Kansas Geological Survey

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The Kansas water context: Background, description, and summary of work

By

R. W. Buddemeier, B. B. Wilson, and D. O. Whittemore
(Kansas Geological Survey)

T. Huntzinger and T. Alder
(Kansas Department of Agriculture – Division of Water Resources)

E. Lewis and S. Stover
(Kansas Water Office)

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Kansas Geological Survey Open File Report 2002-25A

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The University of Kansas, Lawrence, KS 66047: (785) 864-3965; www.kgs.ukans.edu

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1. Introduction and background

1.1 Description of report origins and objectives

This report (OFR 2002-25A) describes and summarizes the activities and findings of the Kansas Geological Survey (KGS) as part of the Ogallala Technical Support Activity during state fiscal year 2002 (July 2001- June 2002). Details of the activities and findings are reported in the other components (B-G) of the report series KGS OFR 2002-25. The report series serves as the contract completion report for Kansas Water Office (KWO) and Kansas Department of Agriculture – Division of Water Resources (KDA-DWR) contracts with KGS, and also presents related material relevant to the FY 2004 Draft Kansas Water Plan's planning goals and objectives for the Ogallala-High Plains aquifer. Box 1 discusses and defines the aquifer names and terms used. Figure 1.1 represents the region of interest, with the management and regulatory bodies identified by their area of responsibility.

This project benefited greatly from 'adaptive management' in the form of both coordination and active cooperation among the major participating agencies, KGS, KWO, and KDA-DWR. Although the technical contents of the topical reports are the responsibility of KGS, this overview report lists as authors the key contributors from all agencies, reflecting the broadly based contributions to formulating the objectives and presentations.

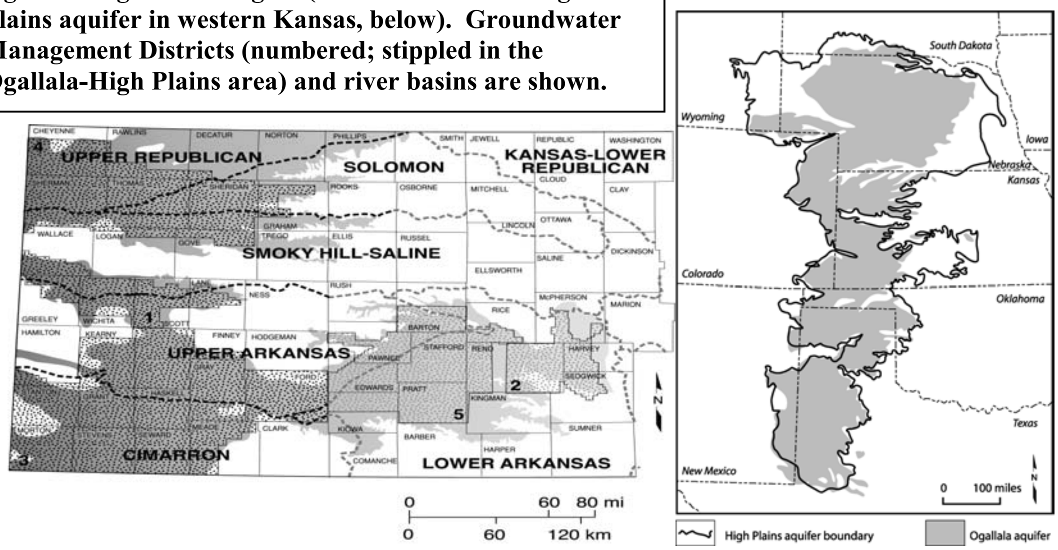
Box 1: Terminology and definitions

The term High Plains Aquifer refers to a regional aquifer system that is made up of numerous hydrologically similar formations. In Kansas, the major components of the High Plains system are the Ogallala, Equus Beds, and Great Bend Prairie aquifer areas, plus the alluvial (stream valley) deposits that overlie and connect with the larger, deeper aquifer deposits.

We use the term "**High Plains aquifer**" to refer to all of the components of the system, and "**Ogallala-High Plains**" to discuss issues particularly relevant to the Ogallala region of the Kansas High Plains. The term "**Ogallala**" is reserved for discussions that relate only to the area that includes the geologically defined Ogallala Formation (right-hand map, figure 1.1). The Ogallala region of the Kansas High Plains is the western part of the state; it differs from the eastern High Plains more in terms of climate (drier in the west) and water management traditions (historically, programmed depletion in the west, safe yield in the east) than it does in geology or hydrology. For this reason we adopt the KDA-DWR convention of defining the boundary between the Ogallala-High Plains and the eastern High Plains as approximately the Ford-Edwards county line (left-hand map, figure 1.1).

The Kansas Water Plan context for the work includes the contributions of the Ogallala Aquifer Management Advisory Committee (MAC) and its supporting Technical Advisory Committee (TAC), which were formed from stakeholders and field experts to review options and submit recommendations to the Kansas Water Authority for inclusion into the State Water Plan. The KGS agreed to provide information on a set of basic science issues identified as contract deliverables, to provide technical support as required for the committee deliberations, and to coordinate closely and regularly with KWO and KDA-DWR to achieve overall objectives within the fixed resource base and the context of the committee recomendations. This report series represents the product of that ongoing close coordination and cooperation among the participating agencies.

Figure 1: The Ogallala geologic formation compares with the High Plains Aquifer System (right) and the Kansas Ogallala-High Plains region (darker area of the High Plains aquifer in western Kansas, below). Groundwater Management Districts (numbered; stippled in the Ogallala-High Plains area) and river basins are shown.



1.2 FY2002 activities and developments

During the first quarter of FY 2002, the KGS provided technical support to the Ogallala MAC and TAC committees. Technical information sheets produced in response to specific questions posed by the committees or individual members are reproduced in section 2 of OFR 2002-25G of this report series, and are precursors of some of the topical report sections.

The Committee reports (KWO 2001) that were adopted for inclusion into the FY 2004 State Water Plan recommend designation of hydrologic subunits of the aquifer, subunit prioritization in terms of expected usable lifetime and/or other relevant variables, assessment of management options, and development of additional or refined data in support of enhanced management approaches to priority subunits. Three of the specific recommendations and a number of the implementation options suggested are central to the development of the directions and work products reported here, and are reproduced in section 3 of OFR 2002-25G.

The Kansas Water Plan schedule recommends that each management organization (GMDs 1, 3, 4, and the DWR) prepare a draft protocol for identifying and prioritizing aquifer subunits by November, 2002, with the expectation that final versions would be adopted by the KWA in July 2003. It is anticipated that management approaches will be developed following identification of high priority subunit areas. Therefore the emphasis in this report is on concepts, procedures, and findings that can be applied on a time scale of months and implemented on a time scale of a few years. Existing data and technology are considered adequate to designate initial subunit areas and develop management goals for them; the topical reports in this series describe and assess those, and identify improvements that may be necessary or desirable for implementation of detailed subunit management. These reports draw on a range of existing data and other sources of information to present the most comprehensive and up-to-date response to the questions and data needs posed.

1.3 Report organization and contents

This report (OFR 2002-25A) presents a summary of the interagency consensus on objectives and rationale developed through the regular meting and joint reviews conducted by KGS, KWO and DWR in section 2. Section 3 of the report consists of an executive summary of the key technical findings and conclusions of the topical report sections, OFR 2002-25B-F. Section 4 acknowledges contributions and sources of information, logistic and financial support not spelled out in the body of the reports.

The major technical products are the topical reports in this OFR 2002-25 series, addressing the deliverable categories of the contracts (reproduced in section 4, OFR 2002-25G) within the context of the background and rationale described in sections 1 and 2 of this report (OFR 2002-25A). OFR 2002-25G is a compilation of supporting documents that includes the technical information sheets developed for committee support, the contracts, and relevant excerpts of the committee report. These reports and information products derived from them are available over the WWW (http://www.kgs.ukans.edu/HighPlains/OHP/), and may be purchased from the KGS in printed form.

2. Product objectives and interagency rationale

This section presents the consensus statement of major report objectives and their primary justifications, arrived at by discussions among KDA-DWR, KWO, and KGS.

2.1 Kansas Water Plan background

The Kansas Water Authority 2001 report to the State Legislature on “The potential for competing water needs for at least the next 20 years and the means of addressing the competition” (H.S. for S.B. 287) recommended development of state policy that serves to sustain the replenishable portions of the State’s ground water, provide transitional guidance when the ground water starts to become exhausted, and delineates the Ogallala portion of the High Plains aquifer into subunits based on aquifer characteristics.

In response to these recommendations, the Kansas Water Office convened an Ogallala Aquifer Management Advisory Committee that prepared a report addressing the challenges of long-term management of the Ogallala-High Plains aquifer. Their report and recommendations are approved in the FY 2004 Kansas Water Plan. A fundamental issue for long-term management of the Ogallala-High Plains aquifer stems from the depletion occurring as substantial withdrawals for irrigation far exceed recharge in many areas of the aquifer. Also, the spatial variability in aquifer characteristics and withdrawal rates result in varying levels of depletion, ranging from no water level decline to declines that have resulted in near exhaustion of the water supply. Technical guidance was needed for implementation of some of the Ogallala-High Plains aquifer management recommendations. At the request and with the support of the Kansas Water Office and the Division of Water Resources, the Kansas Geological Survey has prepared a series of reports that are intended to provide technical guidance that will support development of sustainable water management of the Ogallala-High Plains aquifer in western Kansas.

2.2 Protocol development and management objectives

Goals of sustainable management of the Ogallala-High Plains must focus on scientifically valid and socioeconomically effective ways to decrease withdrawal rates and consumptive use in a spatially and temporally variable hydrologic setting. It is also important to recognize the expansive area covered by the Ogallala-High Plains, and that addressing all management questions with equal intensity over the entire area is neither achievable nor necessary. This series of reports focuses on approaches to quantifying the variability of selected parameters of the water budget that are critical targets for decreasing or eliminating groundwater depletion, and on evaluating information needs and the applicability of existing data. In addition, the papers provide insight into objective technical criteria for defining high priority areas where the need for water management action is the most urgent.

An effective approach to sustainable water management of the Ogallala-High Plains will include two parts, planning and management. The planning effort should encompass three primary objectives:

1. Define the most significant aquifer and hydrologic parameters that describe variability.
2. Identify, describe, and establish accessible data sets that can be used to define hydrologic subunits of similar aquifer characteristics and hydrologic settings and to quantify aquifer water budgets.
3. Determine priority areas based on projected useable lifetime of the aquifer, or appropriate related parameters.

The planning effort will define and enable water management activities that are expected to result in extending the life of the aquifer system, and ultimately in sustainable management of the resource. Primary management-related activities include:

1. Focusing refined information compilation and water management efforts in the highest priority subunits based on the highest levels of risk from projected groundwater depletion and shortages
2. Defining scientific, economic, and social factors that are required for sustainable water management.
3. Determining the withdrawal rates and threshold water levels that are expected to result in sustainable water use management in each high priority area
4. Comparing water management options using the projected lifetime and economic thresholds as measures of relative success of each option.
5. Selecting and implementing specific management options for each priority subunit.

2.3 Topical report descriptions and purpose

This series of reports addresses the scientific and hydrologic topics that are essential to implementing the planning and management approach described above. The technical foundation established by this work is expected to provide a common scientific understanding and initial focus for a coordinated water planning and management effort for the Ogallala-High Plains, and for the necessary development and interpretation of the supporting data and information bases. State agencies, local entities, water users, and the general public will have equal access to the information and technical tools needed to address the challenges of sustainable water use management.

The following paragraphs briefly describe the major report components in terms of their primary rationale and objectives. Section 3 of this report provides a brief outline summary of the key findings and conclusions of those reports.

2.3.1 Recharge

2002-25B: Best estimates of aquifer recharge: magnitude and spatial distribution.

A reliable estimate of recharge magnitude is important in defining long-term management options that include setting goals for withdrawal rates. Recharge to the aquifer is the only volume of water that is a renewable resource, and withdrawals must be of the same magnitude as the recharge to be sustainable. Although recharge rates are not easily measured, there have been several studies in the past that have computed estimates of recharge. The first topical report summarizes past estimates and provides a range of values. It discusses distinctions between natural recharge and modifications by human activity, assesses uncertainties in the estimates, and provides information about the availability and appropriate use of existing and probable future data.

2.3.2 Well Yield

2002-25C: Calculation of yield for High Plains aquifer wells: relationship between saturated thickness and well yield.

Water use in the Ogallala-High Plains is dominated by large-scale irrigation withdrawals. Well yields are a limiting factor in the ability to effectively apply irrigation water, and water supply is limited by the saturated thickness of the aquifer. Topical report 25C describes the relationship between saturated thickness and well yields and how its spatial variability is defined by the spatial variation of hydraulic conductivity that is how easy it is for water to flow through the aquifer. For a given set of aquifer and water use characteristics (i.e., density and pumping rate of nearby wells), a threshold saturated thickness can be defined for the minimum well yield required to sustain large-scale irrigation. The saturated thickness required to maintain an effective well yield for irrigation is a key threshold that needs be determined to predict the water level at which large-scale withdrawals would cease or substantially decrease. The same considerations apply to determining a specific threshold water level that needs to be maintained in order to establish a secure minimum water supply for all users. For a more general application, it would be important to determine if the well yields at the minimum acceptable saturated thickness for non-irrigation water supplies are capable of delivering a flow rate adequate to support large-scale irrigation.

2.3.3 Usable Lifetime/Aquifer Subunits

2002-25D Exploring relationships between water-table elevations, reported water use, and aquifer lifetime as parameters for consideration in aquifer subunit delineations.

Report 2002-25D addresses the approach to projecting a usable lifetime of the aquifer. The pumping rate is the only variable in the water balance relationship that is directly controlled by water management options, so it is critical to develop some means of relating pumping rates in specific subunits to sustainability and rates of depletion. It is also important to describe the spatial variation in the time required to reach the threshold water levels in terms of time intervals useful for water management and economic decisions. Many business decisions such as capital investment and operational loans are made with 10-year time lines.

Two basic approaches may be used to make this projection. One extends the historic trends in water level decline to the time when the saturated thickness reaches a given minimum threshold value. This the typical technique; it relies only on historic water level data that is readily available, but projections of future declines necessarily assume water use and management practices similar to those of the past. The second approach uses withdrawal rates and aquifer storage characteristics to compute the time required to exhaust the current volume of water in storage above the minimum saturated thickness threshold by projecting future withdrawal rates until the cumulative withdrawals exceed the calculated volume of water available. This approach has the advantage of making it possible to test the expected effectiveness of various water management options that would affect withdrawal rates.

This report shows how lifetime estimates are affected by estimates of threshold values, and uses the results of the well yield determinations in 2002-25C to produce refined maps of expected useable lifetimes. Statistical comparisons show that in many areas of the aquifer the two methods (water level trends and volumes withdrawn) will give similar results when applied to past aquifer declines to determine the time to deplete. For applying water level trends, the report shows that limitations of the data require time intervals on the order of 25 years to assess results at the local (section-scale) level. However, the more desirable 10-year interval is probably adequate for use at the township scale in most areas, and report 2002-25F addresses ways in which trend data can be improved at all scales.

2.3.4 Climate

2002-25E: Climatic variation: implications of long-term records and recent observations.

Withdrawals from the Ogallala-High Plains are primarily used to satisfy irrigated crop demands, which are driven by climatic conditions. This report shows the frequency and duration of climatic variations (such as drought occurrence) that affect water demand. Successful water management options will be measured by their ability to satisfy crop moisture demands projected into the future while staying within the limits of the water supply. Climatic records adequate for estimating crop consumptive use covering the Ogallala-High Plains are at best 50 years in length. The experience of water users with large-scale irrigation is also limited to 50 years or less. It is important to determine how representative of the long-term climatic patterns of wet and dry periods these 50 years have been, since sustainable water use management will ultimately rely on natural precipitation and minimal irrigation, and recharge must replenish withdrawals over the long term. Analysis methods are available to define long-term variations by using correlations of instrumental records (the past 100 years) with paleo-evidence such as tree ring data. Climatic indicators comparable to the Palmer drought index and some evapotranspiration models are used to show climatic patterns back to the 1700s with reasonable precision and can indicate major features for the past 1000 years or more. These analyses provide a useful quantitative sense of the expected frequency and duration of dry and wet periods.

2.3.5 Uncertainty

2002-25F Scale, uncertainty, and the relationships among basic data, information, and management perspectives.

The fifth topical report addresses the question of the appropriate scales of data application and analysis, and of implementation of results. Planning decisions involve a more general application of data and analysis than is required to assess water management alternatives. In turn, assessing management alternatives can effectively be done at a greater level of generality than the detail that may be required for implementing selected management options. The uncertainties in the data sets used in analysis determine the spatial scales and temporal frequency that can be used in management decisions, and management plans will intrinsically specify the amount and quality of data needed to implement them. In general, the outcomes of planning and management decisions must relate to criteria or predictions that can be reliably evaluated with the data sets and analytical tools that are or will be available. Knowledge of the data available and their accuracy, precision, and sources of uncertainty permits reliable judgment about the appropriate space and time scales of decision outcomes that can be evaluated with confidence.

Most data sets that provide input to a water budget and define the basic hydrologic setting are or can be made available by interpolation or extrapolation to the spatial scale of about a square mile. However, these data sets vary in their appropriate scale of application; the report summarizes these scales, demonstrating that currently available data can support planning and management option evaluation at about the township size scale. Temporal resolution of data sets is generally annual or seasonal; this report and 2002-25D show that decadal scales of integration are appropriate for township-scale and larger units, but that uncertainties in the present water level data set require longer time periods of consideration in some local-scale cases. The report identifies means of reducing uncertainty levels in water level data for the high priority areas. It is therefore reasonable to expect implementation of subunit protocols, prioritization, and management plan development at these scales (township and decadal), which are acceptable for all planning outcomes and most water management applications. However, identification and evaluation of local management criteria and objectives, as well as enforcement and regulatory functions, would require refinement of some data sets with well-defined objectives.

3. Summary of major findings and conclusions

The points listed below are excerpts of the major points from the other reports in the series. This summary extracts the key findings reported in OFR 2002-25B-F, with an emphasis on considerations relating to subunit protocol and management plan development. In addition to the specific excerpts, an integration and summary section is added to each topic to link relevant material across the separate reports and to develop recommendations for those who will be developing and applying protocols.

3.1 **Recharge:** Detailed explanations and illustrations are presented in OFR 2002-25B.

- Recharge is influenced by precipitation amounts and patterns, temperature and other climate factors, soil and sediment type, topography, depth to water, and land cover and water use (especially irrigation). Although some of these factors are relatively constant over time, all vary over space and a number of them are subject to either substantial variability or long-term trends over time.
- Recharge for a given hydrologic system can be calculated from measurements of water inventories, inflows, and outflows; it can be modeled by other techniques such as ground-water flow simulations, or it can be measured directly over relatively small areas and short periods of time.
- Available estimates or measurements for the High Plains in general and Kansas in particular are either very large-scale budget or model estimates, or quite localized point or small area measurements (see section 1, OFR 2002-25F for discussions of scale issues). Measurements or models applicable at the intermediate (township-size) scale of aquifer subunits are generally lacking. Quantitative assessment of the effects of irrigation on recharge is not currently practical based on available data. Significant improvements would require extensive field studies conducted on time scales of many years.

- Irrigation return flow can be a major source of localized recharge. Although this does not necessarily reflect new water being introduced to the local hydrologic system, it is a parameter that complicates the accounting, especially in water balance equations or budget calculations.
- Annual recharge to the Ogallala-High Plains aquifer ranges from substantially less than an inch over grassland in uplands with clayey soil to probably as much as a couple of feet under the alluvial aquifer of the Arkansas River valley where clay layers are thin or absent between the alluvium and the underlying aquifer.
- As a case study example, the substantial spatial and temporal variations in recharge occurring in the upper Arkansas River corridor are reviewed in section 3 of OFR 2002-25B, and serve to further illustrate how recharge and the parameters associated with its process are highly variable in time and space even at the sub-regional level. Similar or greater variability can also be expected at the regional level.
- **Integrative and summary conclusions:** There is little practical likelihood that recharge estimates or measurements can be made sufficiently quantitative and predictive to serve as a primary basis for management on the scale of aquifer subunits. However, the factors influencing recharge can be evaluated and mapped, and can serve as useful classification or comparison indicators for distinguishing hydrologic subunits. On the basis of these factors and existing estimates, the probable magnitude of recharge can be estimated at the subunit scale.

3.2 Well Yield

- Well yield (the maximum sustainable rate of pumping) is determined by the available saturated thickness, aquifer hydraulic conductivity, and aquifer storage coefficient (specific yield), in addition to pumping well interactions and well construction and condition.
- For a given well design and set of aquifer characteristics, the minimum saturated thickness required to sustain any specific pumping scenario can be calculated. An example of the type curves is given in figure 1.2.
- An initial set of estimates of minimum saturated thickness required for three theoretical well yield values and three pumping geometry scenarios has been prepared. The relationships to current saturated thickness are mapped in Section 3.2 of OFR 2002-25C (see also figure 1.3 below).
- The 2000 Atlas of the Kansas High Plains Aquifer (Schloss et al., 2000) used thirty feet as an approximate value to represent the minimum saturated thickness needed to support large volume water demands. Although this value was obtained from discussions with other state agencies and local water users, results from OFR 2002-25C and 25D indicate the minimum required saturated thickness needed to support large-volume demands is significantly greater. Required saturated thicknesses may exceed 100 feet for high-volume pumping in areas where the aquifer transmits water relatively slowly (i.e., has low hydraulic conductivity). Field observations in GMD4 confirm the prediction of drawdowns much greater than 30'; these are shown in figure 1.3. See also figures 1.2 and 1.4.
- Present regional estimates of required saturated thickness are limited primarily by the coarse detail of the readily available maps of aquifer characteristics, and the need to assume average well construction. It is practical to make significant refinements and improvements at local and subunit levels by using local knowledge of well types and pumping practices, and by using available drillers' logs to develop more vertically and horizontally distributed information about aquifer characteristics.

- The relationship between well yield and saturated thickness depends on the aquifer's hydraulic conductivity (see above) and specific yield (the fraction of the aquifer volume occupied by extractable water). Section 4 of OFR 2002-25C uses drillers' logs from study areas in GMD4 to illustrate both aquifer variability and the potential for deriving additional information about the distribution of characteristics.
- **Integration and Summary:** Yield-based saturated thickness values offer significant potential for use as targets for usable lifetime estimates (figure 1.4), for subunit characterization, and in setting thresholds for management options. They combine a scientifically sound family of results based on water use and aquifer hydrogeology that can be refined and evaluated in terms of local conditions and policy preferences.

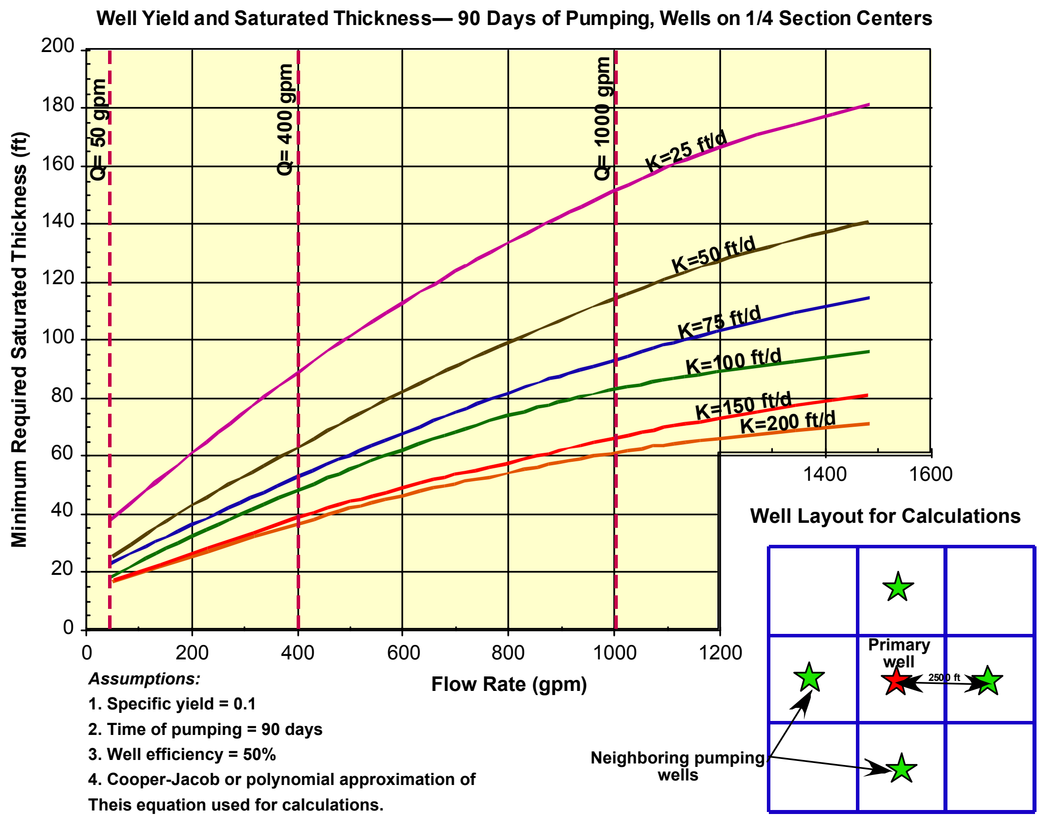


Figure 1.2: Curves of required saturated thickness as a function of pumping rate and aquifer hydraulic conductivity. See section 3.1 of OFR 2002-25C for detailed discussion.

3.3 Usable Lifetime/Aquifer Subunits: OFR 2002-25D

- Estimates of the usable lifetime of areas within the aquifer are a potentially important approach to defining possible aquifer subunits. Sub-regional lifetime classifications demonstrate that the spatial distributions of amounts and trends in water resources for a given area are well suited to the approach of location-specific subunit prioritization and water management.
- Lifetime estimates can be highly variable in certain areas, depending on the methodologies, assumptions, and past trend data used. However, areas projected to reach the selected threshold saturated thickness within 25-50 years are susceptible to resource exhaustion. Classification of the estimated usable lifetime of the aquifer by

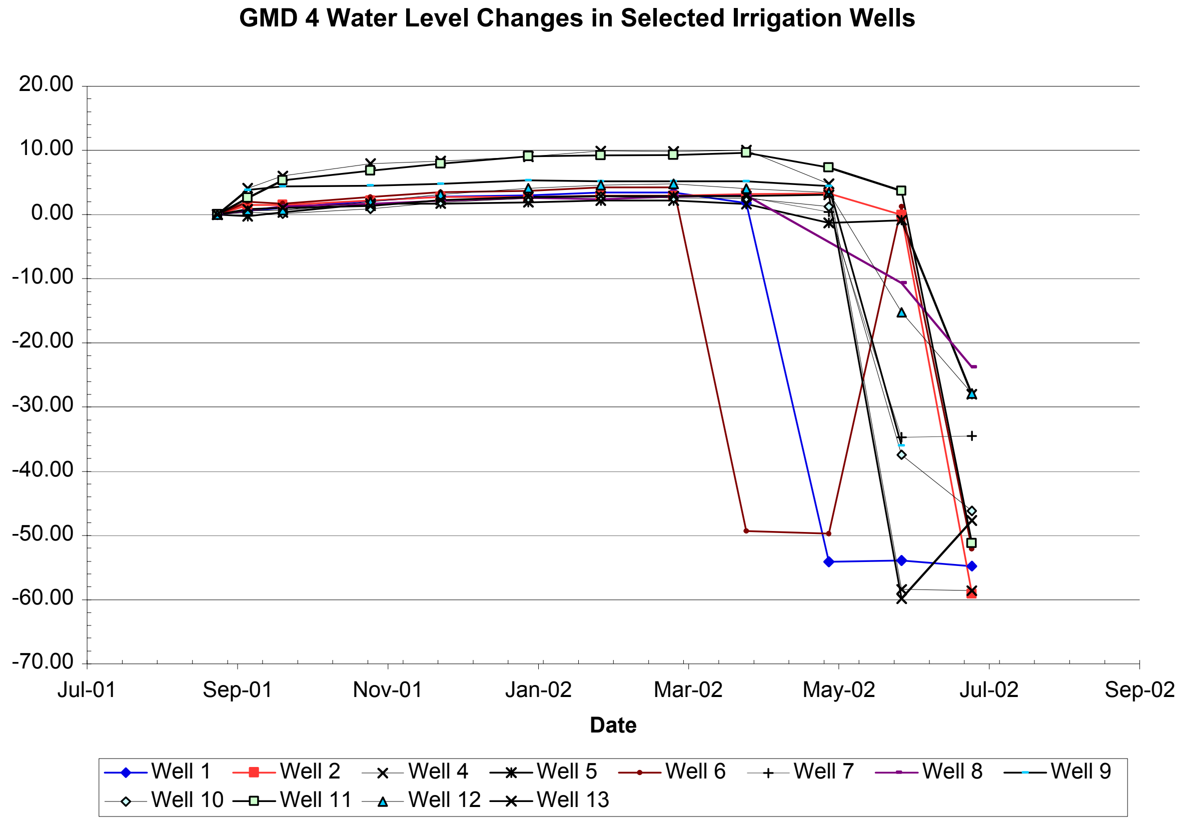


Figure 1.3: Monthly measurements of water level in central GMD4 wells (Sherman-Thomas-Sheridan counties). Note that early in the pumping season drawdowns range from near zero to over 60 feet; four of the wells show prompt initial drawdowns of more than 30 feet.

ten-year intervals is informative for prioritization at the township scale or larger, but its detailed use for local management on ten-year or shorter time scales will probably require refinement of the water level trend and climate-water use relationship information in some areas.

- OFR 2002-25D maps and compares estimated usable lifetimes based on various water-level trend formulations, and using both the 30' saturated thickness threshold and the yield-based minimum saturated thickness (section 3.2 above, figure 1.4, and OFR 2002-25C)
- Geo-statistical clustering procedures (similarity analysis and classification methods) show promise as tools to identify potential aquifer subunits; initial results of identifying statistically similar areas in terms of water use and aquifer parameters are encouraging.
- **Integration and Summary:** Both the estimated usable lifetime and geo-statistical clustering methods show promise as tools for developing protocols, for delineation of aquifer subunits, and for further evaluation of potential management concepts within subunit areas. Initial results (described in OFR 2002-25D) have identified areas of similar characteristics that could serve as subunits, and for which data could be further developed to evaluate management options.

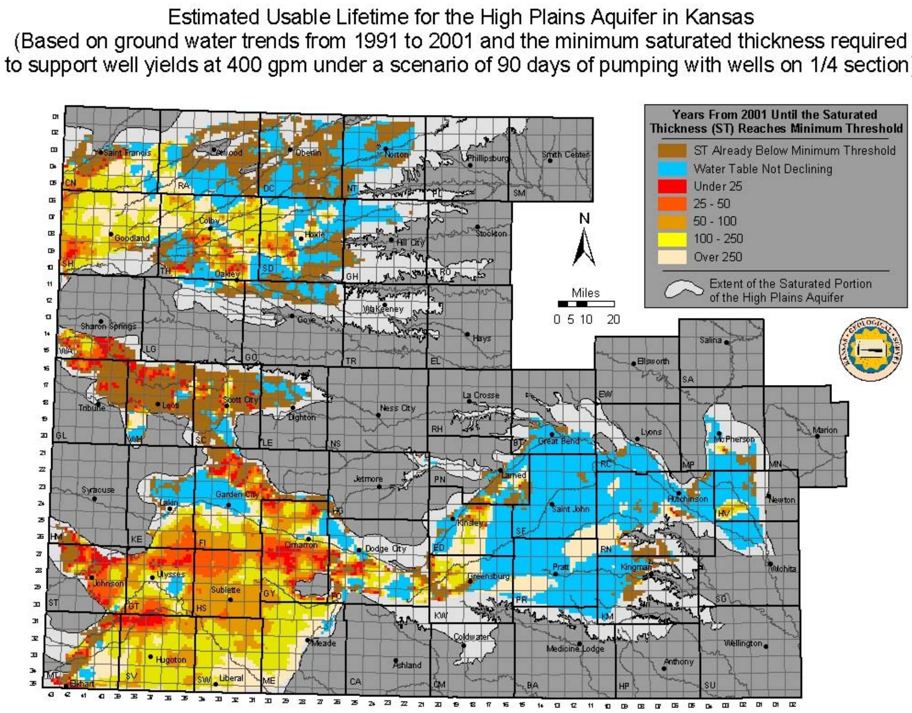


Figure 1.4: Estimated usable lifetime based on a 400 gpm pumping rate from adjacent quarter-sections and the available data on large-scale hydraulic conductivity. See OFR 2002-25D for details and additional results.

3.4 Climate

- Instrumental climate records are accurate for the past 50 years, and adequate for the previous 50 years (to slightly before 1900). Detailed (annual-scale) regional paleoclimate studies based on tree rings permit semi-quantitative extension of the record to 1700, and lower-resolution data reveal large-scale patterns back to at least 1000 years before present. Figure 1.5 illustrates the general agreement among the types of records, and illustrates the points made below.
- Although patterns are generally similar, there are substantial N-S and E-W differences in the total amounts and time-series histories of precipitation across the Kansas Ogallala-High Plains area. Similarly, related variables such as water surplus and deficit show related but not identical patterns.
- Over the period of record, wet and dry intervals alternate at a variety of time scales. Although the data suggest periodicity, the cycles are not regular enough to provide detailed predictive value.
- Serious multi-year regional droughts, such as the "Dust Bowl" period in the 1930s, appear to occur once or twice per century. More protracted (10-20 years or more) droughts appear to occur every few centuries.
- Management considerations should focus on extremes or ranges in precipitation in place of mean values, as climatic average values seldom occur on a year-by-year basis, and are not the primary controls on water demand or availability.
- **Integration and Summary**: (1) There is a significant probability (~15%) that a drought more serious than any in the last 60 years will begin in any decade, and the

chance of occurrence increases the longer the period considered. Such an event will accelerate ground-water depletion due to the combination of increased demand and reduced recharge due to lower precipitation, soil moisture, and streamflow; the experience of the last 30-40 years of irrigated agriculture is therefore an optimistic baseline for estimating future water demands. (2) More ordinary fluctuations in precipitation also influence water use and the year-to-year ground-water decline rates, which means that calculated depletion trends may be distorted unless the effect of short-term climate variation is corrected. This is illustrated in figure 1.5 by the wetter-than-normal conditions of the 1990s; decreasing rates of ground-water decline in that period may be partly due to unusual climatic conditions that temporarily reduced demand and increased recharge.

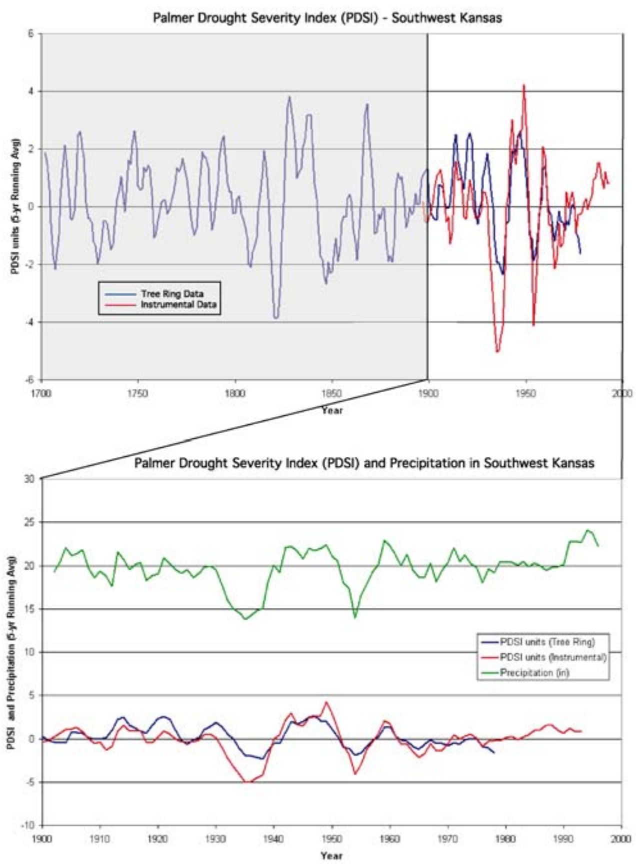


Figure 1.5: Palmer Drought Severity Indices (top) calculated from the instrumental record for the past century and compared to tree-ring derived estimates for the past 300 years. Note the frequency of occurrence of severe droughts (PDSI values of –2 or below). This can be compared with the index values and actual precipitation records for the past century in the bottom panel. Note the abnormally high rainfall values in the 1990s. See OFR 2002-25E for detailed explanation and additional records.

3.5 Scale, uncertainty, and management applications: OFR 2002-25F

- The PLSS (Public Land Survey System) legal section (approximately one square mile in area) is the spatial scale of intersection between management and the scientific data that support it. Most point data can reasonably be extrapolated to the section level, and most regional data can be interpolated to that level, although uncertainties are likely to be high for application of values at the section scale. OFR 2002-25F lists and classifies the relevant data sets that are or soon will be available in terms of their appropriate present and potential scales of application.

- Uncertainties in the section-level data become less significant when the data are combined, interpreted, and applied at the scale of 10-100 square miles. This is referred to as the 'township level' and is considered the appropriate minimum size for a practical management subunit, but the actual boundaries of legal townships are usually not appropriate management subunit boundaries.
- Lithologic and stratigraphic aquifer characteristics (including the bedrock surface underlying the aquifer) do not vary over time, and data concerning their values and spatial variation can be assembled over time within priority areas identified on the basis of initially-available data sets.
- Hydrologic parameters (hydraulic conductivity and specific yield (discussed in section 3.2 above) do not vary over time for specific layers within the aquifer. However, average values of the parameters for the entire remaining saturated thickness or for the part of the aquifer including the water table may change if there are substantial water-level changes where the vertical distribution of the parameters is not uniform.
- Water-use data and the experience of users and managers are important components of the database for management applications, especially on subunit scales.
- Understanding temporal trends in water level is an important component of both subunit definition and management, but is presently limited to township- and decade-scale estimates because of uncertainties inherent in the water-level database and monitoring program. These are discussed more fully in section 4. of OFR 2002-25F, and some uncertainties are illustrated in figure 1.6.
- Substantial improvements in water-level monitoring and prediction are practical, both in general and for high-priority aquifer subunits. Spatial and temporal uncertainty can be significantly reduced by improved well-selection criteria, shifting the time of measurement, making more measurements in priority areas, and making greater use of automated water-level recorders. See Figure 1.6.
- **Integration and Summary**: Considerations of scale and uncertainty, in combination with specific findings reported in the reports KGS OFR 2002-25B-F, provide guidance concerning the most practical approaches to defining aquifer subunits and the basis for their management, as well as illustrating the needs and methods for improving our knowledge base about critical aspects of the system.

4. Acknowledgments

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Numerous people other than those listed as authors made significant contributions to the development and preparation of these products. At KGS, William Harrison served as overall Principal Investigator for the combined contracts, and as KGS representative to the TAC. Margaret Townsend served as KGS technical support for the TAC, and in that role contributed

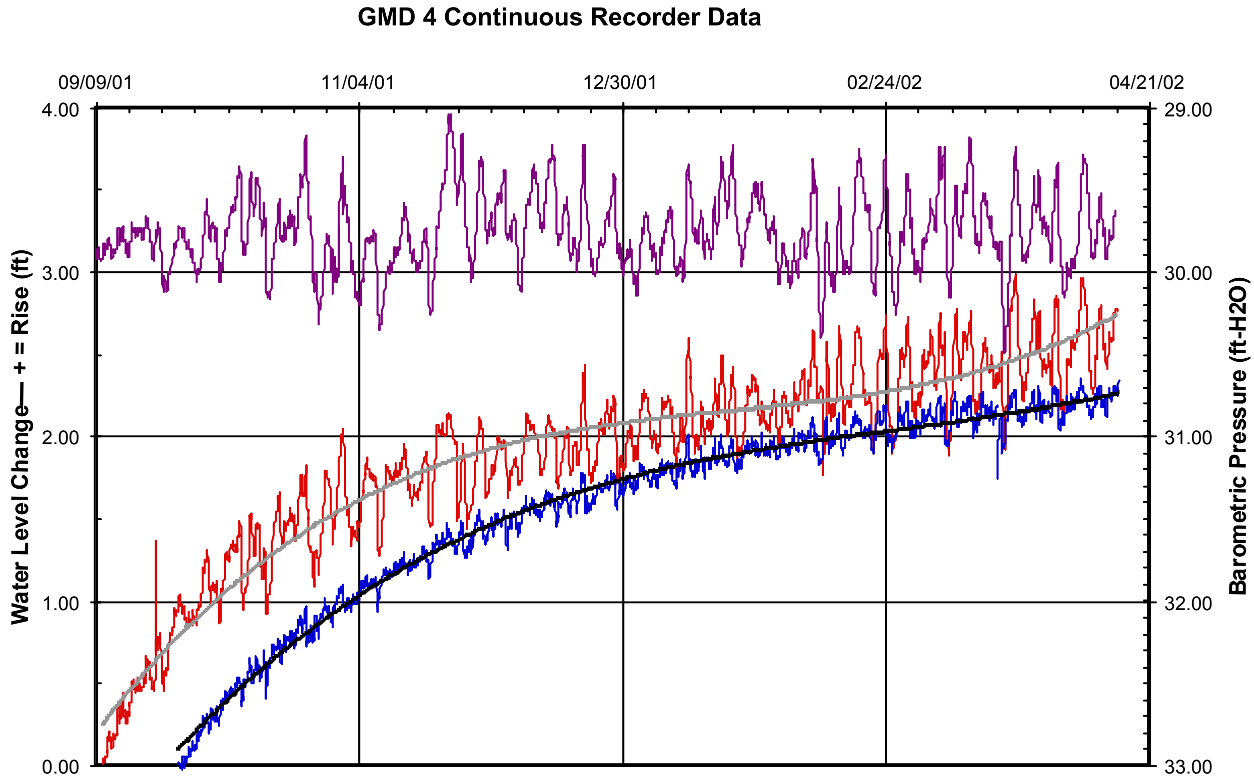

Figure 1.6: Automatically recorded GMD4 well levels during the recovery period show that wells more than a county apart exhibit similar trends (red line = eastern Sherman county, blue line = western Sheridan county). However, the annual water-level measurement period in early January precedes full recovery by a significant amount, and individual measurements in some wells can be as much as 0.5' from the average trend due to responses to responses to barometric pressure (purple line at top).

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