2002 Annual Water Level Raw Data Report for Kansas

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The 2002 Annual Water Level report was published on the Web and on CD and not in paper form. You can find the report in its entirety, including appendices, on the web at http://www.kgs.ku.edu/Magellan/WaterLevels/CD/index.htm

Report to the Director
Kansas Geological Survey
University of Kansas
Lawrence, Kansas

Open-file Report No. 2002-1 April 2002

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of the
Kansas Geological Survey
University of Kansas

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EXECUTIVE SUMMARY

The Division of Water Resources (DWR) of the Kansas Department of Agriculture and the Kansas Geological Survey (KGS) manage and operate the statewide cooperative annual water level measurement program. Water level measurements are scheduled annually for about 1,400 wells spread across 51 central and western Kansas counties (Figure 1). These annual measurements are nominally made during the month of January and include wells used for stock, irrigation, household, and monitoring (some abandoned agricultural or domestic wells). The data acquired during these yearly measurements are tabulated to establish trends and allow evaluation and judgments for effective water resource management.

The KGS and DWR share responsibility for acquiring annual water levels. The KGS measures 510 wells in 15 counties while DWR has responsibility for 848 wells in 34 counties (two counties are shared) (Figure 2). Most wells in the network (73.2%) are currently used for irrigation. During 2002, 94.6% of all annual network wells were successfully measured. Approximately half of these measurements (46.5%) encountered water at depths of less than 100 ft. About 1.77% of network wells have depths to water greater than 300 ft (up from 1.3% in 2000, and down from 1.78% for 2001). At the present time 1,347 of the 1,358 annual network wells have GPS-measured latitudes and longitudes. This means that 99.19% of the program wells have a GPS stamp; this is down from 99.85% for the 2001 acquisition year but up from 46.74% for the 2000 acquisition year. After completion of the 2002 measurement season, 10 network wells have been targeted for retirement due to plugging, surface or downhole obstructions, inaccessibility to the water surface as a result of changes in measurement point, destruction, or "dry hole." Attempts over the last three years to fill holes in the network represent the first increase in the High Plains Aquifer's annual well inventory since the mid-1980s. Reduction of the sampling holes by the yearly incorporation of enhancement wells will be an ongoing process that will be based on number and location of wells retired from the network each year. Digital and analog 2002 annual raw water level data were available for widespread distribution around March 1, 2002.

Data acquisition enhancements evaluated or refined during the 1999, 2000, and 2001 campaigns were incorporated into the 2002 KGS program, and DWR changes include the initial use of computers running the WaterWitch software for several hydrographers in 1999 and the initial use of the Palm Pilot 3 with the Water Bug program for enhanced data collection in 2001. The most significant enhancement for KGS was the inclusion of a seventh person functioning as a troubleshooter and enhancement/replacement well investigator for 2000, 2001, and 2002. The seventh person operated alone, following the three two-man crews, doing re-measurements of wells that were out of trend as well as locating and measuring wells previously selected as candidate enhancement or replacement wells. Use of the KGS-developed, computerized data acquisition system (WaterWitch) permitted on-site entry of measurements and comments, automated checks of data quality, optimized routing, and the encryption of a location stamp on each measurement. Improved routing and the computerized acquisition system has steadily reduced data acquisition time from 8 days in 1997 to 5 days for 2002 for the three two-person crews. Improvements in training/technique and routing increased the 13 wells/person/day measured in 1998 to 17 wells/person/day measured in 2002. Insight gained through statistical

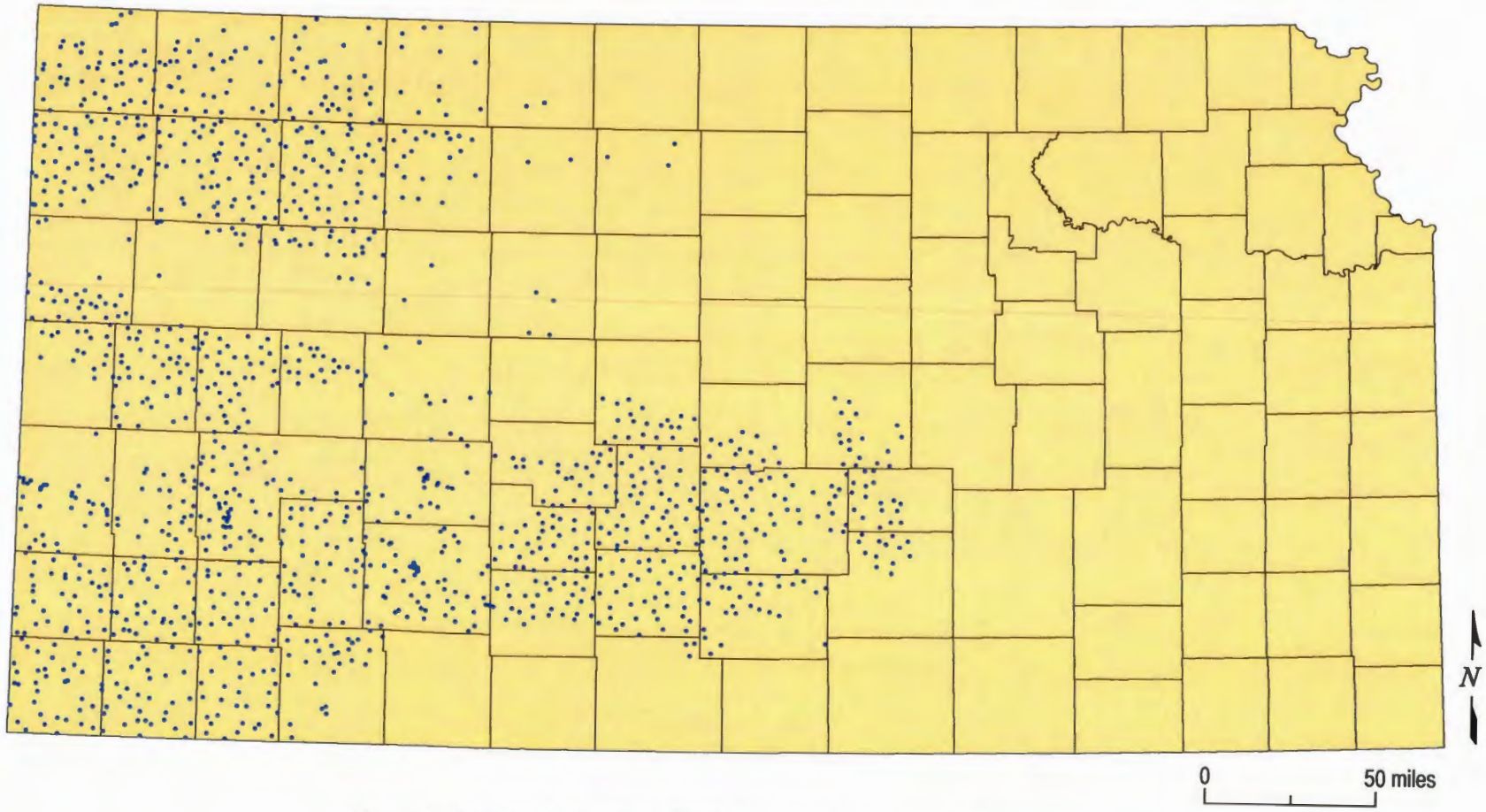

Figure 1. Locations of wells in 2002 water-level measurement program.

analyses of the 10% re-measurement wells (QA) continued in 2002 to prove invaluable in both improving our product and in determining the overall quality of the measurement data. Re-visits and re-measurement of wells classified as out-of-trend during initial measurements (QC) improved confidence and minimized measurement errors in the database.

Data acquisition enhancements evaluated during the 2000 and 2001 campaigns included the introduction a paperless data entry system centered around a small (3"x5"x½") handheld computer, the Palm Pilot 3, running custom in-house software. Results from 2000 showed this system to be an extremely effective and a highly efficient data acquisition/recording tool, so this system was supplied to and used by several members of the DWR crew during the 2002 data collection campaign.

Spatial analysis of the 2002 water level data identified 13 locations where new wells should be incorporated into the annual measurement network to eliminate sampling "holes." Cooperation between the groundwater management districts (GMDs), DWR, and KGS staff identified wells acceptable for inclusion in the network at all locations. Even though only 12 of the 13 sites actually resulted in water level measurements in 2002, a procedure is now in place for the incorporation of new wells into the annual network, allowing overall completeness of sampling to improve each year. The last five years have seen positive growth in the number of wells in the annual network in response the retirement or replacement of inconsistent, plugged, or inaccessible wells.

The Quality Control program continues to achieve its objectives of identifying and quantifying sources of unwanted variation in observation well data collection, and in flagging wells whose measurements require verification. In 2000 and 2001, most of the possible sources of unwanted variation were not significant, in strong contrast with results obtained in 1999 when most exogenous variables were significant. QC for the 2001 data acquisition was remarkably free of inconsistencies compared to previous field seasons, as was the data for 2002. The results can be interpreted as reinforcing the need for training and the desirability of deleting troublesome wells from the monitoring program. As the Quality Control process continues to be applied to the KGS observation well measurement program in the future, and particularly if it is applied to the entire Kansas observation well network, the quality of the groundwater measurement data is expected to improve over time (Davis, 2002).

The original observation well network designed in 1984 was based on a regular hexagonal pattern, with observation wells located at or near the centers of the hexagons. Unfortunately, some current observation wells are far from the centers of their hexagons, and some hexagons no longer contain a network well at all, resulting in "holes" in the network. The integrity of the network is being restored through the selection and measurement of new wells optimally located to fill existing undersampled areas. Determining the very best places for replacement wells requires a geostatistical study, which unfortunately delays the measurement of the water surface in undersampled areas. Replacement wells selected by measurement staff during the measurement campaign are preferred over leaving a "hole" in the network for that measurement year while waiting for a computer-aided replacement well to be selected for the following year. A good rule of thumb for field workers to use for selecting a replacement for a lost observation well is to choose a new well as close as possible to the center of the hexagon. It is possible to

have holes form in the network if replacement wells deviate too far from the center of the hexagon. Yearly geostatistical studies will define undersampled areas (holes) and select optimum locations for replacement wells to eliminate extraneous holes in the network occasionally left by the hexagon system.

2002 KGS ACQUISITION ACTIVITY

Data Acquisition

A field crew from the KGS acquired data from 495 wells in 15 western Kansas counties during January 2002 (Figure 2). The measurement technique and overall responsibilities associated with the 2002 annual water level measurement program were completely consistent with previous years' acquisition activities of both the USGS and KGS (Miller, 1996; Miller, Davis, and Olea, 1997; Olea, 1997; Miller, Davis, and Olea, 1998; Miller and Davis, 1999; Miller, Davis, and Laflen, 2000; Laflen and Miller, 2001). Prior to 2001, data acquisition was accomplished during two field periods with the first (primary) extending approximately from January 3 to January 9, with the second about a week later. During primary acquisition, each well was visited and data collected (water level below ground surface, well condition, GPS, photograph, well characteristics, and general observational notes). New in 2001, enhancement/replacement wells were located and measured during the primary visit as well as all the Quality Assurance (QA), Quality Control (QC), and missing (MIA) wells. The secondary acquisition, designed to finish the measurement of QA, QC, and other missing wells, was incorporated into the primary acquisition campaign for 2001, thus removing the need for a "clean up" or secondary trip. In 2002, difficult-to-measure or initially inaccessible wells have been visited multiple times by several individuals, usually within 24 hours of the initial suspect reading, thus giving a more timely comparison of individual results and a better understanding of potentially problematic areas. All raw data acquired by the KGS on the annual water level measurement program were compiled, digitally stored, and available for widespread circulation in their raw, unprocessed form (digital and/or analog) on or about March 1, 2002. This section represents a summary of all KGS activity related to the raw data, acquisition activities, and technique development.

Acquisition Logistics

The 2002 measurement trip was completed in 5 days by a crew of six people (with a seventh picking up problem wells and measuring new wells). Each person was equipped with a vehicle, computer, GPS, cellular phone, field notes, steel measuring tape, and associated supplies. The far northwestern counties (Cheyenne, Sherman, Thomas, and Wallace) were completed the first day, requiring an overnight stay in Syracuse. The second day of measurements ended in Garden City and saw the completion of two counties (Hamilton and Kearny). The third field day ended in Liberal with three counties finished (Finney, Haskell, and Grant). The fourth day ended in Dodge City, with three more counties (Stevens, Seward, and Meade) completed. The crew returned to Lawrence on the fifth day after completing four more counties (Gray, Ford, Hodgeman, and Ness).

During the primary acquisition trip the six crew members were divided into three teams. Each team was responsible for 28 to 42 wells per day along predesignated closed routes. Each day's route was designed so team members would meet along the route after all wells were visited. This method balanced workloads by compensating for different degrees of measurement difficulty (different lengths of time are necessary to measure individual wells), insured that no wells were overlooked during the primary measurement trip, and minimized the number of miles traveled per well and route. Distribution of crew members and routes was designed to insure that no crew member was more than 15 to 20 miles from another crew member. This increased safety

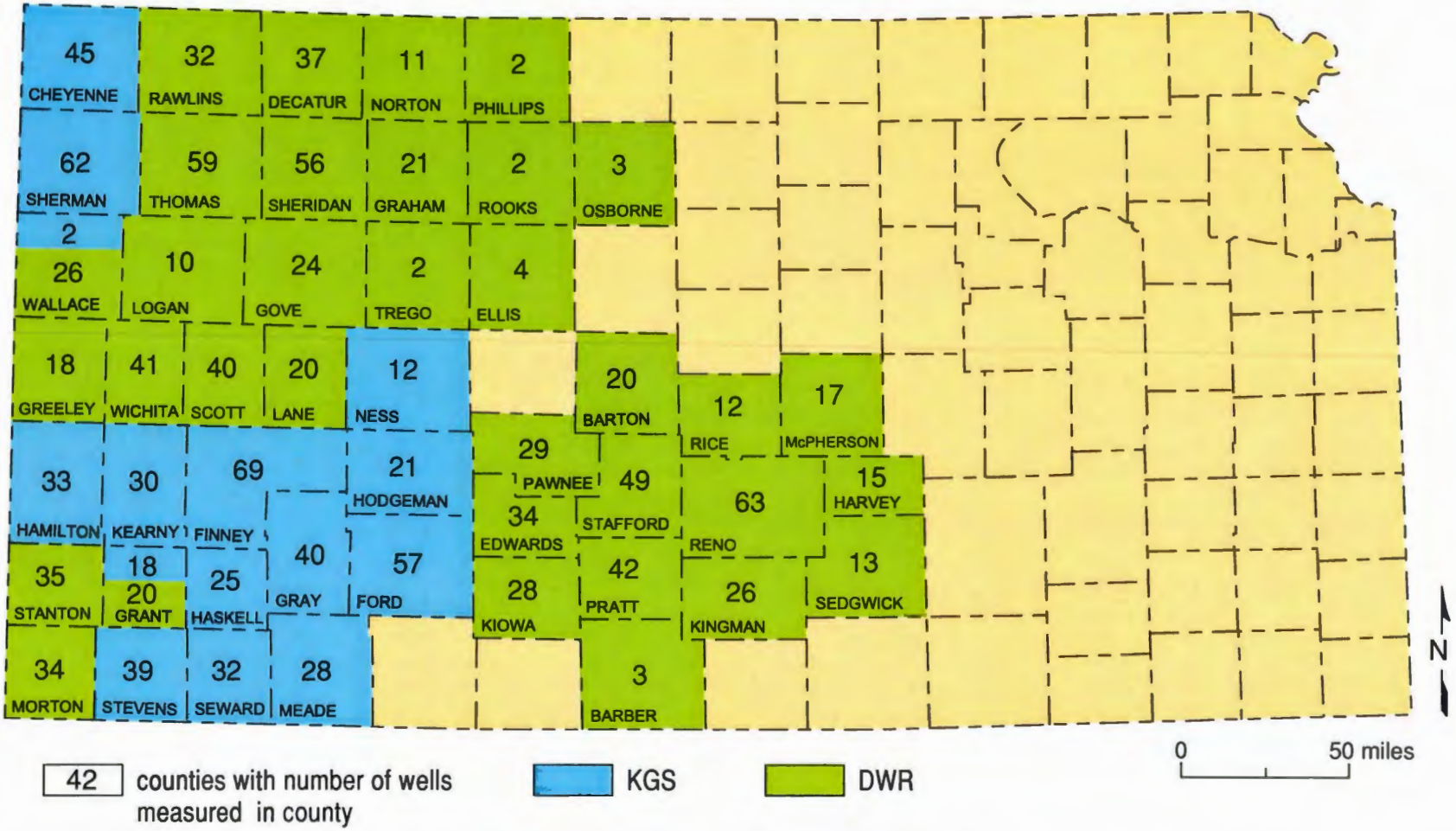

Figure 2. Number and organizational responsibility by county for the 2002 network wells.

and minimized the time necessary to complete a county. Once a team completed its route, the other teams were contacted to determine if assistance was necessary to complete all routes prior to sunset. After a team completed its route and fulfilled any requests for assistance, they proceeded to a predesignated motel. Approximately 11,500 miles were logged during the measurement trip with the average crew member visiting 17 wells per day and spending about 15 minutes at each well and about 25 minutes traveling from well to well.

QC/MIA/QA Wells

Prior to 2001 the QC/MIA/QA/enhancement well trip required a minimum of two days for two people to complete. In 2001 the QC/MIA/QA/enhancement data acquisition was incorporated into the primary trip, thus eliminating the second trip and adding to the overall program efficiency. The QC accomplished during the primary trip was designed to remeasure wells classified as out of trend during primary acquisition. The 2002 QC water level remeasurement included wells in all counties. These wells were selected based on the following criteria:

1) calculated water level was up by more than 1 ft from historical and 2002 trend; or
2) calculated water level was down by more than 4 ft from historical and 2002 trend.

Fifteen wells identified as MIA were not measured during the trip for one reason or another. The fifteen represent the difference between the total number of wells (510) and the number of wells with readings (495).

The QA acquisition provided repeat measurement data for the purpose of statistical appraisal of measurement error. Fifty-one wells, or about 10% of all the wells measured by the KGS during 2002, were randomly selected by computer for remeasurement.

Again this year, an attempt was made to fill some of the spatially undersampled areas within the network (Olea, 2001). To fully sample the High Plains Aquifer from water level data, 13 new well sites were needed. Input from the GMDs, DWR, and KGS identified 13 wells in areas that are spatially undersampled and that have sufficient historical and construction data to justify an attempted measurement. From those 13 candidate wells, 12 were sampled during 2002 as new annual network wells. The selection and measurement of these enhancement wells is critical to establishing a method for maintaining the health and continuity of the network through the insertion of new wells to replace unusable wells already in the network.

Well and Measurement Point Information

A few key well characteristics have been compiled for general information and incorporation into efforts to improve and maximize the network. Statistics and characteristics for DWR wells are also included.

Wells Measured in 2002

Type of Well	KGS	DWR
Irrigation	397	599
Unused (monitor or abandoned)	87	179
Stock	17	31
Household	6	21

Depth to Water	KGS	DWR
Less than 100 ft	151	481
100 to 200 ft	222	257
200 to 300 ft	103	48
More than 300 ft	19	5

Drill Depth of Well	KGS	DWR
Unknown	64	89
Less than 100 ft	58	265
100 to 200 ft	69	285
200 to 300 ft	130	144
300 to 400 ft	97	33
More than 400 ft	86	29

Measurement Characteristics	KGS	DWR
Oil on the water	94 (18.4%)	125 (14.7%)
Difficult measurement (restrictions, snags, catches)	32 (6.3%)	52 (6.1%)
Noted changes in restrictions	27 (5.4%)	7 (0.9%)

In-field confidence in a particular measurement was qualitatively determined through inspection of chalk cut while general accuracy was quantitatively appraised using historical and local trends.

Measurement Confidence

Wells Measured Only	KGS	DWR
Once	324	787
Twice	131	9
Three times	26	1
Four times	14	0

Total Measurements	KGS	DWR
Primary, QA, and QC	840	832

Measurements Judged	KGS	DWR
Excellent	462	660
Good	25	131
Fair	10	6

Network Continuity

An uninterrupted historical record is important for trend determination and analysis. Significant efforts were made to acquire measurements in all wells regardless of whether the well had been successfully measured in any of the last three years. Wells with problems that were not likely to improve between measurement years were identified by each measurer and then cross-checked by the QC measurer. If both visitors indicate that a well needs to be removed from the network, it generally is dropped from the next year's list of annual measurement wells. A total of 15 wells were flagged by KGS field personnel during the 2002 acquisition season.

15 Wells from KGS Portion Requiring Replacement and Reason—2002

09S 42W 08 AAA 01	Plugged.
22S 24W 25 DDC 01	Confined space with electrical hazard.
22S 33W 22 BAA 01	Dry.
23S 31W 28 CDD 02	Pumping.
24S 36W 33 ADD 01	Plugged.
25S 33W 03 BCC 01	Blockage.
26S 29W 35 CCC 01	Blockage.
26S 41W 32 DDB 01	Difficult measure.
27S 27W 01 BAA 01	Blockage.
27S 37W 04 ABB 01	Abandoned and plugged.
27S 38W 15 BBB 01	Downhole damage.
28S 36W 31 BDD 01	No information.
30S 32W 31 BAB 01	No information.
31S 35W 15 BAA 01	No M.P.
34S 38W 34 CAA 01	Could not enter M.P.

16 Wells from DWR Portion Requiring Replacement and Reason—2002

01S 23W 15 AAA 01	Destroyed.
03S 30W 03 CBA 01	Destroyed.
04S 29W 10 DCC 01	No MP.
04S 30W 07 BBB 01	Collapsed.
15S 41W 05 ACB 01	Plugged.
16S 41W 20 ABC 01	Plugged.
19S 38W 26 CCB 01	Destroyed.
19S 38W 26 CBB 01	No M.P.
20S 37W 29 DCC 01	Plugged.
22S 13W 12 CAC 01	Destroyed.
22S 17W 27 BAB 01	Destroyed.
23S 07W 20 BCA 01	Destroyed.
26S 09W 10 DDB 01	Destroyed.
27S 43W 02 BDD 01	Destroyed.
29S 35W 28 ACC 01	Collapsed.
30S 36W 04 ABB 01	Cascading water, unable to see chalk cut.

To maintain the long-term health and continuity of the network, both wells that should be replaced and acceptable replacements should be immediately identified. Field observations are the most important and insightful method of identifying wells needing replacement; however, statistical quality control analysis has provided valuable insight into the reliability of network wells measured in 2002.

For a fourth year the KGS crews were deployed with acquisition software running on notebook PCs interfaced to GPS units. This system has been under development at the KGS for the last five years. It is designed to provide the measurer with historical data, warning messages

in the event of an out-of-trend measurement or incorrect well location, automated depth-to-water calculations based on hold and cut, and real-time tracking and vehicle location displays. The system's primary focus is on insuring that the correct wells are measured and on enforcing complete well site documentation. The GPS units provide the associated computer with a tracking log, which permits time and location of each measurer to be determined throughout the day. During the 2002 measurement program the KGS crews logged over 11,500 miles in 5 days (Figure 3). GPS-measured latitudes and longitudes can be extracted from this log and used to improve the accuracy of well locations in WIZARD.

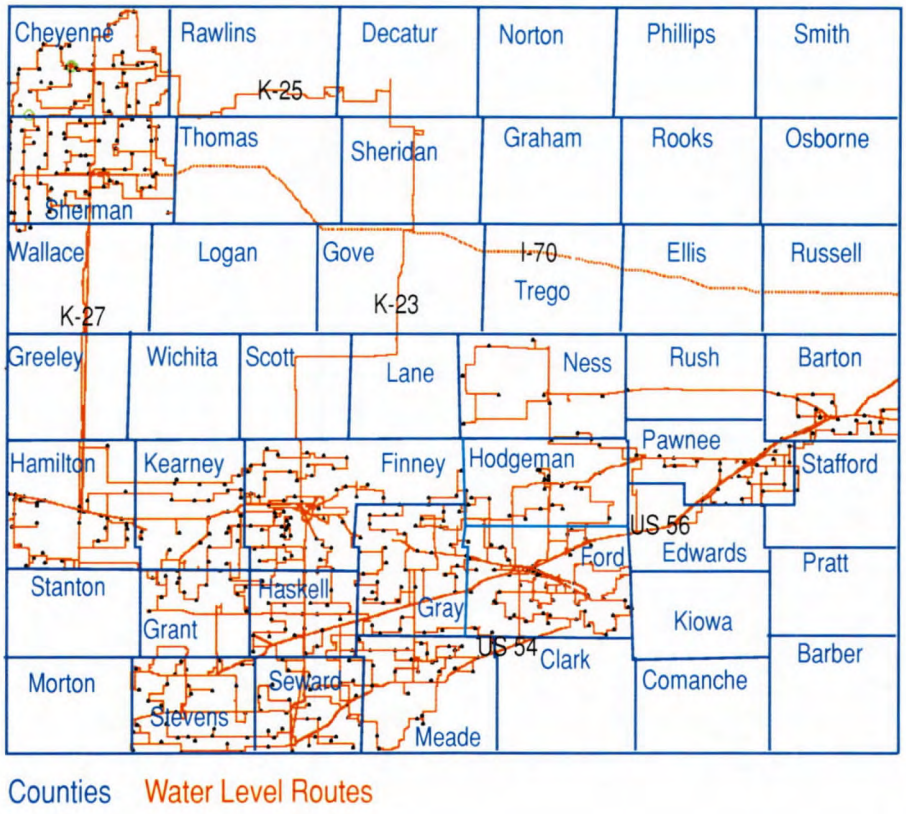

Figure 3. Example tracking logs of all measurers as recorded by the GPS/computer systems located in each vehicle (not to scale).

WATER LEVELS FOR 2002

Wells are grouped by county and then cataloged according to well ID (township, range, section system). All measurements taken during the annual measurement period are reported in Appendices C and D. In some cases a single well may have as many as four recorded measurements. The best value was determined by the field person(s) who measured the well. The best measurement was based on quality of cut, difficulty reaching the hold line, ease of retrieving the tape from below water level, pre-cut moisture, level of confidence that the tape was hanging unimpaired in the borehole, and accuracy of measurement point hold.

The raw data tabulated in this report are organized into five appendices. A brief discussion of the contents of each appendix follows.

Appendix A Contains a summary of information for all wells measured by KGS. This appendix includes only county, well legal description (ID), and 2002 depth of water below ground surface (BGS). QA measurements (QA) are identified.

Appendix B The same information as Appendix A, but for DWR wells.

Appendix C Contains all measurements and characteristics taken at every well in the KGS portion of the network. Included are the following categories of information: County, legal description (ID), GPS Lat, GPS Long, hold point, cut line, measurement point (MP) elevation, 2002 depth to water BGS, initials of measurer, measuring agency, and all comments.

Appendix D The same information as Appendix C, but for DWR wells.

Appendix E List by county of wells (legal description, ID) measured as part of the QA program. The list includes the primary measurement of DTW and the QA measurement of DTW.

Appendix F Contains the same information as Appendices C and D for all enhancement wells.

A direct comparison of primary measurements and the QA measurements made by the KGS reveals important information about the accuracy and repeatability of information in the database (Appendix E). In general, the time separation between the primary and QA measurements is less than 24 hours in all cases, and often the same day. This remeasure information, along with parts of the primary data, are integral to quality control discussions documented in subsequent sections of this report.

KGS Data Acquisition Summary

In summary, this year's effort by the KGS staff to acquire annual water level measurements met or exceeded most expectations. Based on preliminary analysis:

1) Systematic errors are an important indicator of erratic wells that should be removed from the network to insure that the network is accurate and that confidence can be placed in the data (see Davis, 2002).

2) More data have been acquired in each of the last six years (1997-2002) than in the previous 7 years (1990-1996).
   2002, 495 wells measured (KGS) (97%)
   2001, 504 wells measured (KGS) (99%)

2000, 548 wells measured (KGS) (99%)
1999, 542 wells measured (KGS) (97%)
1998, 542 wells measured (KGS) (98%)
1997, 542 wells measured (KGS) (96%)
1996, 504 wells measured (USGS) (90%)
1995, 509 wells measured (USGS) (91%)
1994, 513 wells measured (USGS) (91%)
1993, 489 wells measured (USGS) (87%)
1992, 481 wells measured (USGS) (87%)
1991, 493 wells measured (USGS) (88%)
1990, 485 wells measured (USGS) (86%)

3) The availability of digital and analog measurement data (for entire network) to DWR, KGS Geohydrology staff, and GMDs has been dramatically improved over years prior to 1997. These data will be provided on CD-ROM.

4) Field acquisition time has been reduced (2002 and 2001 required 5 days; 2000 and 1999 required 5.5 days; 1998 required 6.5 days; 1997 required 8 days); the historical average of time required for field data collection has been about 2 months.

5) Long-term improvements to the network and database are being made.
   a) All wells measured in 2002 have GPS lat and long and photographs;
   b) Errors, missing information, and incorrect information in both KGS and USGS historical database are being identified, evaluated, and corrected;
   c) Spatial distributions of wells based on aquifers were evaluated in 2000 and remediation efforts are underway for a third year;
   d) Wells are being added by the KGS to the network to fill "holes" as determined by spatial analysis;
   e) Acquisition techniques and procedures are being modified and improved based on statistical analyses;
   f) The Kansas water well database (WIZARD) has been established for quick access to all water level information in the state through a Web site; and
   g) The Quality Control program is providing valuable information about measurable wells that have erratic behavior and which should be removed from the network.

6) The total program costs for 1999, 2000, 2001, and 2002 were about 75% of 1998 and 1997, which were both consistent with the amount paid to the USGS in 1996 to complete this study. When calculated using an equivalent* product, the cost to the Kansas Survey for the 1997 and 1998 water level data is about half that assessed by the USGS in 1996 and less than one-third of the USGS 1996 costs for the 1999 acquisition season.

Development of a Kansas water well database was undertaken by the KGS in an attempt to make information quickly and easily accessible to the general public about water wells, both those that are part of the annual network and many that are not. This database will hopefully provide quick and accurate information about potential replacement or enhancement candidates

*Equivalent product cost does not include extra program activities such as QA or QC data acquisition, analysis, or computer and GPS equipment.

throughout the State. At the present time this database is still under development, but should be fully operational by next field season. The database, by design, will include all significant information contained in the USGS's GWSI database, the KGS's KIWI database, and the KGS's WaterWitch database. It is the intent of the database's designers to incorporate portions of DWR's WRIS, KDHE's WWC5, City of Wichita, and each of the five GMDs' water well databases. Once this database, named WIZARD, is complete it should contain the most inclusive listing anywhere of information on water wells in Kansas. It is the intent that frequent uploads from each of the parent databases will insure that information in the database is current.

Conclusions

The field measurement phase of the annual cooperative water level measurement program was successfully completed by both the KGS and DWR prior to February 1, 2002. The annual program is designed to regionally sample the High Plains Aquifer in Kansas so trends can be established and evaluated for effective incorporation into water resource management strategies. Water levels were recorded in 94.6% of the 1,358 network wells with data quality evaluations completed on the 510 KGS wells. Modifications to the acquisition methodology developed after statistical analysis of the 1997, 1998, and 1999 KGS annual measurements were implemented during 2000, continuing in 2001 and 2002. Systematic errors detected in water level data collected from 1997 to 2001 provide valuable clues to long-term improvement in network reliability.

Spatial analysis of the 2001 annual network well distribution revealed 13 locations that required additional water level data to permit continuous and uniform sampling of the High Plains Aquifer. Candidate wells for all 13 locations were identified through the cooperative efforts of the KGS, DWR, and the GMDs. Of those 13 candidate wells, 12 had sufficient construction and historical information and landowner cooperation to attempt a water level measurement and were actually measured. The 12 were incorporated into the network for 2002 and will be measured in all future measurement campaigns unless the wells become unreliable or are plugged. Yearly geostatistical studies will define undersampled areas and will be used to select optimum locations for replacement wells to eliminate extraneous holes in the hexagonal network.

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FIGURE CAPTIONS

Figure 1. Locations of wells in 2002 water level measurement program.

Figure 2. Number and organizational responsibility by county for the 2002 network wells.

Figure 3. Example of tracking logs of measurers during the first 6 days of the measurement program as recorded by the GPS/computer systems located in each vehicle.