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Potential Impacts of Past Land Use and Recharge Rates on the Ogallala Aquifer: Water Quality Issues in Kansas

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Potential Impacts of Past Land Use and Recharge Rates on the Ogallala Aquifer: Water Quality Issues in Kansas

Abstract

Quantification of available water and the rate of recharge to the High Plains aquifer in western Kansas are much discussed but little agreed upon topics. The usable lifetime of the aquifer is under investigation, but thus far studies have focused largely on the quantity of water and ignored the quality. The quality of the remaining water for agricultural and water supply uses is an issue that deserves attention and further research.

Land use in the High Plains aquifer area is dominated by irrigated agriculture. Water levels and water quality in the Ogallala portion of the High Plains aquifer continue to be impacted by past land uses. KGS site studies and USGS National Water Quality Assessment (NAWQA) program regional studies show that irrigation recharge enhances the movement of contaminants to the water table.

Overall increase of nitrate-N (20% - 80%), specific conductance (3% - 30%), chloride (11% - 50%), and sulfate (4% - 90%) concentrations measured at the same irrigation wells in the 1970's and 1990's indicate movement of contaminants to the water table. The USGS NAWQA study has observed atrazine and its metabolites in soil water and at the water table at monitoring sites. Nitrogen-15 analyses of soil water and ground water indicate that row crop and feedlot agriculture are major sources of contamination.

Recharge estimates and calculated fluxes by both KGS and USGS show that recharge from flood irrigation return flows moves contaminants faster than does natural recharge or center pivot or drip irrigation. Still, the amount of recharge is only a fraction of the amount of water pumped for irrigation. Although irrigation efficiency improvements could result in slower downward movement of contaminated water in the distant future, the current problem is to determine (1) the quantity of contaminated water in transit to the aquifer within the next few decades, and (2) will the quality of water sustain current and future demands in the area.

Objectives of Study

The objectives of this preliminary study are as follows:

1) Calculate a ground-water balance for Sherman County, KS to determine the quantity of inflow and outflow of ground water for the Ogallala portion of the High Plains aquifer.

2) Calculate a nitrogen budget for Sherman County, KS to try to determine if the amount of nitrogen (usually observed as nitrate-N) observed in the ground water is consistent with estimates of nitrogen inputs.

Introduction

Quantification of available water and the rate of recharge to the High Plains aquifer in western Kansas are much discussed but little agreed upon topics. The usable lifetime of the aquifer is under investigation, but thus far studies have focused largely on the quantity of water and ignored the quality. The quality of the remaining water for agricultural and water supply uses is an issue that deserves attention and further research.

The area of study for this report is in Sherman County in northwestern Kansas in Groundwater Management District #4 (GMD4) (Figure 1). Data and information for this study was acquired from numerous agencies including: University of Kansas Applied Remote Sensing (KARS), Kansas Department of Agriculture Division Water Resources (KDA DWR), Kansas Geological Survey (KGS), Kansas State University (K-State), National Agricultural Statistics Service (NASS), and the National Atmospheric Deposition Program (NADP) and US Geological Survey (USGS) National Water Quality Assessment (NAWQA) SWKS study. A listing of references and web sites accessed is included in the reference section of this report.

The period of time used for the budget calculations is from 1990-1995. This time period coincides with the study of the South Fork of Beaver Creek in the Sappa Creek watershed in Sherman County to determine the source of high nitrate-N levels observed in irrigation wells to the east of Beaver Creek (Townsend, 1995). Data from that study and other water chemistry data available from that time period were utilized for the nitrogen budget.

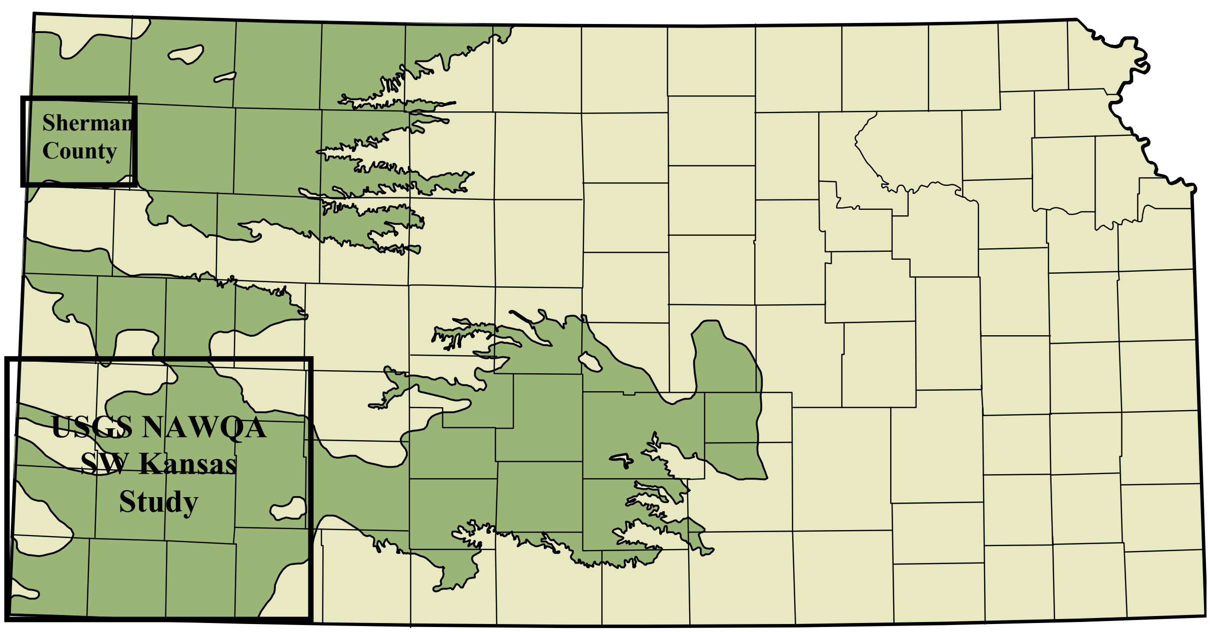

Figure 1. Location of Sherman County study area and USGS NAWQA SW Kansas study. Data from these two regions are used in the determination of at water balance and nitrogen balance for Sherman County.

Land use in Sherman County consists of 80% cropland and 20% rangeland (Figure 2). The majority of the cropland (59%) is in dryland wheat with irrigated corn (16%) being the second highest crop produced (Figure 3). The northwestern two thirds of the county are irrigated as illustrated in Figure 2. The southeastern portion of the county has little to no saturated thickness available for irrigated agriculture.

Fertilizer applications follow the trend of acres of crops harvested. The majority of the fertilizer sold in the county goes to dryland wheat (Figure 3) based solely on acreage planted. However, 28% of the fertilizer is utilized by irrigated corn production (Figure 4). Work by the USGS in SW Kansas indicates that irrigated agriculture results in increased recharge, and hence potential movement of contaminants, to ground water (P. McMahon, USGS, 2002, personal communication).

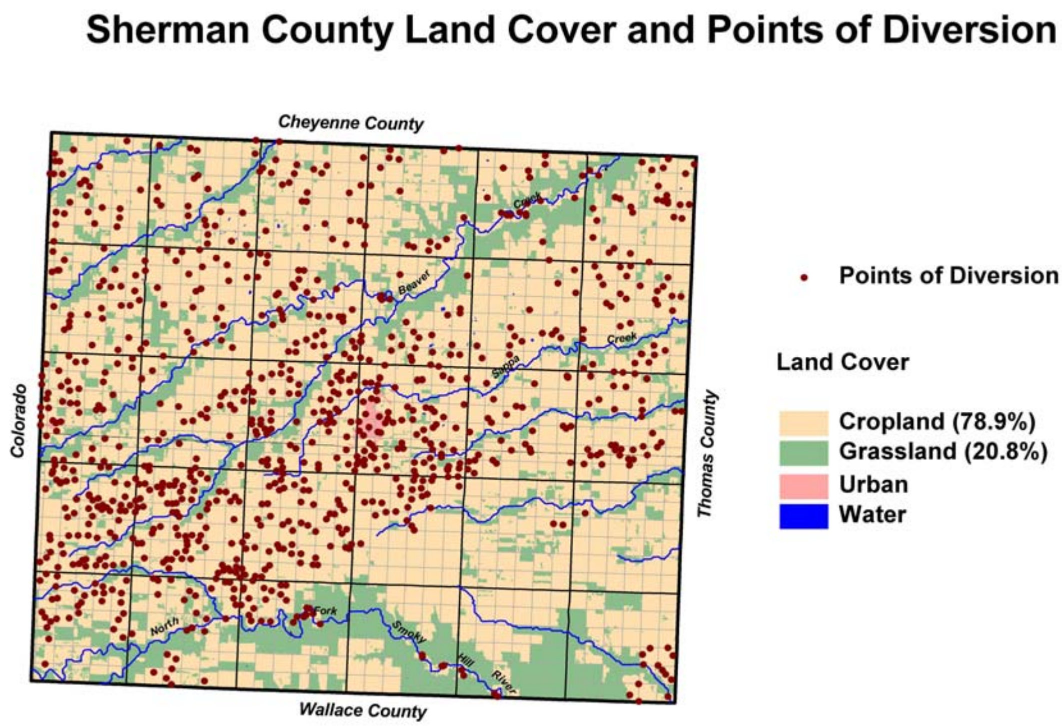

Figure 2. Sherman County points of diversion and land cover. Major land use is agricultural cropland with rangeland as the next largest category. Data from DASC (2002) and KARS (2002).

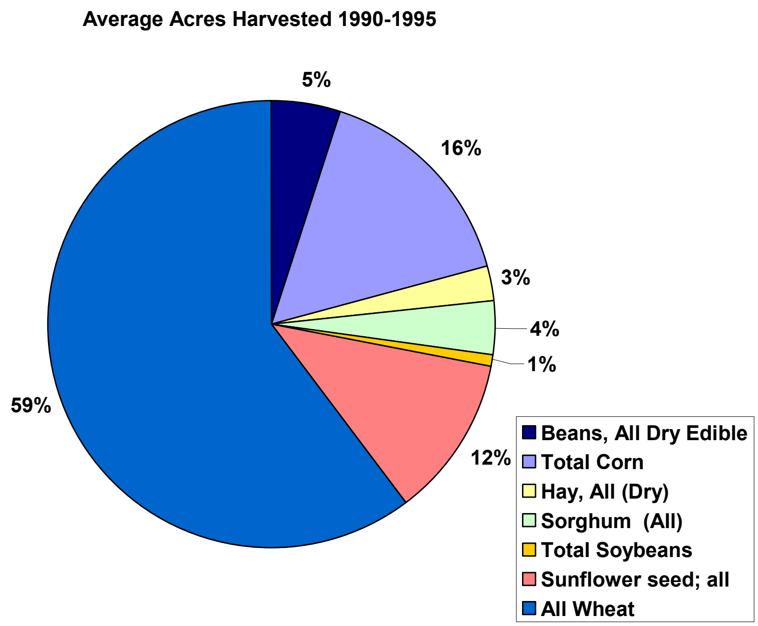

Figure 3. Average acres harvested (1990-1995). Data are from NASS (2002) and KSU (2002).

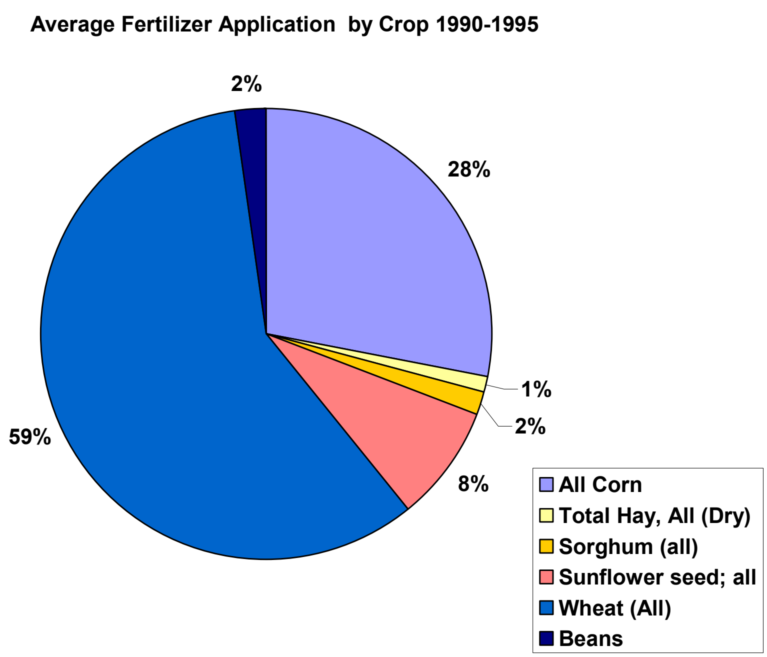

Figure 4. Average fertilizer application by crop (1990-1995). Data are from NASS (2002) and K-State (2002).

Sources of Nitrogen

Agriculture is the principal industry in Sherman County, KS. Because of the agriculture emphasis the major sources of nitrogen are primarily agriculturally related. Table 1 lists the major potential sources of nitrogen to the ground water system based on the 2000 Bureau of Census records for human and animal populations in Sherman County.

The potential available N values for fertilizer were based on the assumption that 70% of applied fertilizer is utilized or removed by harvest of crops (D. Leikam, KSU Agronomy Department, personal communication, 2002). This leaves 30% available for leaching and/or mineralization. For this analysis we assumed that the 30% is available for leaching. We took the mean of the 30% value for all crops over the total calculated acreage farmed (NASS, 2002 data) and used this value to determine the amount per acre that is potentially available. As can be seen from Table 1, fertilizer nitrogen is the largest potential source of available nitrogen for leaching.

Table 1. Sources of potential available nitrate-N based on Sherman County 2000 Census figures.

2000 Census Sherman County Data*	**Lbs N produced**	**Number of Animals, Humans, Acres**	**Tons Potential Available N/yr**
Dairy (lbs N/ton manure)	10	26,500	132.5
Beef Cattle (lbs N/ton manure)	14.5	7,900	56.5
Swine (lbs N/ton manure)	10	2,000	10
Septic tanks	14.5 lb/person/yr	1943	13.5
Mean N-fertilizer unused by crops	25 lb/acre	621,081	7,484
Mean annual N deposition*	3.12 lb/acre	621,081	968
* NADP (2002); US Census Bureau (2002)			

Table 2 shows the recommended fertilizer application rates for the major crops grown in Kansas. Figure 5 illustrates the range of excess fertilizer N that is potentially available for leaching based on crop type. As can be seen the major fertilizer use is for wheat and then corn. As indicated in figure 4 corn uses approximately 28% of the fertilizer applied in the county. In addition, corn is usually irrigated which means there is more water available to move excess N.

Table 2. Recommended fertilizer application rates by crop.*

Crop	**Minimum lb/acre**	**Maximum lb/acre**
Wheat	60	80
Corn	150	200
Other Crops	10	50

* Data from K-State Agronomy (2002).

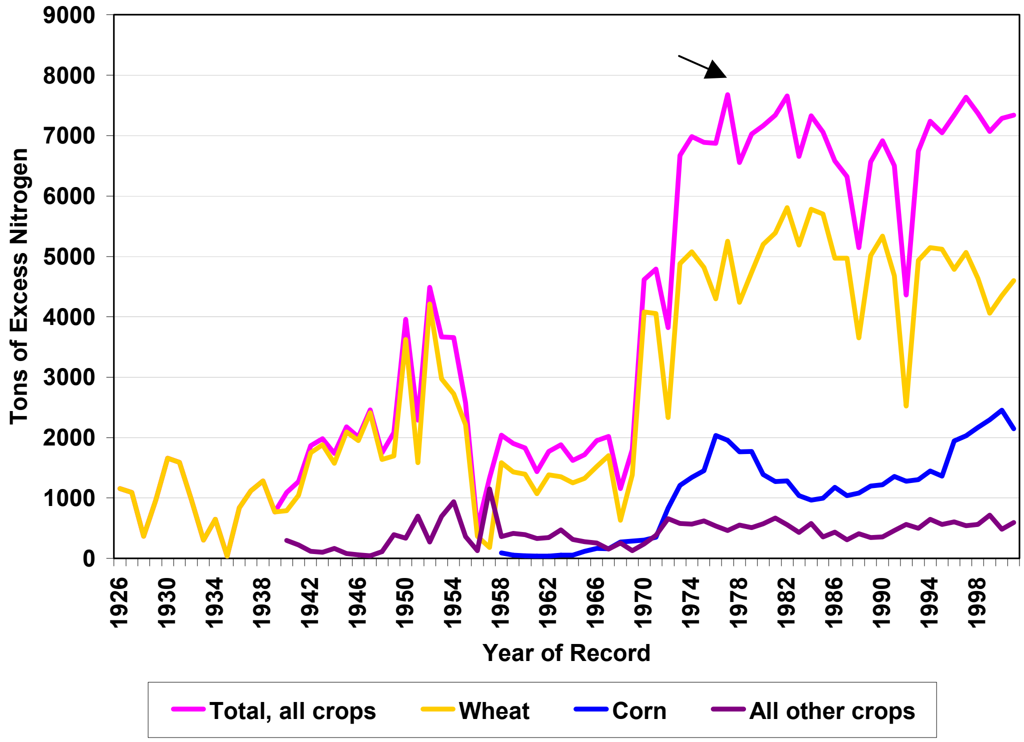

Figure 5. Tons of excess nitrogen available for leaching and/or mineralization after removal of 70% of fertilizer nitrogen (D. Leikam, 2002, KSU Agronomy Dept., personal communication) by harvested crops. Data from National Agricultural Statistics Service (NASS, 2002) web site: http://www.usda.gov/nass/ (verfied December 2002). Arrow indicates potential nitrogen observed in the 1990-1995 period of this analysis (see recharge section for discussion).

Figure 6 shows the increasing trend of water right applications granted and nitrogen fertilizer sold. The third line on the graph shows the annual quantity of excess nitrogen available for leaching and/or mineralization from all crops.

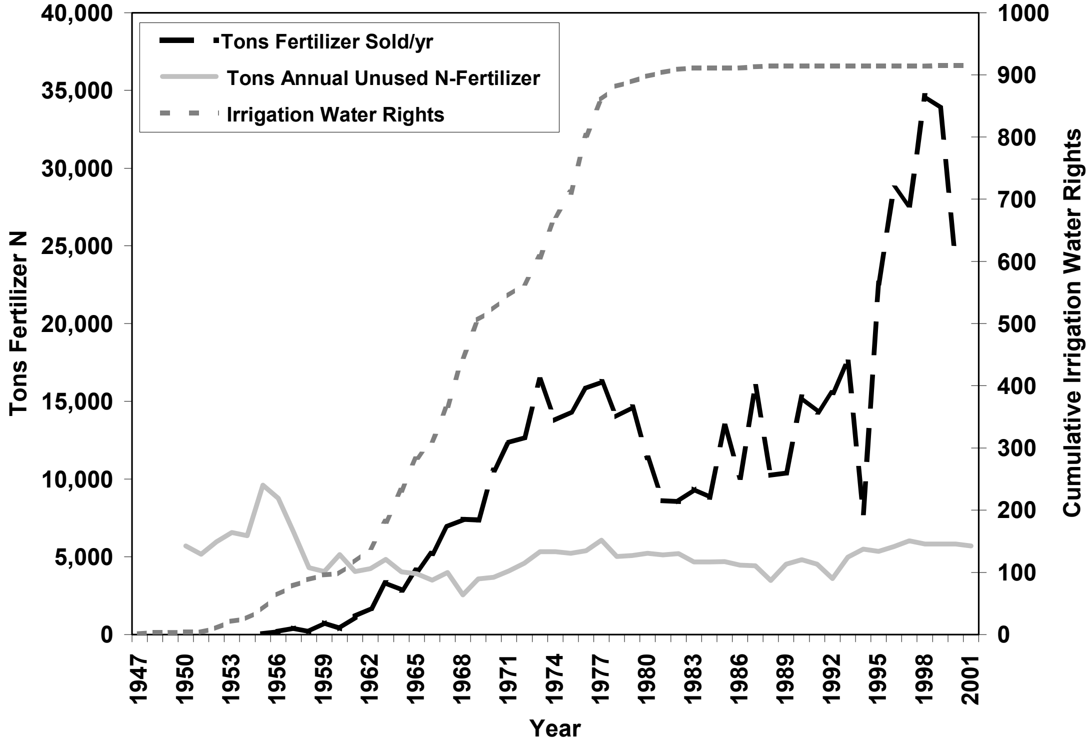

Figure 6. Graph indicates general increasing trend of irrigation water rights issued and fertilizer sold in Sherman County. Annual tonnage of unused fertilizer available for leaching and/or mineralization is fairly constant. Data available from DASC WIMAS (2002) and KDA (2002).

High Plains Aquifer Properties

High Plains aquifer properties indicate a depth to water of 100 to 230 feet throughout the entire High Plains region (Figure 1). The horizontal K values range from 10 to 150 ft/day (Cederstrand and Becker, 1998). Results from the USGS NAWQA study in southwestern Kansas showed that atrazine and tritium are present at the water table (depth of approximately 150 to 200 feet) and that nitrate-N above the U.S. EPA drinking water limit of 10 mg/L occurred in 10 of 30 domestic wells sampled in Kansas (Becker and others, 1999).

Table 3 lists the range of recharge values measured and calculated from several studies in Kansas, principally the USGS NAWQA work in 1998-present. Overall the non-irrigation related recharge rates are low and are not likely to contribute a significant amount to ground water. Irrigated agriculture, however, was found to potentially contribute a relatively large volume of recharge to the system.

Table 3. Estimates of recharge to High Plains aquifer from USGS studies.

USGS NAWQA SW Kansas Studies	Recharge in/yr
Furrow irrigation (mean 1953 - 2000) atrazine and tritium[1]	1.4
Irrigated sites (current moisture) Unsaturated Zone study[2]	< 1.4
Rangeland (Chloride) Unsaturated Zone study[2]	0.09 – 0.3
USGS Estimated Recharge (1991)[3]	0.25

[1]McMahon 2002, personal communication; [2] USGS High Plains web site: http://webserver.cr.usgs.gov/nawqa/hpgw/; [3] Hanson, 1991.

The first records of atrazine use in Kansas are from 1975 (D. Lambley, KS Dept. Agriculture, 2002, personal communication). Using and estimate of 25 years and a depth to water of 230 ft (USGS NAWQA data, http://webserver.cr.usgs.gov/nawqa/hpgw/, 2002) the estimated maximum rate of recharge is approximately 9 ft/yr. Using this rate of travel, unused excess nitrogen from the 1970's (arrow in Figure 6) could be the source of the nitrogen observed in the ground water in Sherman County (where the depth to water is approximately 100 ft) in the 1990-1995 period of study.

Water Balance for Sherman County

Assumptions for Water Balance (1990 – 1995)

Previous work on a water balance for Groundwater Management District #1 indicated that irrigation return flows contributed up to 10% of the water recharged in GMD1 in west central Kansas (Hecox,2001, personal communication). This value was used in the current water balance calculation.

Recharge estimates ranged from 0.1 to 0.5 in/yr. These values were based on the data from the USGS NAWQA values presented in Table 3. The range of recharge volumes were calculated using 0.1 in/yr of the USGS 1991 value, the average value of 0.25 in/yr recharge, and 0.5 in/year.

Storage depletion is defined as the volume of water present in the aquifer when the ground-water levels rapidly decline during pumping season. This water is available for recharge by slow drainage from the aquifer.

The values calculated for the various portions of the water balance are presented in tables 4A to 4F. Table 4A gives the background information on the acreage of the study area, total water usage, and the estimated irrigation return flows available for recharge. Table 4B gives the minimum, mean, and maximum recharge estimates and the corresponding volume of water available. Table 4C shows the impact of storage depletion estimates on the volume of water recharging the system. Table 4D shows the minimal input from stream channel inflow. This calculation illustrates the disconnection between the streams and ground water table that is present in the area. Table 4E shows the contribution of ground water inflow from Colorado. Table 4F shows the fairly minimal outflow from the county to the east.

Table 4A. Background information on acreage and water use estimates for Sherman County

Sherman County Water Balance	
Total Acreage	676,000
Water Use and Irrigation Return Flows (acre-ft)	677,482
Estimated Irrigation Return Flow (10%) (acre-ft)	68,000
Number of Years of Record	6

Table 4B. Calculated recharge volumes for study area.

Water from Recharge [1]Recharge volume= (6 years * Recharge rate * Area)/12 in/ft			
	Mean	Min	Max
USGS Recharge Rate (in/yr)	0.25	0.1	0.5
Volume Recharge (acre-ft)	85,000	3,000	169,000

[1](Hecox, 2002, unpublished data).

Table 4C. Calculation of volume of water from storage depletion that contributes to water budget.

Water from Storage Depletion [1]Storage depletion volume = Specific yield * ATREND * Total Area * 6 years			
	Mean	Min	Max
Specific Yield	0.17	0.1	0.25
Rate of Water Level Change (ATREND) (ft/yr)	-0.52		
Water Storage Depletion (- indicates more withdrawal than recharge)	-359000	-211000	-527000

[1](Hecox, 2002, unpublished data).

Table 4D. Volume of water recharged via stream channel inflow.

Stream Recharge	
Length of stream channels (ft)	666,000
Width of channel (ft)	50
Hydraulic gradient during runoff (ft/ft)	0.25
Unsaturated K (ft/day)	1
Duration of flow (days/yr)	20
Inflow (per year) acre-ft	4,000
Length of stream channels (ft)	666,000

Table 4E. Recharge from ground-water inflow from the west of Sherman County. Calculation based on Darcy equation.

Water Inflow from the West	
Variable	
Hydraulic gradient (ft/ft)	0.003
Hydraulic conductivity (ft/day)	75
Saturated Thickness (ft)	174
Cross-sectional Width of flow path (ft)	79,000
Inflow/year (acre-ft)	26,000

Table 4F. Water outflow to the east using two levels of saturated thickness.

Water Outflow to the East		
Variable	**High Saturated Thickness**	**Low Saturated Thickness**
Hydraulic gradient (ft/ft)	0.00231	0.00353
Hydraulic conductivity (ft/day)	53	150
Saturated Thickness (ft)	174	25
Cross-sectional Width of flow path (ft)	157,000	66,000
Outflow/year (acre-ft)	28,000	7,000

Figure 7 shows the comparison of groundwater use and outflow to the east in comparison to inflow into Sherman County. The figure clearly illustrates the impact of ground water withdrawals on the water balance of the county. The volume of recharge into the system is generally lower than the groundwater use (withdrawals) based on water use records.

The numbers calculated in this budget are used to determine the volume of nitrogen that is moving through the unsaturated and saturated zones.

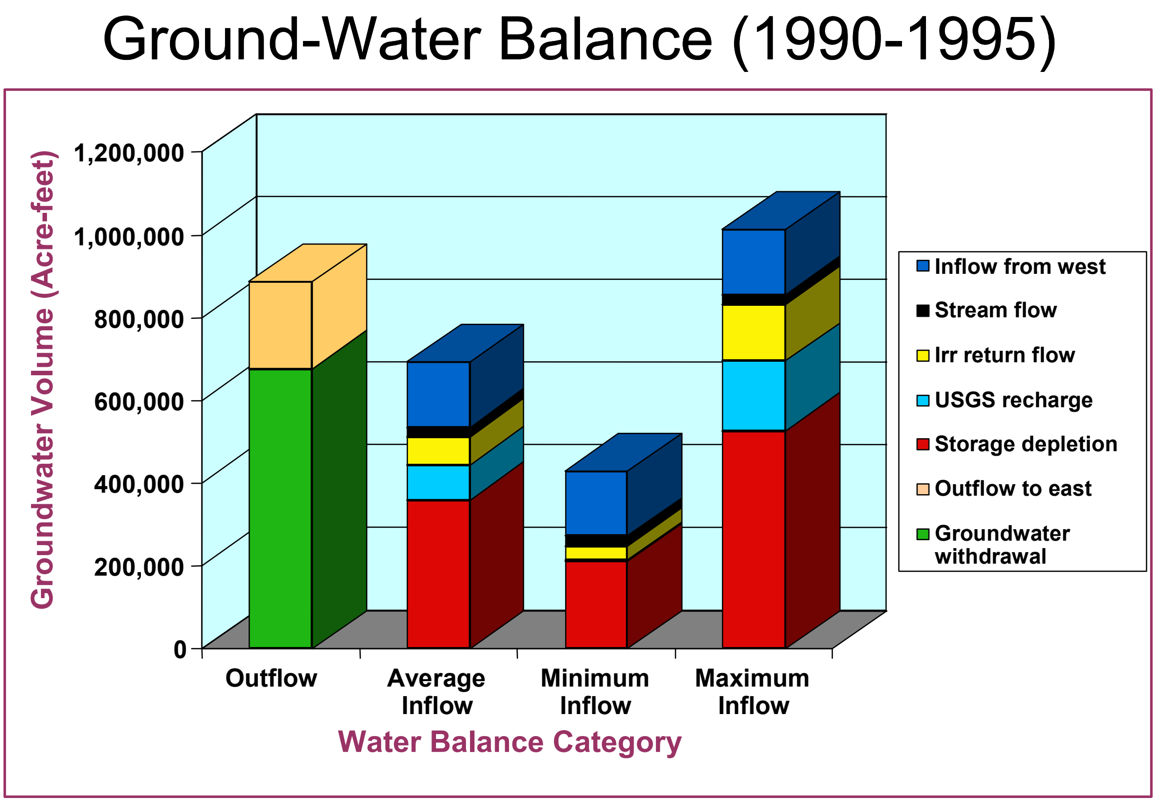

Figure 7. Schematic of water balance showing impacts of different estimates of recharge and storage depletion on ground-water inflow into Sherman County study area. Values calculated on a county-wide basis.

Nitrogen Budget Assumptions

In order to do the nitrogen budget some assumptions were made. First, only nitrate-N values were considered in this analysis. One reason for this is that nitrate is the mobile form of nitrogen and is generally not chemically impacted in an oxygenated environment. Also, the form of nitrogen fertilizer that is most mobile is the nitrate form. Anhydrous ammonia and other nitrogen-based fertilizers frequently are converted into nitrate by bacteria if the fertilizer is not utilized by plants.

The mass of excess nitrogen fertilizer potentially accumulated during the 1990-1995 time period was used as a comparison for what might be going into the unsaturated with what is observed in the ground water at the same time period. This value was calculated as the 30% of fertilizer nitrogen that is not utilized by plants.

The mean NO_3N value for the county was 8.3 mg/L. The average NO_3N value for the unsaturated zone and irrigation return flows was 73 mg/L. These values are based on the study done in the watershed of the South Fork of Beaver Creek (Townsend, 1995). These values probably skew the data set in that much of the data comes from a nitrate contaminated ground water study. However, these values enable the authors to present a “worst case” scenario.

Ammonium-N is not included. Most of the samples had high nitrate values indicating and oxygenated environment. Other nitrogen losses via denitrification also were not included because of lack of data.

Figure 8 illustrates the mass loading of nitrogen in Sherman County for 1990-1995. The graph illustrates that the outflow of nitrogen from the system (10,000 tons) is considerably less than even the minimum inflow value (7,850 tons) plus the excess fertilizer N available (38,600 tons). This suggests that there is potentially a large volume of nitrogen available in the unsaturated zone that has yet to arrive at the ground water table.

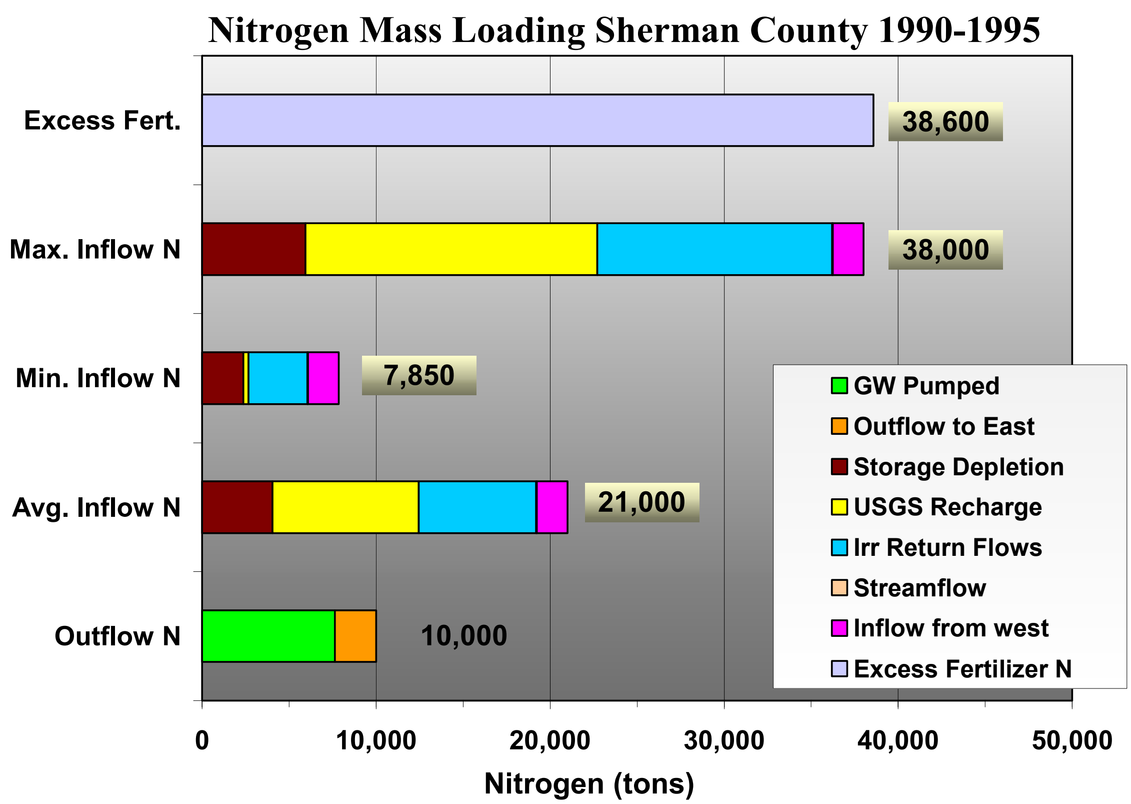

Figure 8. Nitrogen mass balance for Sherman County using minimum, maximum, and mean water balance values. Excess fertilizer nitrogen from values calculated for Figure 5.

Table 5 shows the potential sources of nitrate-nitrogen identified by use of the nitrogen-15 natural abundance isotope method (Townsend, 1995; USGS NAWQA, 2002). The majority of the samples show a fertilizer signature. The median values are quite wide ranging but all of the values are above the "background level" of 2 mg/L that indicates possible anthropogenic sources for the nitrogen (Mueller and Helsel, 1996). The median value for irrigated land use in the USGS NAWQA studies is 7.05 mg/L indicating that nitrate is definitely making it down to the ground water table.

This table is just an indicator of possible sources of nitrogen. The nitrogen cycle is complex and affected by bacteria, water chemistry, and soil components. This budget is a preliminary attempt to try to determine the volume of nitrogen that may be moving through the system.

Table 5. Potential sources of nitrate-nitrogen identified by use of nitrogen-15 natural abundance isotope method and reported median nitrate-N values for studies

Source of Data	**Nitrogen-15 Signature Source**	**Median NO3N mg/L**
USGS NAWQA Irrigated Land Use Study (2000)	Fertilizer and manure	7.05
USGS NAWQA Domestic Well Study (2001)		2.3
KGS 1949		2.5
KGS 1979 (Irr wells)		3.3
KGS 1990 (Irr wells)	Fertilizer	6.2
Soil Water (Pasture) (Towsend, 1995)	Mineralized Fertilizer	6.9
Soil Water (Irrigated Sites) (Townsend,1995)	Fertilizer	53

Table 6 presents the estimated quantity of nitrogen stored in the ground water under Sherman County, Kansas. The mass in tons that is potentially present in the ground water is quite high. The concentrations used in this table are estimates based on a few studies. As stated previously this is a preliminary attempt to calculate a nitrogen budget. Future work will attempt to evaluate the mass present in areas with minimal measured nitrogen content and to factor in some of the many processes of nitrogen removal.

Table 6. Estimated quantity of nitrogen stored in ground water under Sherman County, Kansas

Parameter	**Mean NO3-N**	**Median NO3-N**
Concentration (mg/L)	8.3	5.1
Area (acres)	677000	677000
Thickness (ft)	175	175
Porosity	0.25	0.25
Mass (Tons)	**334,000**	**205,000**

Indicators of Nitrate-N Contamination of Ground Water

Figure 8 shows the increase of nitrate-N in samples collected in Sherman County during three different time periods: 1949 during the original geologic and ground-water survey of the county (Prescott, 1953), 1978 as part of a statewide irrigation water quality survey (Hatheway et al., 1979), and in the 1990-1995 study (Townsend, 1995). As can be seen in the graph the overall trend is in increasing nitrate-N. The graph is based on all samples collected in these studies and does not show a comparison of values from the same wells.

However, Figure 9 does show a comparison of samples collected from the same wells in both the 1970's and the 1990's. This figure clearly shows that during the 20-year period the nitrate-N concentration increased for most of the wells. Concentrations of sulfate also showed an increase of 4% to 90%; chloride increased from 11% to 50%; and nitrate-N increased from 20% to 80%.

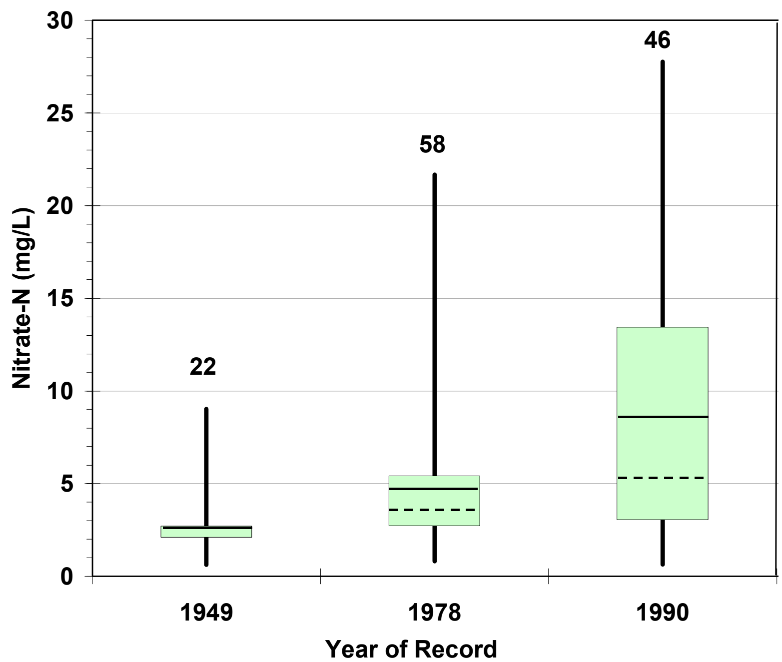

Figure 8. Comparison of mean, median, and range of nitrate-N concentration from ground water samples collected in Sherman County, Kansas. Data from Hathaway et al., 1979; Prescott, 1949, and Townsend, 1995.

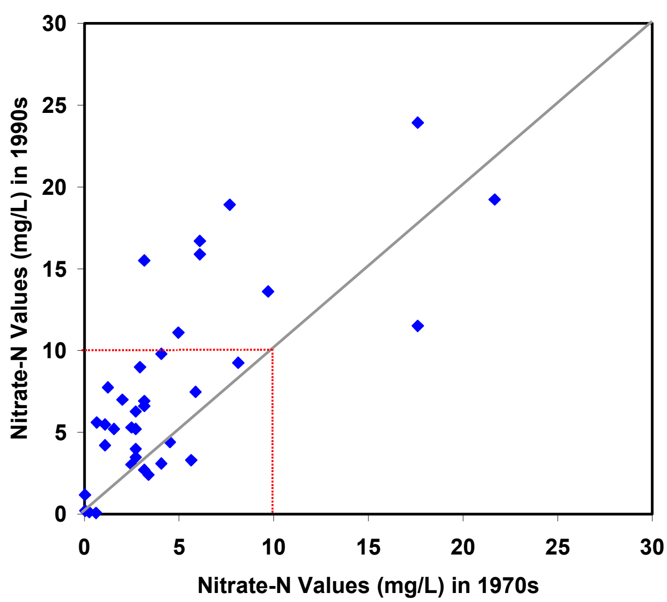

Figure 9. Observed increase in nitrate-N from samples collected at the same irrigation wells in 1970's and 1990's. Graph indicates that an overall increase in nitrate occurred during the 20 year period.

Conclusions

Nitrogen Budget

1) Nitrate concentrations are increasing in ground water.
2) Large concentrations of N observed in vadose zone near irrigated fields.
3) Large quantities of N are not accounted for in the nitrogen budget and may be in transit.
4) Nitrogen-15 isotopes indicate primarily fertilizer sources.
5) Other processes that affect nitrogen transformation need to be included in future nitrogen mass balance calculations.
6) Water quality issues need further research in order to determine if future use of ground water resources are at risk.

Water budget

1) Recharge estimates need to be refined in terms of present and past land use in order to more finely tune the volume of water (and possible contaminants being moved) that can potentially recharge the aquifer.
2) Influence of irrigation return flows on recharge estimates needs to be evaluated in terms of present and past calculations of volume of recharge.
3) Collection of available water use data across state lines is vital to determine the inflow of ground water into the system.

References

Becker, M. F., Bruce, B. W., Pope, L. M., and Andrews, W. J., 1999, Ground-water quality in the central High Plains aquifer, Colorado, Kansas, New Mexico, Oklahoma, and Texas: USGS Water-Resources Investigations Report 02–4112, 43 p.

Cederstrand, Joel R. and Becker, Mark F., 1998, Digital map of hydraulic conductivity for the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Open-file Report 98-548, http://webserver.cr.usgs.gov/nawqa/hpgw/GIS.html.

Hansen, C.V., 1991, Estimates of freshwater storage and potential natural recharge for principal aquifers in Kansas, U.S. Geological Survey, Water-resources Investigations, No. 87-4230, 100 p.

Hathaway, L. R., Waugh, T. C., Galle, O. K., Dickey, H. P., 1979, Chemical quality of irrigation waters in northwestern Kansas: Kansas Geological Survey Chemical Quality Series 8, 45 p.

Mueller, D.K., and Helsel, D. R., 1996, Nutrients in the nations' waters – too much of a good thing?: U.S. Geological Survey Circular 1136, 24 p.

Prescott, G. C., 1953, Geology and ground-water resources of Sherman County, Kansas: Kansas Geological Survey Bulletin 105, 130 p.

National Agricultural Statistics Service (NASS): http://www.usda.gov/nass/

National Atmospheric Deposition Program (NADP), 2002: http://nadp.sws.uiuc.edu/

Townsend, M. A., 1995, Potential sources of nitrate in South Fork of Beaver Creek watershed, Sherman County, Kansas: Kansas Geological Survey open-file rept. 95-73, 25 p.

U. S. Census Bureau, 2002: http://quickfacts.census.gov/qfd/states/20/20181.html (verified December 2002).

U. S. Geoloigcal Survey High Plains Aquifer NAWQA: http://webserver.cr.usgs.gov/nawqa/hpgw/ (verified December 2002)