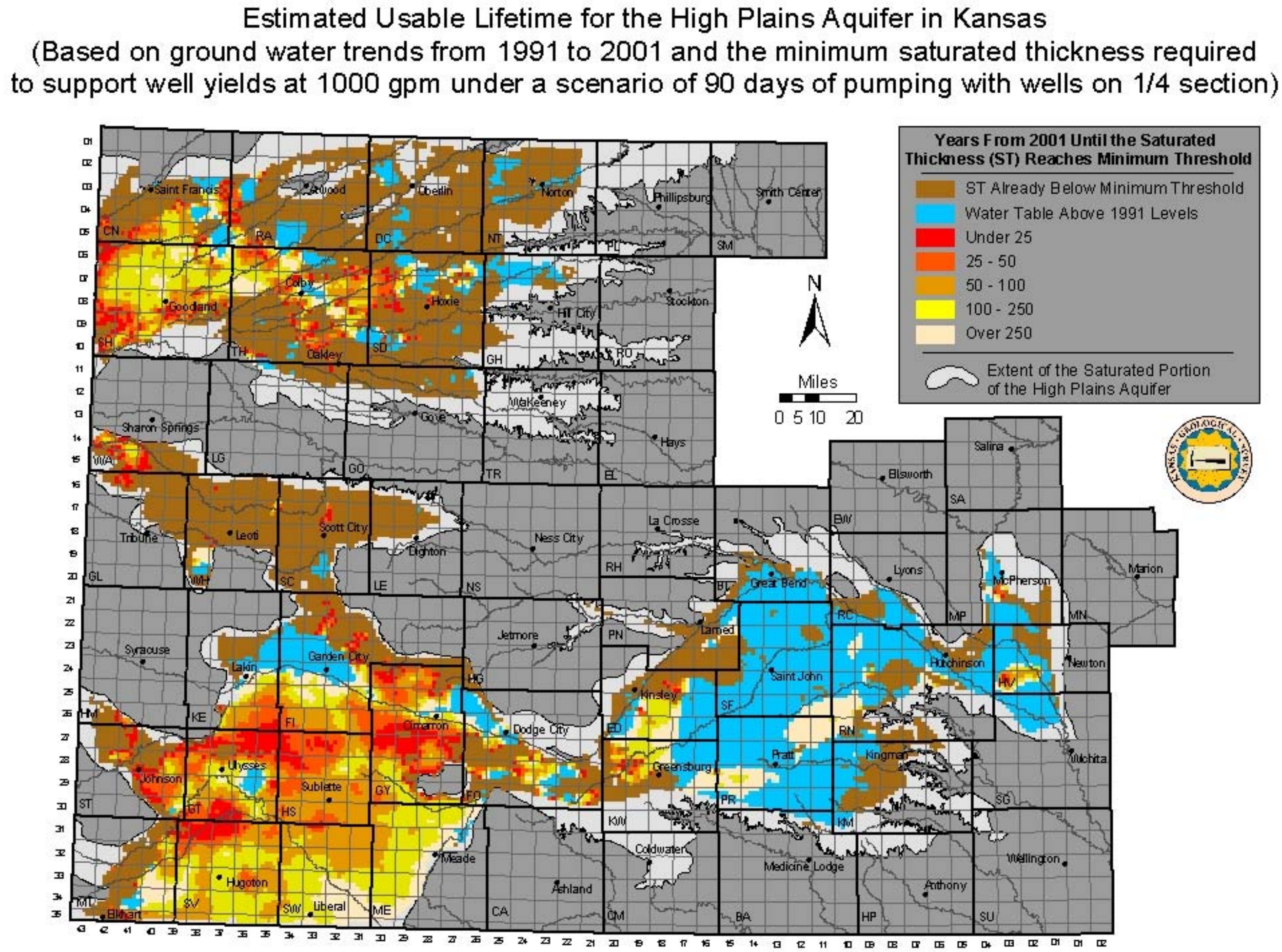


Figure 14- Estimated usable lifetime for the High Plains Aquifer in Kansas based on ground water trends from 1991 to 2001 and the minimum required saturated thickness required to support well yields at 1000 gpm under a scenario of 90 days of pumping with wells on ¼ section

represent an approximate value for low well yields. The lifetime estimates required for 1000 gpm (Figure 14) shows the greatest difference, particularly in terms of areas identified as already being below the minimum saturated thickness threshold. This is particularly true in the west central portions of the Ogallala-High Plains Aquifer and in the fringe areas of the aquifer in the northwest portion of the region where there historically has been less water right development.

A pumping rate of 400 gpm is used as an approximate value to represent the minimum flow required to operate a low-pressure sprinkler irrigation system. Comparison of the minimum required saturated thickness for 400 gpm identified in KGS OFR 2002-25C (Figure 13) and the 30 feet threshold (Figure 5) shows some interesting patterns. Overall, the two maps show similar patterns, but the most notable difference is in areas identified as already being below the minimum requirements, especially in the west central portions of the Ogallala-High Plains aquifer. The similarity and variability is expected given that the two figures are both based on the same estimates of saturated thickness and annual trends in the water table but use differing minimum saturated thickness thresholds. It is also interesting to note that the fringe areas of the northwest portion of the Ogallala-High Plains region where the water table is shown as not declining tend to be the same general areas where the saturated thickness is below required levels to support yields at 400 gpm.

3. Exploratory Geo-statistical Clustering Exercises

3.1 Unsupervised Classifications

Geostatistical clustering techniques, using the LoiczView web-based software (Maxwell and Buddemeier, 2002; www.palantir.swarthmore.edu/loicz/help), were employed to explore various ways to first subdivide the Ogallala aquifer portion of the High Plains aquifer and then based on those units, establish regression equations that can determine the change in the water table as a function of the amount of ground-water reported pumped each year. The clustering techniques were based on two data parameters consisting of section-centered values for the changes in the water table from 1991 to 2001 (Figure 1) and the density of average reported ground water use from 1991 to 2000 (Figure 15c).

Past clustering exercises involving reported water use resulted in very spotty cluster groupings caused by the nonuniform nature of water right development over the High Plains aquifer region. The concept of representing reported use as measure of density helps to regionalize the reported water use values. To create the maps shown in Figure 15 a-c, a 500x500 meter grid network was overlain across the region. Then for each grid cell, the average reported ground water use per square mile occurring within 2, 5, and 10 miles (Figures 15a, 15b, and 15c, respectively) of the cell was calculated. The goal of the water use density plots for this application is not to identify actual water use quantities per square mile, but rather to regionalize the influence of ground water pumping across an area. That regional characterization can then be used to compare the reported use within specific areas with corresponding changes in the water table. For the purposes of this report, the 10 mile water use density (Figure 15c) was selected for the clustering exercise.

Each of the Groundwater Management District areas of the Ogallala- High Plains, including the fringe areas surrounding each district, was clustered separately into 5 groupings. Since variance within and between data sets is the primary factor used by the k-means clustering algorithm, clustering the districts separately helps to focus relationships between the data parameters to better represent the conditions within each district area. Once the cluster groups were identified, the total reported ground water use and the average depth to water for all monitoring wells was calculated for each year between 1990 to 2000 for each subunit area.

Linear regression equations were then generated for each unit area to establish how total annual reported use in each year explains the variation in the changes in the water table. This process yields a factor, the R^2 value, that assesses the strength of the relationship tested. The higher the R^2 value, the stronger the correlation between water use and decline; values greater than about 0.8 represent an extremely strong relationship, and values greater than 0.5 - 0.6 are significant but weaker.

Results from this exercise are encouraging and can be seen in Figure 16, which shows the cluster groups for each GMD area and the resulting R-square value for the unit areas. Since each GMD area was clustered separately, the common colors between the GMD areas do not signify a relationship; they simply represent a unique area in terms of reported water use and changes in the water table within each GMD.

In general, the R^2 values are better in the GMD 1 and GMD 3 areas, and show weaker statistical relationships in the GMD 4 area. This may be caused by the spatial extent and size of each area, the number of water rights and monitoring wells within each area, the percentage of wells that reported metered water use (which is lower in GMD4), and the influence of other factors such as streamflow or surface water diversions, or the influence on recharge of topography, depth to water, land use, or streamflow (see OFR 2002-25B). Overall, where the R^2 values are high (> 0.8), it indicates that water withdrawals are the primary influence on ground water levels, which in turn accounts for the strong relationships to changes in the water table. Areas where the R^2 values are lower indicate the influence of other parameters such as the presence of surface water flow, higher local or regional recharge amounts, or data quality considerations (e.g. metered water use).

3.2 Supervised Classifications

The LoiczView software provides the option to conduct supervised clustering routines on data sets where unique areas within a region are identified as core or "type" areas. Similar to satellite classifications, the clustering routine associates other areas that contain data parameters that best match or fit the data variations within the core area. The Western Kansas GMD #1 was selected as a test case to explore various clustering exercises. This district was chosen for similar exploratory exercises with the Ogallala Technical Advisory Committee's work, which resulted in several clustering examples and unique data sets that are not yet available for the other western Ogallala-High Plains districts.

The GMD1 Manager was asked to identify some geographic areas that might serve as type specimens for regions or classes of conditions. He selected seven blocks of sections that were approximately township size, including: two in Scott County from the Scott-Finney depression area (area 1 has adequate quantity, somewhat questionable quality, and concerns about over appropriation; 2 has good quantity and quality); three that were considered representative of their general geographic regions in terms of hydrology and water use (locations 3, 4, and 7 in Lane, Wichita and Wallace Counties, respectively); one (Area 5 in Greeley County) where there are concerns about overdevelopment, and one (Area 6 in Wallace County) that is considered unique and unlike the rest of the District in overall hydrology.

The supervised classification function of Loiczview was used to cluster the district into areas that best fit the characteristics of the core areas initially identified by the GMD #1 Manager. For comparison purposes, a separate unsupervised classification routine was run as well. For this particular exercise, the clustering procedures were based on changes in the water table from 1991 to 2001 (Figure 1), the 2001 saturated thickness (Figure 4), and the 10 mile reported ground water use density (Figure 15c).

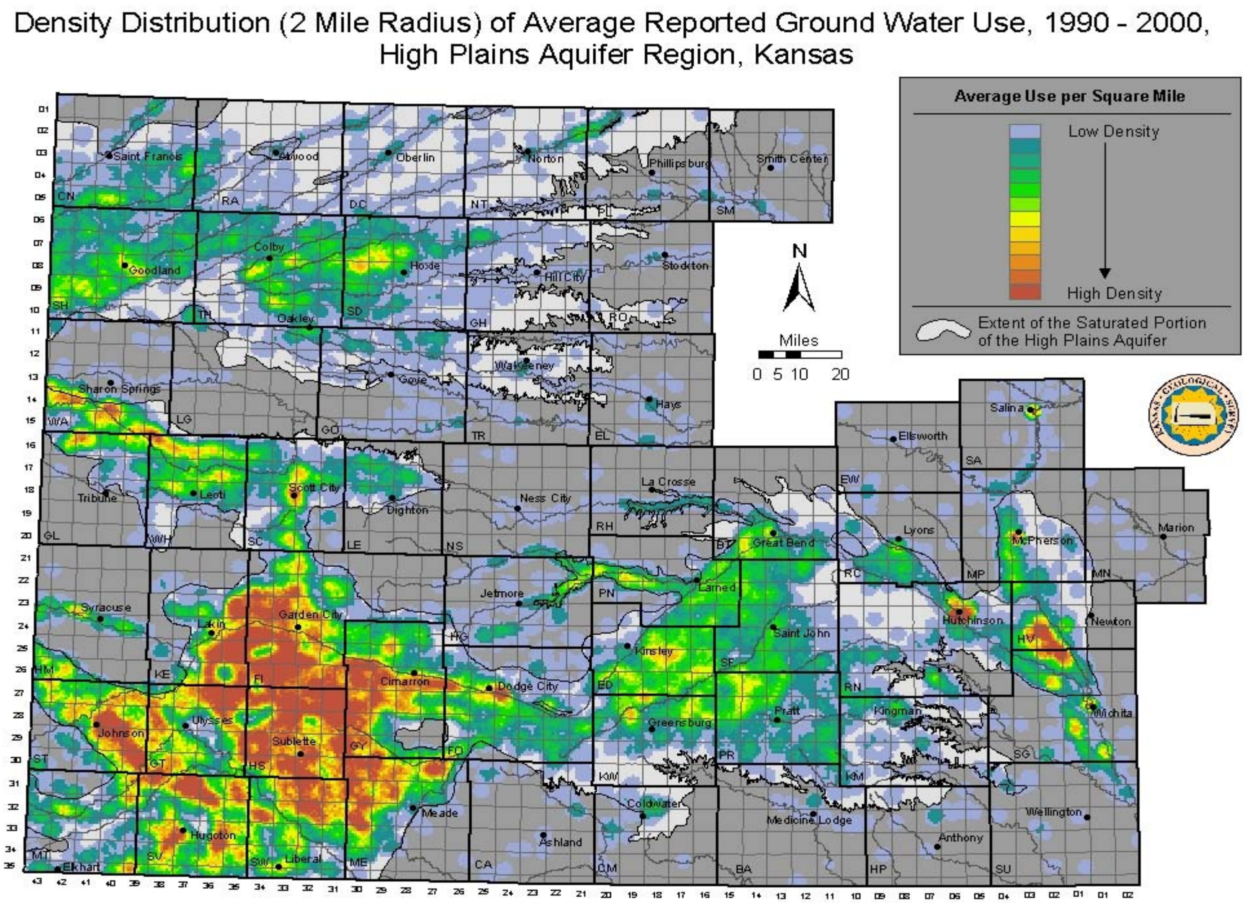


Figure 15a- Density Distribution (2 Mile Radius) of Average Reported Ground Water Use, 1990-2000, High Plains Aquifer Region, Kansas

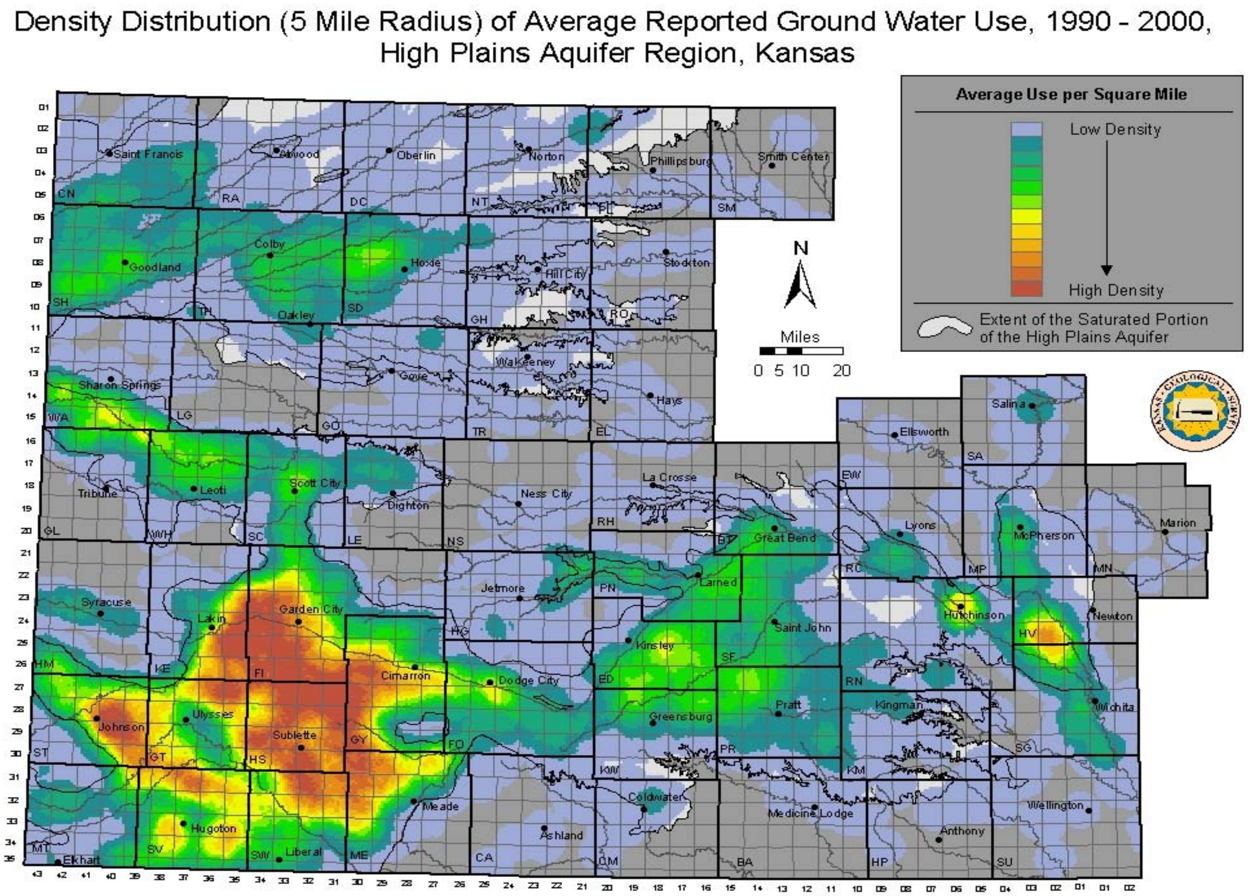


Figure 15b- Density Distribution (5 Mile Radius) of Average Reported Ground Water Use, 1990-2000, High Plains Aquifer Region, Kansas

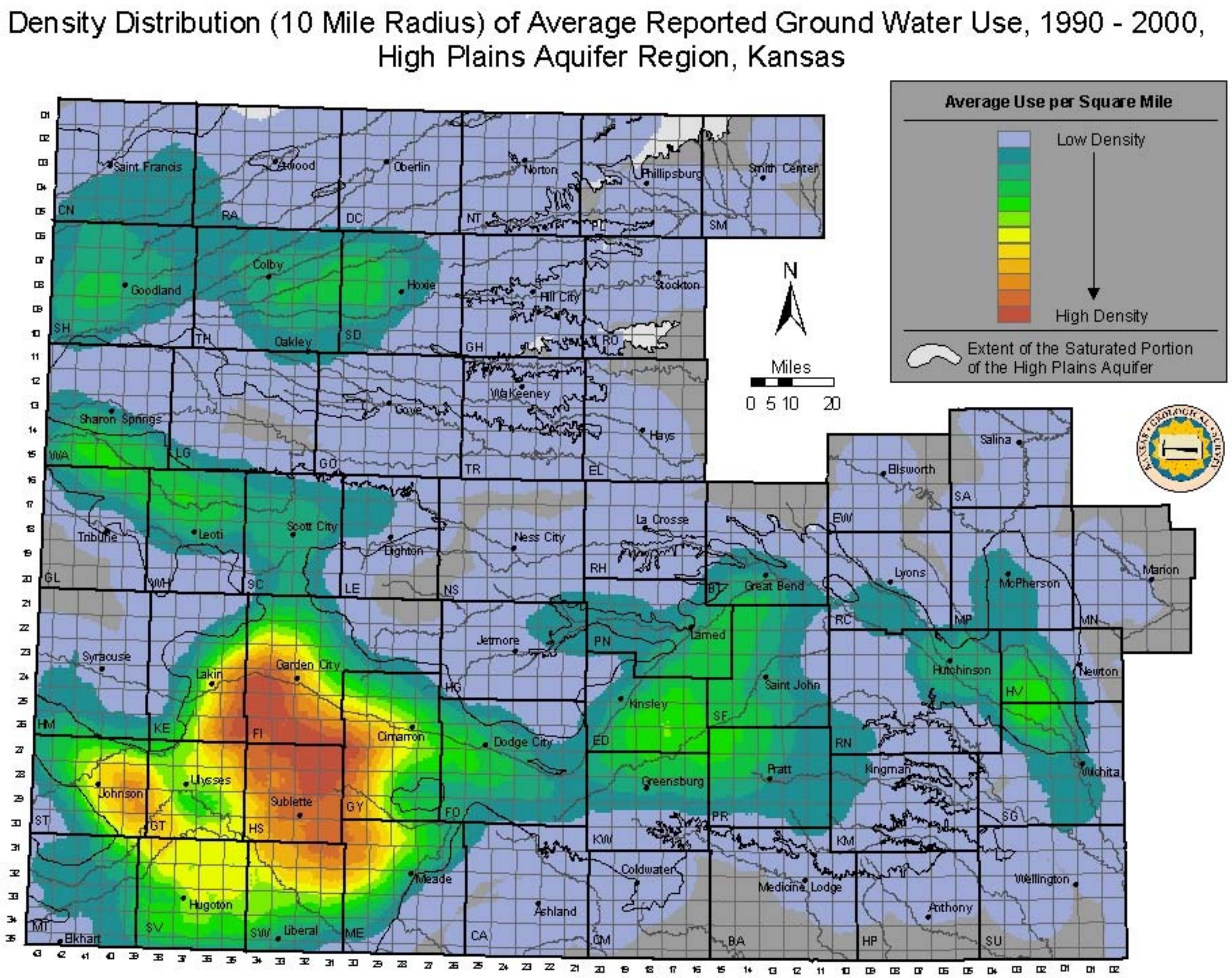


Figure 15c- Density Distribution (10 Mile Radius) of Average Reported Ground Water Use, 1990-2000, High Plains Aquifer Region, Kansas

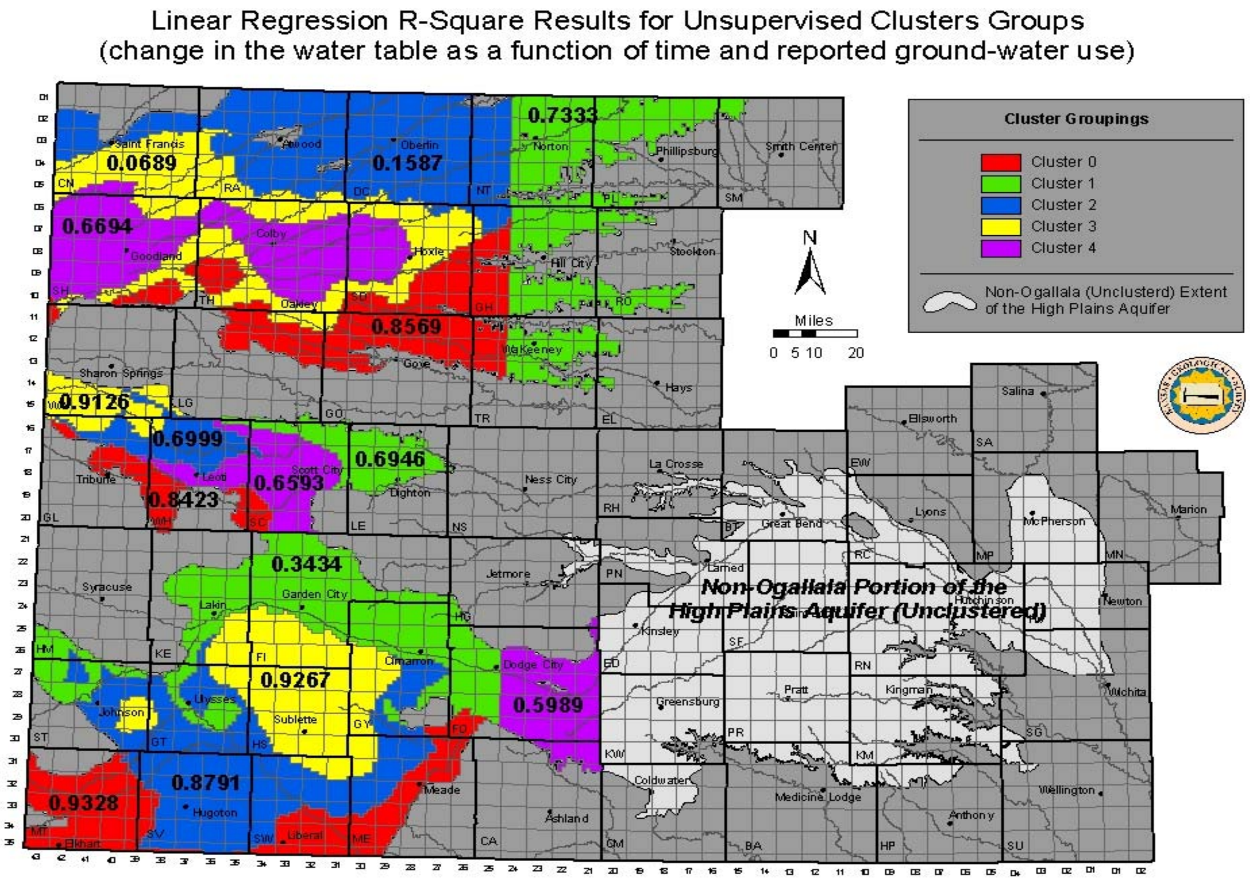
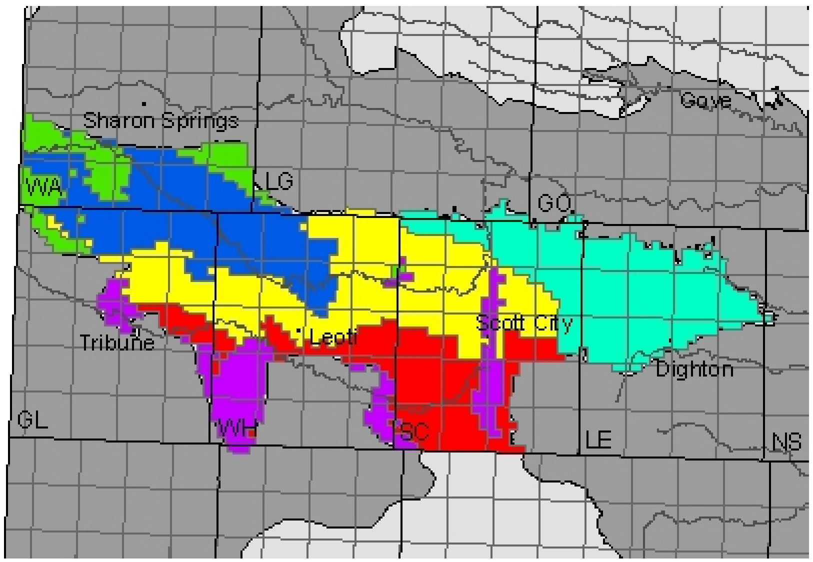


Figure 16- Linear regression R-square results for unsupervised cluster groups. Each GMD area of the Ogallala-High Plains, including the fringe areas surrounding each district, was clustered into five groupings. The common color schemes between the district areas have no relationships to one another.

Comparison of Unsupervised vs Supervised LoiczView Clustering Groups, GMD #1

Unsupervised



Supervised

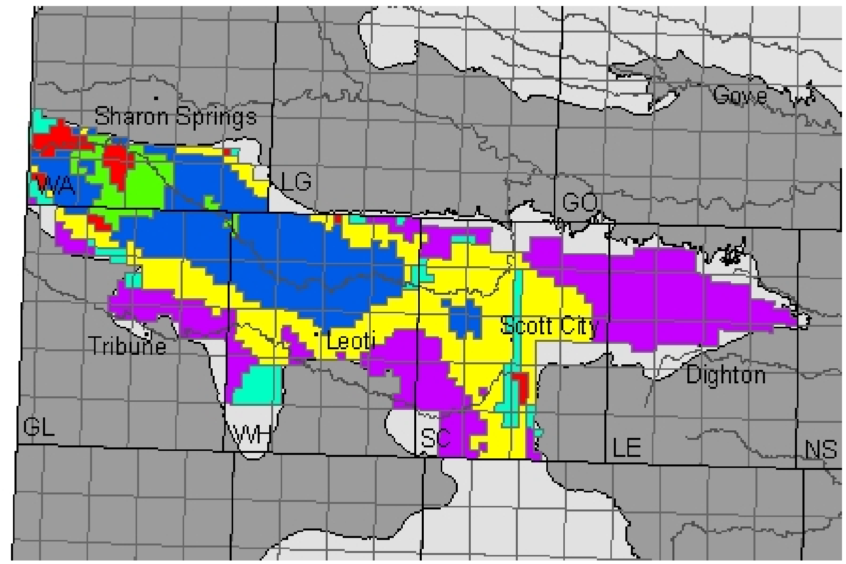


Figure 17- Comparison of Unsupervised vs Supervised LoiczView Clustering Groups, GMD #1.

The results of this comparison between unsupervised and supervised clustering routines can be seen in Figure 17. Overall, both the unsupervised and unsupervised methods produced similar groupings. The advantages of the supervised clustering applications for the purpose of identifying aquifer subunits is that local expert knowledge and judgment can used as the initial input to the clustering process. This allows managers to identify other areas within a region that may have similar characteristic to areas of known aquifer properties, and to test the results of unsupervised clustering against local expertise. The primary advantage of the unsupervised clustering routines is that data relationship that may not be well known or recognized can be identified. The common colors between the clustering groups do not signify a common relationship between unsupervised and supervised methods; they simply represent a unique area in terms of the 2001 saturated thickness, density of reported water use and changes in the water table within each GMD. The unique areas that are identified spatially do represent a common relationship such as can be seen in Lane County in the eastern portion of the district.

4. Data Limitations and Applications

4.1 Estimated Usable Lifetime

The estimated usable lifetime maps are a unique way to classify ground water changes in the aquifer. However, they are based simply on estimates of past rates of change and how that change, if it is accurately assessed and continued unabated into the future, would impact the existing aquifer storage. The results of KGS OFR 2002-25C indicate that the minimum saturated thickness required to support large-volume demands is substantially greater than the thirty foot value originally used to estimate the usable lifetime. Considering the great variations that occur in climatic factors (OFR 2002-25E), pumping amounts, and other economic considerations, there is considerable uncertainty in those estimates. This is particularly true for the longer time estimates (50 years or more).

Lifetime estimates based on well yield are dependent on the data quality and level of detail available for aquifer characteristics such as hydraulic conductivity and specific yield. Although the available maps provide a basis for classification and management planning, detailed management implementation will need to take into consideration the issues of aquifer heterogeneity raised in OFR 2002-25C.

The annual rates of change used to estimate the usable lifetime of the aquifer are based on the differences in elevations from the start to end of a given time period. If the water table over a ten-year time period dropped ten feet, the annual rate of change is calculated as 1 foot per year. This approach does not account for the various possible conditions of how that change actually took place; the water table could have dropped 11 feet in one year and then risen one foot over the remaining nine years. The conditions under which this pattern of change can be projected into the future are very different from the scenario where the water table gently declined 1 foot a year over a 10 year time period. Detailed observations show that the water table fluctuates significantly over both time and space (see OFR 2002-25F). The trend uncertainties caused by these variations and calculation assumptions suggest that classifying the estimated usable lifetime of the aquifer at 10-year intervals should be approached with caution. However, regardless of classification, the estimated usable lifetime maps do outline areas that are subject to potential resource exhaustion, and provide relative comparisons among different areas.

4.2 Geo-statistical Clustering

The use of geo-statistical clustering techniques is showing strong promise in identifying areas of the aquifer that share common parameters and association. The limitations in the process are generally the limitations imposed by the data, and how those data are portrayed, interpolated, or classified. For example, past attempts at using reported water use at the section level were probably not suitable for identifying larger homogenous areas. Using techniques such as a reported use density helps smooth out the data, and provides a better representation of the influence of the parameter at spatial and temporal scales comparable to water level and other data collected on a larger scale.

5. Policy and Management Implications

Both the estimated usable lifetime concept and geo-statistical clustering methods show promise as tools to develop the protocols necessary for the delineation of aquifer subunits and to further evaluate potential management concepts within subunit areas. Areas of similar characteristics could be defined as a subunit. For a given set of conditions and data relationships, management scenarios could be developed and further evaluated.

The maps portraying the estimated usable lifetime of the Ogallala-High Plains aquifer are based on changes in the water table elevations in a manner that can be readily understood by most individuals. In the past, data and maps showing only changes in the ground water, although informative, did not account for how that change relates to the amount of water in storage. Relating the change in the water table to a specified storage level allows management and policy development that can be better related to the implications of ground water changes for future planning and socioeconomic issues. Regardless of the uncertainties involved with the methodology, this technique of portraying ground-water changes identifies the relative vulnerability of areas to resource exhaustion in terms of large volume water demands.

The use of geo-statistical clustering procedures shows great promise for identifying potential aquifer subunit areas with common characteristics. Relationships between different data parameters can be further identified and examined, and clustering with projected characteristics can show how proposed management concepts might impact the water resource and the nature of the subunits. The use of expert judgment in identifying unique areas for the supervised clustering approach allows local knowledge to be incorporated into the statistical processing procedure, permitting the clustering focus to be tailored to unique characteristics of the individual management areas.

6. Potential for Improved Data or Applications

In view of the prospects for aquifer subunit identification and future management focus on smaller target areas, a review of the state's cooperative monitoring well program should be undertaken (see OFR 2002-25F for a more detailed discussion). The initial network (see section 2.5, OFR 2002-25G) was established for a particular purpose and need, which may not suffice for the management approaches of the near future. The program goals and objective should be evaluated to insure the resources used for this program are focused on the overall planning and management effort of the State.

Well log and local pump tests can be used to refine estimates aquifer of characteristics at higher resolution in selected regions. The procedures and results of OFR 2002-25C can be used to further refine and improve usable lifetime estimates. In addition, climatic factors

(OFR 2002-25E) and reported water use should be explored as potential parameters to include and account for when making lifetime estimates of the aquifer.

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