Chapter 16

Groundwater beneath a Phase III Management Area in the Central Platte Natural Resources District, Nebraska: National Institute of Food and Agriculture–Conservation Effects Assessment Project

D.W. Meals, R. Spalding, M. Exner, R.B. Ferguson, M.L. McFarland, D.L. Osmond, and J. Spooner

The goal of the Nebraska National Institute of Food and Agriculture–Conservation Effects Assessment Project (NIFA–CEAP), Phase III, Central Platte Natural Resources District Project, Effectiveness of Irrigated Crop Management Practices in Reducing Groundwater Nitrate Concentrations, was to evaluate the effectiveness of documented farm management practices in lowering groundwater nitrate concentrations in a predominantly irrigated-corn watershed. The specific objectives included the following:

1. Analyze the trends in groundwater nitrate concentrations for the period of 1988 to 2006
2. Evaluate the effect of irrigation and nitrogen (N) inputs on groundwater nitrate concentrations using statistical approaches, including ArcGIS and cokriging and Bayesian Maximum Entropy
3. Evaluate the effects of crop rotation and conversion to sprinkler irrigation on groundwater nitrate concentrations using statistical covariate analysis
4. Assess the sensitivity of reductions in nitrate concentrations to management alternatives using statistical models
5. Assess the impact of uncontrollable (natural) variables on groundwater nitrate concentrations and overall effectiveness of management policies
6. Determine practices that can optimize reduction in leaching and improve groundwater quality
7. Compare groundwater nitrate concentrations and trends with those from less intensive spatial and temporal monitoring
8. Analyze the economic efficiency of the present policy in terms of cost per unit gain
9. Determine the impact of outlier producer behaviors on groundwater nitrate concentrations
10. Meet individually with producers who were slow to adopt identified practices (objective 6) to encourage acceptance and demonstrate appropriate practices on selected producers' fields
11. Evaluate producer adoption of identified practices after three years of targeted education
12. Disseminate results to stakeholders and decision makers through a variety of outreach mechanisms

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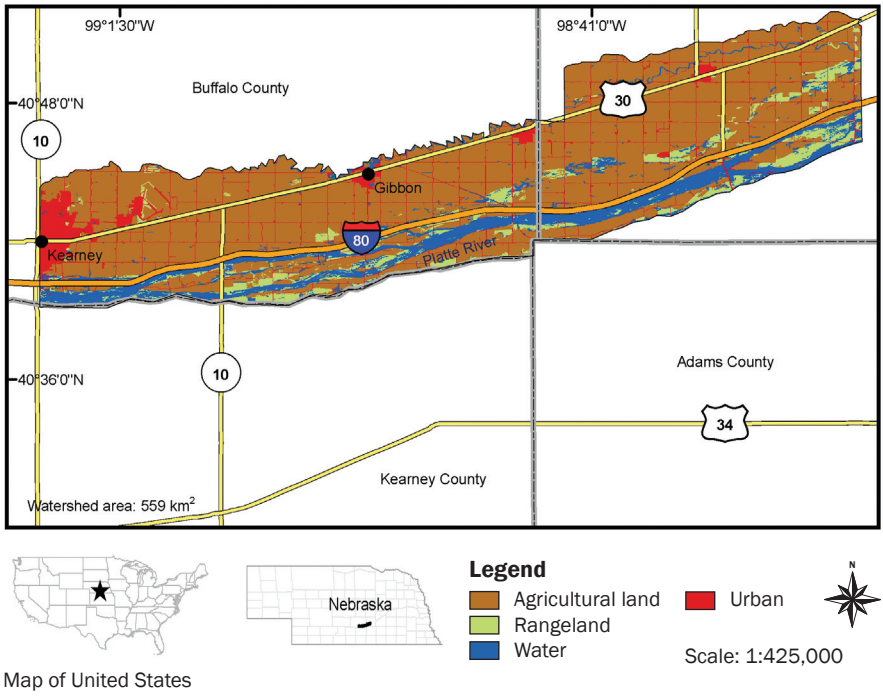
13. Modify the existing Web-based agrichemical groundwater database to accommodate project data

Watershed Information

Nitrate-contaminated groundwater of the Central Platte Valley encompasses more than 202,343 contiguous ha (500,000 ac) and lies wholly within the 8,547 km^2 (3,300 mi^2) Central Platte Natural Resources District (figure 16.1). The primary aquifer is a shallow, unconfined alluvial aquifer of high horizontal hydraulic conductivity. The Platte River penetrates the shallow alluvium and is hydraulically connected to the aquifer. The secondary aquifer is deeper, separated from the primary groundwater by a silty-clay aquitard and is known as the Ogallala Formation (Spalding and Exner 1980). Both the primary and secondary aquifers are used for irrigation and drinking water. However, because of the much higher hydraulic conductivity of the shallow alluvial (primary) aquifer, the majority of irrigation wells draw from this aquifer. Groundwater nitrate concentrations in the shallow aquifer generally exceed 10 mg L^{-1} nitrate-nitrogen (NO_3-N), and concentrations greater than 30 mg L^{-1} NO_3-N have been recorded.

The groundwater flows to the east-northeast, and the average hydraulic gradient is 1.4 m km^{-1} (7.5 ft mi^{-1}). Pump test data indicate that the horizontal hydraulic conductivity of the pri-

Figure 16.1
Groundwater beneath a Phase III management area in the Central Platte Natural Resources District, Nebraska, land use and stream networks.



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mary aquifer ranges from 104 to 119 m d^{-1} (340 to 390 ft day^{-1}), while in the Ogallala formation the range is 5.2 to 5.8 m d^{-1} (17 to 19 ft day^{-1}). The vertical hydraulic conductivities are 10.4 m d^{-1} (34 ft day^{-1}) for the primary aquifer, 3.1 to 6.1 cm d^{-1} (0.1 to 0.2 ft day^{-1}) for the Ogallala aquifer, and 0.18 to 0.31 cm d^{-1} (0.006 to 0.01 ft day^{-1}) for the aquitard. The extremely low vertical hydraulic conductivity of the aquitard indicates a lack of downward movement and is the reason for the observed absence of nitrate in Ogallala monitoring wells. Hydrologic analysis indicates that river water flows into the groundwater under the bottomland and dilutes the groundwater NO_3-N concentrations (Shu and Chen 2002).

The Buffalo-Hall County Phase III groundwater quality management area was selected as the Nebraska Conservation Effects Assessment Project (CEAP) because of long records of both high NO_3-N concentrations in the shallow groundwater exceeding the maximum contaminant level (10 mg L^{-1}) and management practices implemented to reduce NO_3-N concentrations. There is a 19-year history (1988 to 2006) of nutrient management and as many as nine years of measured water-use data for each field.

The 58,812 ha (145,215 ac) project site is located in the Platte River Valley of South Central Nebraska in the Wood hydrologic unit code (#10200102). The valley has very little relief; consequently, runoff is minimal. Differences in soil drainage, land use, and hydrogeology distinguish the terrace and bottomland areas. The terrace lies 1.5 to 3 m (5 to 10 ft) above a broad bottomland and is separated from the bottomland by an obvious gradient that parallels the North Channel of the Platte River. Terrace soils are well drained, silty loams to medium or fine sands. Bottomland soil is poorly to excessively well-drained. The water table lies from 1.5 m (5 ft) beneath the bottomland to 7.6 m (25 ft) beneath the terrace. The saturated zone consists of sand and gravel below which exists an aquitard of clayey silt that is 9.1 to 19.8 m (30 to 65 ft) thick. Below the aquitard, the lower groundwater system is comprised of heterogeneous materials. Not all of the study area has both a primary and secondary aquifer.

Agriculture is primarily irrigated corn. Irrigation increased dramatically in the 1970s concurrent with an increase in corn production and the widespread use of atrazine and inexpensive N fertilizer. The Central Platte region is characterized by 0.9 to 1.8 m (3 to 6 ft) thick well to excessively well-drained soils highly vulnerable to leaching, with a short distance (<6 m [<20 ft]) to groundwater. Groundwater levels are fairly stable, and the supply seems adequate to support crop production. Elevated NO_3-N concentrations are common in groundwater. Published research suggests that the use of N in excess of crop needs was a result of overly optimistic yield goals, over irrigation, and lack of adherence to commercial fertilizer application guidelines. A survey of NO_3-N in the groundwater (1974) indicated that fertilizer applications were causing increased NO_3-N concentrations.

Approximately 86% of terraced acres are irrigated cropland, 80% of which is in corn. Prior to 1993, seed corn production constituted <1% of the acres planted to corn. Seed corn acreage gradually increased to ~5% in 1997 and remained stable until 2003, when it decreased to ~3%. About 67% of the bottomland is irrigated. During the study, ~45% of the irrigated bottomland area was cropped with corn. Furrow irrigation is the predominant irrigation method used on both the terrace and bottomland areas. Approximately 1,000 to 1,100 wells are in the terrace. In the 1990s, farmers began soybean-corn rotations.

Over the last several decades, more than US$8 million have been expended to address groundwater nitrate contamination in the Hall-Buffalo County Phase III management area, where there are more than 3.5 wells km^{-2} (9 wells mi^{-2}). To date, the Central Platte Natural

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Resources District has spent about US$3 million in the Phase III area. The USDA has expended more than US$4.5 million for Nebraska Management Systems Evaluation Area activities near Shelton in the center of the Phase III area, and more than US$1 million have been contributed to district water quality assessments through the United State Geological Survey National Water Quality Assessment program. In addition, the USDA Natural Resources Conservation Service (NRCS) has invested about US$550,000 in cost-share funds for conversion from furrow to pivot irrigation in the project area.

Although the groundwater supply for irrigation has been historically adequate, there is now a moratorium on new well development and expansion of irrigated acres due to decreased Platte River flows. Thus, in recent years, the concern in this project area has shifted from controlling excess N in the groundwater to increasing surface water flows.

Water Quality Information

When this study began, the principal pollutant of concern was groundwater NO_3-N derived from irrigated agriculture. The Central Platte region is the largest area in Nebraska, and possibly in the United States, that is highly vulnerable to agrichemical contamination and is underlain by groundwater with nitrate concentrations exceeding 10 mg NO_3-N L^{-1}. The first NO_3-N measurement in excess of the 10 mg NO_3-N L^{-1} maximum contaminant level (a standard set by the US Environmental Protection Agency) in the Central Platte Natural Resources District's groundwater was reported in Merrick County at the eastern end of the Central Platte Natural Resources District in 1961 (Nebraska Water Quality Survey 1965). A 1974 baseline water quality study (Exner and Spalding 1976) revealed that NO_3-N concentrations in approximately half of the 511 wells sampled throughout the Central Platte Natural Resources District were significantly above 2.5 mg NO_3-N L^{-1} and that ~20% of the district was underlain by high nitrate (≥10 mg NO_3-N L^{-1}) groundwater. Stable N isotope studies confirmed that the major source of this nitrate was leachate from commercial N fertilizer (Gormly and Spalding 1979). Resampling the 1974 baseline wells revealed that the approximate rate of nitrate increase was ~1 mg N L^{-1} y^{-1} (Exner 1985). Thus, there is ample research documenting the increase in elevated groundwater NO_3-N levels from fertilizer leaching in the region. Particularly susceptible regions are areas of irrigated corn monoculture on well to excessively well-drained soils with less than 15.2 m (50 ft) to groundwater.

Specific water quality objectives of the Nebraska CEAP included the following:

1. Analyze the trends in groundwater NO_3-N concentrations for the period of 1988 to 2006
2. Assess the sensitivity of reductions in nitrate concentrations to management alternatives using conventional statistical analysis
3. Evaluate the effects of crop rotation and conversion to sprinkler irrigation on groundwater nitrate concentrations using statistical covariate analysis
4. Evaluate the effects of irrigation and N inputs on groundwater nitrate concentrations using spatial analysis and statistical approaches, including cokriging and Bayesian Maximum Entropy

Because of regulatory requirements instituted in 1988, farmers in the Buffalo-Hall County Phase III management area were required to file detailed annual reports for each well irrigating corn, sorghum, and potatoes. As a consequence, a large long-term annual dataset is available for ~2,200 irrigation wells. All irrigation wells must be registered with the Nebraska Department

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of Natural Resources. Irrigation wells were located using a global positioning system, and these locations were overlaid with registered irrigation well locations in the Nebraska Department of Natural Resources database so that pedigree information (well depth, screen depth, etc.) and geologic logs could be linked to each sampled irrigation well (Nebraska Department of Natural Resources 2012). This information was needed to identify wells that pump from both the primary and secondary aquifers.

All groundwater NO_3-N data from routine monitoring, water quality assessments, and special studies by local, state, and federal agencies and the University of Nebraska are archived in the Quality Assessed Agrichemical Contaminant Database for Nebraska Ground Water (Exner et al. 2005; University of Nebraska-Lincoln 2011). The Central Platte Natural Resources District provided annual producer report data as a Microsoft Access file; each report was identified by the location of the irrigation well. These files, containing more than 23,800 reports, were combined into a producer data Microsoft Access table. Registration numbers and well attribute information for the ~1,900 irrigation well locations were obtained from the Quality Assessed Agrichemical Contaminant Database for Nebraska Ground Water. While much of the well attribute data in the agrichemical contaminant database was downloaded from the Nebraska Registered Groundwater Wells database, the well attribute data in the contaminant database include well-screen depth intervals that, for the majority of wells, were obtained from paper registrations or, for newer wells, were obtained by viewing registrations online. Well depth, screened interval(s), and the geologic log available online in the Nebraska Registered Groundwater Wells database were used to determine the source aquifer(s), which were entered into the well attributes table. The well attribute and producer data tables are in an Access database and are linked by the well location.

Water-level data are also available from the Central Platte Natural Resources District. Yearly maps are constructed from water-level measurements in 600 irrigation wells across the district. Irrigation well monitoring and agricultural management required reporting allows the establishment of a very tight temporal and spatial relationship between management and water quality monitoring. Regression models were used to calculate the trends in annual average irrigation well contaminant concentrations in the primary aquifer. The estimated primary aquifer NO_3-N data were also input into the statistical applications to assess the spatial distribution of nitrate in the Phase III area.

Land Treatment

The Central Platte Natural Resources District was the first in Nebraska to develop an action plan to manage NO_3-N leaching and to reduce NO_3-N levels in the groundwater. Aquifer NO_3-N concentrations were mapped and efforts were focused on those areas with the greatest contamination. The Central Platte Natural Resources District CEAP Study intentionally targeted this area of groundwater contamination as did the earlier USDA Management Systems Evaluation Area Project (Spalding et al. 2001).

Land treatment in the watershed is regulated by the Central Platte Natural Resources District. All producers are expected to implement conservation practices and in Phase II and III groundwater quality management areas, submit the appropriate producer reports. Specific management measures include timing of fertilizer applications, recommended rates of N fertilizer application, education and certification, and submission of a two-part annual producer report.

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All farm operators using N fertilizer must be certified by the district. The extent of conservation practices to reduce N leaching was dependent upon the management phase.

Phase II requirements prohibit commercial N fertilizer applications on all soil types until after March 1. Annual N analyses are required for the following:

- Irrigation water
- Any applied manure or sludge
- Soil to a depth of 0.9 m (3 ft)

Soil samples cannot represent more than 32 ha (80 ac). It is assumed that 22.9 cm (9 in) of irrigation water are applied and by multiplying the well water N concentration by the applied irrigation water volume, total N applied through irrigation is calculated. These additional sources of N, as well as previous crop credits (50 kg N ha^{-1} [45 lb N ac^{-1}] for soybeans and 135 kg N ha^{-1} [120 lb N ac^{-1}] for alfalfa), are used to reduce the total N fertilizer rate. Under Phase III requirements, producers must follow all Phase II guidelines. Nitrogen fertilizer cannot be applied before March 1, and if total preplant N fertilizer is greater than 90 kg N ha^{-1} (80 lb N ac^{-1}), N applications must be split between preemergence and sidedress or applied with an approved inhibitor.

Since 1988, ~300 producers in this area have been required to submit detailed N management and production reports for each of the ~2,200 wells irrigating corn, sorghum, or potatoes annually. Reports were required to be submitted March 1 (crop, acres irrigated, yield goal, N needed, and University of Nebraska fertilizer recommendation) and December 31 (actual yield, amount of N applied, and amount of irrigation water applied). Starting in 1989, producers had to send in detailed management reports that captured N management practices. Although reports were required, starting in 2002, the number of reports began to sharply decline, even though a fine could be levied against those not reporting. Changes in the 2002 farm bill had given producers anonymity such that it was difficult for the Central Platte Natural Resources District to take action against farmers who did not comply.

The study results showed that from 1988 through 1993, sprinkler-irrigated acres on the terrace remained constant at ~1,175 ha (~2,900 ac), which is approximately 4% of the irrigated area. Gradual increases occurred in subsequent years with the largest addition of ~1,400 ha (~3,460 ac) occurring in 2002. In that year, ~4,900 ha (12,154 ac) or ~17% of the terrace's irrigated area was under sprinkler irrigation.

The four conservation practices most commonly used were conversion from furrow to sprinkler irrigation, improved nutrient management, acceptance of realistic yield goals, and improved water management. It is widely recognized that many producers are applying more irrigation water than recommended. Some are applying N at rates above recommendations. Researchers have found that producers need to adopt additional conservation practices that include cover crops, controlled-release N fertilizers, more sprinkler irrigation, lower water rates, and crop canopy sensors to achieve further reductions in N leaching.

Funding has been available to producers to assist with the implementation of conservation practices. Since 1998, the Central Platte Natural Resources District provided cost share to convert from furrow to sprinkler irrigation. The amount increased over the years from US$3,000 to US$7,500 per system per producer. When conversion slowed, changes were made to cost share. In 2009, the lifetime limitation of one system per producer was replaced by one system per producer per year. Since 2003, producers have had access to the USDA NRCS Environmental Quality Incentives Program (EQIP) funds for conservation practices. Selected water quality

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practices eligible for either 50% cost share or specific amounts per acre are subsurface drip irrigation, land smoothing, terraces, and the use of nutrient management practices.

Water Quality Response

In order to better understand groundwater NO_3-N trends, the terrace areas and bottomland areas were evaluated separately because hydrology, cropping systems, and irrigation intensity were different. There was a documented decreasing trend in groundwater NO_3-N concentrations in the primary aquifer beneath the terrace, but the groundwater NO_3-N levels continued to significantly exceed the maximum contaminant level. A linear regression of annual nitrate concentration from 1987 to 2003 documented a statistically significant 18% decrease from 26.4 to 22.0 mg NO_3-N L^{-1}. The groundwater NO_3-N concentration beneath the bottomland, however, remained constant and much lower throughout the period of investigation. From 1987 to 2003, average groundwater nitrate concentrations in the primary aquifer beneath the bottomland remained static at ~8 mg NO_3-N L^{-1}. In addition, spatial analysis was used to estimate the amount of spatial variability and to estimate groundwater concentrations in areas where the number of wells reporting data has declined. Mod-Flo analysis also estimated that approximately 180 pumping points were necessary to provide sustainable water levels at steady-state conditions.

Average N application rate was very consistent during the first 16 years of management regulations, averaging 159 ± 11 kg N ha^{-1} (142 ± 10 lb N ac^{-1}). Year to year fluctuations occurred due to changes in N credits, expected crop yields, and volatile fertilizer prices. Fertilizer prices probably caused a sharp decrease in N application rates following peak application rates in 2000; average N application rate decreased by about 25 kg N ha^{-1} (22 lb N ac^{-1}) from a high of 177 kg N ha^{-1} (158 lb N ac^{-1}). Nitrogen application rebounded somewhat as fertilizer prices varied but remained lower than previous highs at around 150 kg N ha^{-1} (135 lb N ac^{-1}) since 2001.

Nitrogen fertilizer application rates remained stable and then declined slightly, and corn yields increased by about 138 kg ha^{-1} y^{-1} (2.2 bu ac^{-1} yr^{-1}). This trend of increasing corn yields while N fertilizer rates remained essentially unchanged has occurred throughout the Corn Belt since 1980. The irrigated corn yields in the study area averaged 10,986 kg ha^{-1} (175 ± 20 bu ac^{-1}), about 1,568 kg ha^{-1} (24 bu ac^{-1}) higher than in Nebraska as a whole. Significant amounts of N (~0.3 kg N bu^{-1} [0.7 lb N bu^{-1}]) are removed during corn harvest; the average amount of N removed has been approaching the average N fertilizer application rate in the study area since about 2001. It appears that the trend was accelerated by high fertilizer prices as in 2001 and 2003. If the trend continues, more N could be removed in the grain than is applied as fertilizer. In both 2001 and 2003, more N was removed in the grain than was applied as fertilizer, and no decrease in yield was observed. The decrease in NO_3-N concentrations in the shallow aquifer beneath the terrace is in part due to the increased N removal associated with increased crop yields, as well as a conversion from furrow to sprinkler irrigation.

Because there is excess residual soil N and irrigation water N, N was still available for crop uptake. However, most of the N applied from irrigation water is reportedly added after the corn crop actually needs it and thus may contribute to groundwater nitrate.

During the study, producers converted ~15% of 28,300 furrow-irrigated terrace ha (~69,800 ac) to sprinkler irrigation, which presumably reduced the total amount of irrigation water applied to the crop, although no flow meters were installed on irrigation wells at that time. A

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one-time Natural Resource District measurement of pumping rates occurred for all irrigation wells, and it was found that the average irrigation water application was around 61 cm (24 in), which is significantly greater than the recommended 22.9 cm (9 in). Changes in irrigation management reduced NO_3-N concentrations by around 6%. The data indicate that groundwater nitrate concentrations have responded to improved management practices, for both N and water management, instituted by the Central Platte Natural Resources District (Exner et al. 2010).

Exner et al. (2010) attributed water quality response to yield increases and improvements in irrigation management, while N fertilizer application rates remained unchanged during the study. Some of the decrease in the nitrate concentration in the primary aquifer beneath the terrace is associated with increasing N removal rates, which in turn are a consequence of increased yields. Another increment of the decrease in nitrate concentration can be attributed to the benefits of sprinkler irrigation: more uniform water applications and the ability to better synchronize N application with crop needs using chlorophyll meter readings, thereby reducing residual N.

Finally, through a series of complex geostatistical analyses, the project team developed methods for predicting groundwater NO_3-N concentrations in an area of interest using less-intensive data than had been previously collected. This is of interest because the intensity of data collection continues to decline, and the prediction techniques can potentially be used to test for changes in nitrate levels in specific areas in future years.

Socioeconomic Analysis

To ascertain nutrient and irrigation management practices, 600 farms were surveyed in the Central Platte Natural Resources District, which is larger than the project area of 58,812 ha (145,215 ac). The survey area totaled 409,947 ha (1,013,000 ac), which were evenly divided between Phase I, II, and III management regimes: 14,462 ha (353,736 ac) in Phase I, 136,943 ha (338,393 ac) in Phase II, and 129, 852 ha (320,871 ac) in Phase III. Irrigated acres accounted for 79% of the acreage, evenly split between sprinkler and furrow. About 50% of producers used crop consultants.

Producers were found to use the following conservation and management practices:

- 91% of the farmers soil sampled for fertilizer recommendations; 70% sampled annually
- 72% of the farmers took deep soil samples
- Soil sampling was completed by fertilizer dealers (46%), by consultants (29%), and by farmers (5%)
- Irrigation water tested annually for nitrate by 50% of the producers
- Variable rate N was used by only 23% of producers
- Nitrification inhibitor use declined from 33% (in 1997) to 12% use at present
- Slow release or controlled release N fertilizer was used only 6% of the time
- Legume credits were used by 75% of the farmers (46 kg N ha^{-1} for soybeans, 76 kg N ha^{-1} for alfalfa, 41 lb N ac^{-1} for soybeans, and 68 lb N ac^{-1} for alfalfa)

There was some comparison with past management, but producers were not submitting the required agricultural data as well as in previous years. In addition, it appeared that having the district move to Phase IV affected the decision making of some producers.

Although not determined in the project itself, Supalla et al. (1995) examined economic factors influencing N management practices and reported that fertilizer cost did not play a large role as there was no correlation between actual or target yield and the amount of nitrogen

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applied in excess of recommended yields. However, there were rather dramatic shifts in N use in this study due to fertilizer price fluctuations, which does affect attention to rate, timing, and interest in stabilizers and slow release. Historically, the low cost of extracting irrigation water from the shallow aquifer and the adequacy of the water supply meant that there was little economic incentive to adopt new irrigation practices.

Outreach

There were previous educational efforts with producers—the Hall County Water Quality Special Project (1980 to 1984) and Platte Valley Nitrogen and Irrigation Management Demonstration Project (1984 to ongoing). In addition, the regulatory efforts started in 1988 with the Central Platte Natural Resources District Groundwater Management Area have continued.

Successive N management research has shown that 50% of the time, there is some reduction in N leaching with N inhibitor products but that climate is critical to the success of these materials. Research on crop canopy sensors for in-season N management has also shown some promise in reducing N application rates, as has work with cover crops. Promotion of these N reduction and conservation practices is occurring through extension, but there has been little adoption to date.

Central Platte Valley National Institute of Food and Agriculture–Conservation Effects Assessment Project Publications

This project's results have been published in numerous journal articles, book chapters, and other publications. One of these publications is provided below.

Exner, M.E., H. Perea-Estrada, and R.F. Spalding. 2010. Long-term response of groundwater nitrate concentrations to management regulations in Nebraska's Central Platte Valley. The ScientificWorld Journal 10:286-297.

Funding

Funding for the Central Platte Natural Resources District Project was provided as follows:

- US$8 million by local (natural resources district) and federal (USDA NRCS) sources have been expended to remediate groundwater nitrate contamination in the Hall-Buffalo County Phase III management area, where there are more than 3.5 wells km^{-2} (9 wells mi^{-2})
- US$9 million by Central Platte Natural Resources District (US$3 million has been spent in Buffalo-Hall County's Phase III area)
- US$4.5 million by the USDA for Nebraska Management Systems Evaluation Area (Phase III area)
- US$1 million in water quality assessments by the United States Geological Survey National Water Quality Assessment Program
- US$550,000 from USDA NRCS cost-share funds for conversion from furrow to pivot irrigation in the project area
- US$600,000 by the NIFA–CEAP (Award No. 2006-51130-03708)

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Project Personnel

All project personnel worked at the University of Nebraska, Lincoln. Roy F. Spalding (hydrochemist) was the project investigator, and Mary E. Exner (hydrochemist), Richard B. Ferguson (agronomist), and Dave B. Marx (statistician) were coproject investigators. Hugo Perea-Estrada (postdoctoral student) and Megan Liedtke Tesar (doctoral student) conducted research under Dr. Spalding and Marx, respectively.

This was a cooperative multidisciplinary project between agronomists and water scientists in the Department of Agronomy and Horticulture and the School of Natural Resources and statisticians in the Department of Statistics at the University of Nebraska.

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