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Key Topic #1: Land Use and Natural Resources – Past and Present

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Study Resources

Cropping Systems in Agriculture and Their Impact on Soil Health – A Review – *Global Ecology and Conservation, Yang et al., 2020* (Page 2 - 14)

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Global Ecology and Conservation 23 (2020) e01118

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: http://www.elsevier.com/locate/gecco

Review Paper

Cropping systems in agriculture and their impact on soil health-A review

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A R T I C L E I N F O

Article history:
Received 14 April 2020
Received in revised form 14 May 2020
Accepted 14 May 2020

Keywords:
Soil health
Cropping system
Crop diversification
Sustainable agriculture
Functional microorganisms

A B S T R A C T

Soil health is defined as the capacity of soil to function, within ecosystem boundaries, to sustain crop and animal productivities, maintain or enhance environmental sustainability, and improve human health worldwide. In agro-ecosystems, the soil health can change due to anthropogenic activities, such as preferred cropping practices and intensive land-use management, which can further impact soil functions. Previous assessment of soil health in agriculture mostly relates to soil eco-functions that are integrated with non-biological properties such as soil nutrients and soil structures. In recent years, biological properties such as soil microorganisms were considered as an essential composition in soil health as well. However, systematic reviews of soil health and its potential feedback to human society under different cropping practices are still limited. In this review, we discussed 1) the impact of common and novel cropping practices in agro-systems on soil health, 2) the evolution of plant—microbe—soil complex and the biochemical mechanisms under the pressure of agriculture that responsible for soil health, 3) changes in the concept of soil quality and health over recent decades in agro-systems and the key indicators currently used for evaluating soil health, and 4) issues in agroecosystems that affect soil health the most, particularly how various cropping practices have developed over time with human activities in agroecosystem. This knowledge, along with necessary policies, will help to ensure healthy soil—a crucial component for sustainable ecosystem development.

1. Introduction

Soil is an extremely complex ecosystem and a highly valuable resource from an ecocentric and anthropocentric perspective. Soil is undoubtedly one of our most essential and strategic resources, due to its many crucial functions, including: (i) provision of food, fiber, and fuel; (ii) decomposition of organic matter (e.g., dead plant and animal material); (iii) recycling of essential nutrients; (iv) detoxification of organic contaminants; (v) carbon sequestration; (vi) regulation of water quality and supply; (vii) habitat provision for myriad of animals and microorganisms (soil is an important biodiversity reservoir); (viii) source of raw materials (clay, sand, gravel). Unfortunately, soil has been and is currently being rapidly degraded at a global scale due to a range of invasive anthropic activities in intensive agriculture, with concomitant adverse effects on human

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https://doi.org/10.1016/j.gecco.2020.e01118

and ecosystem health. This is concerning as soil is a non-renewable resource at a human temporal scale (i.e., soil loss and degradation are not recoverable within a human lifespan).

The definition of soil health under various cropping systems has evolved with the development of agriculture. In the past, researchers and farmers were mostly concerned about soil quality and crop production. Since the 1990s, the concept of soil health assessment has focused on specific soil properties and the soil's ability to maintain a range of ecological functions in its appropriate ecosystem, supporting long-term sustainable cropping systems. Thus, soil health is defined as the ability of a soil to function and provide ecosystem services (Van Es and Karlen, 2019), or the soil's fitness to support crop growth without degrading soil or otherwise harming the environment (Acton and Gregorich, 1995). The terms 'soil health' and 'soil quality' have been used interchangeably, with the emphasis mostly on crop production with some concern for environmental sustainability (Doran et al., 1996). Producers typically prefer 'soil health,' as it portrays soil as a living, dynamic organism that functions holistically rather than an inanimate mixture of sand, silt, and clay. Scientists prefer 'soil quality,' as it describes quantifiable physical, chemical, and biological characteristics of the soil. The 'health' of a soil requires value judgments that cannot be quantified. Later studies further defined the role of soil biological properties in soil health (Ahmad et al., 1999; Pankhurst et al., 1995; Rajasekaran and Warren, 1995), as opposed to 'soil fertility', which is defined as the natural and sustainable ability of a soil to produce plants (Anonymous, 2016) or the capacity of the soil to supply nutrients to a crop (Agegnehu and Amede, 2017). In this context, soil nutrient contents are considered fertility indicators while crop yield is a measurement of soil fertility. Since the start of the millennia, numerous studies have been conducted on soil health, with most targeting soil microbiological characteristics along with soil physicochemical properties. Many soil health indicators among cropping systems have since been discussed and developed, including soil microbial composition and enzyme activities (Ozlu et al., 2019; VeVerka et al., 2019), C:N ratio (Byrnes et al., 2018; Gannett et al., 2019), soil biological properties, including mineralizable (Hurisso et al., 2018; Obrycki et al., 2018) and permanganate oxidizable carbon (Thomas et al., 2019; Van Es and Karlen, 2019), soil physical properties such as water holding capacity, water-stable aggregation, surface and subsurface penetration resistance (Van Es and Karlen, 2019); and soil chemical properties such as alkaline phosphatase activity involved in P cycling (Bhandari et al., 2018) and extractable K, Mg, Fe, Mn, Zn contents (Thomas et al., 2019). The most recent developments on soil health assessments include the Cornell comprehensive assessment of soil health-CASH (Gholoubi et al., 2018; Schindelbeck et al., 2008) and 'Haney soil health test-HSHT' (Chu et al., 2019), which quantify soil health under different cropping systems by focusing on soil biology, such as plant-available nutrients, soil respiration, and bioavailable C and N.

It is essential to design initiatives and implement actions to protect and restore soil health in agriculture. However, the concept of soil health is not easy to define or grasp; consequently, it has been a topic of intense debate and controversy (Sojka and Upchurch, 1999; Sojka et al., 2003). A commonly used definition of 'soil health' or 'soil quality' is "the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal and human health" (Doran and Parkin, 1996; Doran and Zeiss, 2000). However, Pankhurst et al. (1997) suggested using 'soil quality' when referring to the "soil's capacity to meet defined human needs" (e.g., to support a particular crop), and 'soil health' when speaking about the "soil's continued capacity to maintain its functions." Interestingly, 'health' in the context of soil highlights the vital importance of the living component of soils, frequently characterized by overwhelming biodiversity. Here, it must be stated that using 'health' when referring to soils is based on analogy rather than homology, as soil is not a single living organism.

While there are many other definitions of soil health and soil quality in the literature [e.g., "the capacity of soil to perform its functions," "how well is the soil functioning for a specific goal or use" (Karlen et al., 2003); "the capacity of soil to perform its ecosystem processes and services while maintaining ecosystem attributes of ecological relevance" (Garbisu et al., 2011)], most refer to the ability of soil to perform its functions and ecosystem services sustainably. In any case, the terms 'functions' and 'services' have teleological implications, as if soils had a purpose, end, or goal.

One of the most important, well-known limitations of the evaluation of soil health in our current cropping systems is the lack of a healthy control soil that could be used for reference and comparison purposes. This is not surprising because soil is spatially heterogenous (in fact, it is defined more by the heterogeneity of its properties and processes than any average measure) and temporally dynamic. In response to this lack of a healthy reference soil, Karlen et al. (2001) reported that trends over time provide the most suitable way to assess the effects of soil management on soil functional sustainability (i.e., soil health) under different cropping systems. Another problem with the definition of soil health as "the capacity of a given soil to perform its functions" is that often, and specifically depending on the intended soil use, the abovementioned soil functions can be conflicting or incompatible. Therefore, this paper reviews the impact of conventional cropping systems on soil health, microbiological indicators, and other indicators related to soil health evaluation and soil degradation caused by anthropogenic activities in agriculture to provide useful information for future cropping system design and optimization in agriculture.

2. Cropping systems and soil health

Cropping systems, including crop diversification, crop rotation and intercropping, and related agronomic practices used in agriculture impact soil health and quality from various spatial and temporal aspects (Vukicevich et al., 2016). Cropping systems were initially designed to maximize yield from agro-systems, but modern agriculture has become increasingly concerned about the environmental sustainability of cropping systems (Fargione et al., 2018). The goal of soil health maintenance is to ensure long-term stable high productivity and environmental sustainability of cropping systems under five essential function evaluation standards, namely nutrient cycling, water relations, biodiversity and habitat, filtering and buffering, and physical stability and support (Hatfield et al., 2017). Fig. 1 illustrates an example of how an optimized cropping system increases soil health, relative to monoculture.

2.1. Crop diversification

Crop diversification is often described as the 'planned diversity' of cropping systems (Matson et al., 1997). It is not only critical for optimizing crop production but also important for increasing soil health by balancing soil biodiversity, enhancing soil nutrient use efficiency, and reducing soil-borne pathogens (Barbieri et al., 2019; Gurr et al., 2016). It is well accepted that optimized crop diversification has various benefits, not only to growers but also to the environment, as increasing crop diversity can enhance heterogeneity of soil chemical nutrients, soil physical structures, and functional microorganisms at different spatial scales, leading to improved soil health and crop yields (Bardgett and van der Putten, 2014; Maron et al., 2011). However, this relationship can vary with species redundancy and host-specificity of some soil-borne pathogens (Naeem, 1998; Zhu et al., 2000). For example, Bainard et al. (2017b) reported that increased crop diversity did not necessarily reduce soil-borne diseases; in particular, including more pulse crops in rotations significantly increased the pathogen index, which may be due to an increase in pulse-specific pathogens.

The overall richness of crop species in agroecosystems could be the ultimate driver of soil health; thus, to optimize the benefits that crop diversification can bring to the system, the diversity of plant functional groups may be important for crop diversification management (Milcu et al., 2013). Plant functional groups/types were initially used to classify plants according to their biological and physiological characteristics to develop a vegetation model for land-use studies (Bonan et al., 2002). In agroecosystems, the most common functional crop mixtures consist of a mixture of any of the four main groups, namely C3 grasses (such as cotton), C4 grasses (such as maize), legumes which fix N from atmosphere, and non-leguminous forbs (Vukicevich et al., 2016), as plants with different eco-functional types often grow well in community due to their different needs in the temporal and spatial niche and soil nutrient availabilities (Roscher et al., 2013). Similarly, higher diversity of plant eco-functional groups creates heterogeneity of the favorable niches for different soil functional microbes; therefore, crop diversification management with more plant functional groups could enhance soil health and ecosystem services (Vukicevich et al., 2016).

In modern agriculture, growing new crop varieties with improved compatibility of beneficial soil biota could be a powerful way to improve soil health in agroecosystems, as plant genotypes can significantly influence soil microbial communities and

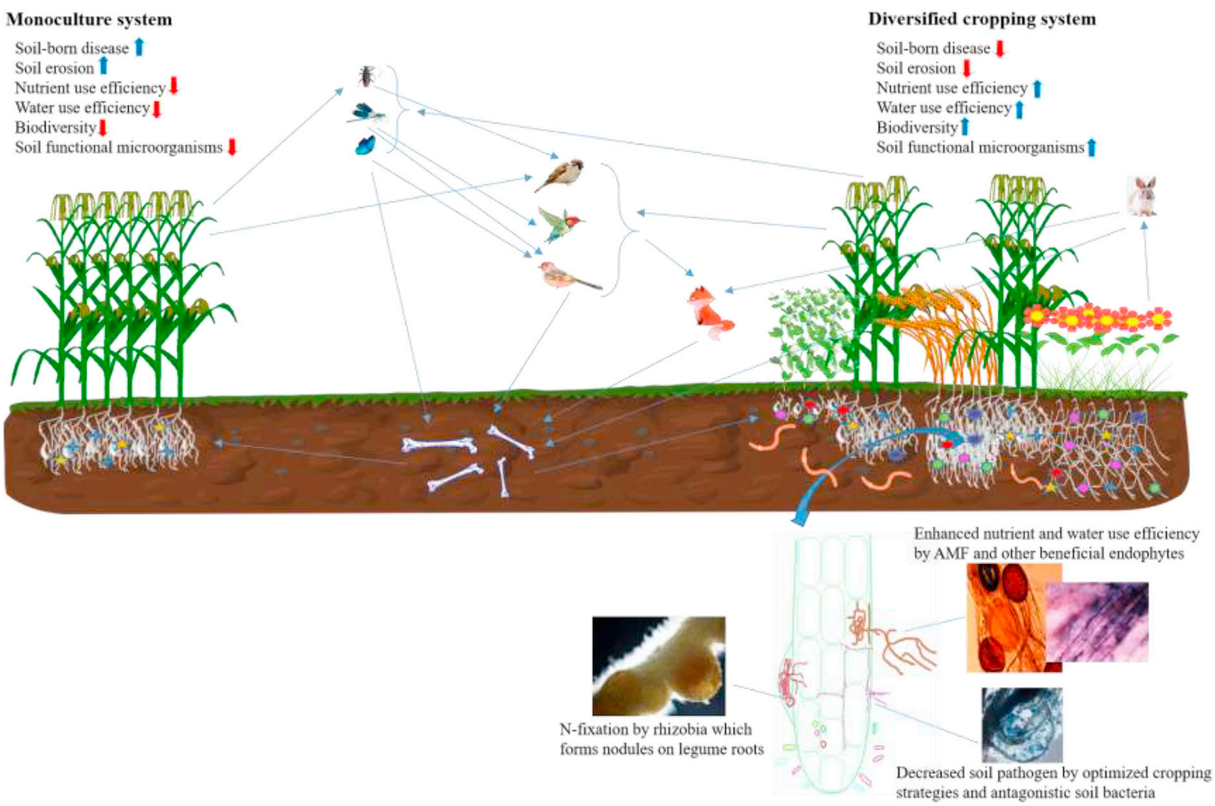

Fig. 1. Soil health comparison in optimized cropping systems and monocultures.

their functionalities in agroecosystems (Ellouze et al., 2013). Studies have shown that some modern breeding programs can produce new cultivars with better nutrient use efficiency and diminished capacity to form close symbiotic relationships with soil functional microorganisms (Pan et al., 2017). Optimized crop diversification creates diverse microhabitats that maintain good diversity and structure of beneficial soil microbial community and functional complementarity (Pivato et al., 2007). To optimize crop diversification with the best cultivar selections, genetically modified cultivars have been tested in agriculture to meet the demands for food requirements, industrial uses, and environmental security. For example, a new *Cassava* cultivar carrying the *PTST1*-or *GBSS*-gene can reduce amylose content in its root starch (Bull et al., 2018), which would be favored by the food industry as amylose can severely impact the physicochemical properties of starch during the cooking process. However, such technology must be applied with caution, as its environmental impact on soil health remains largely unknown. Overall, new crop diversification with an improved ability to communicate with beneficial soil biota could be a new angle for enhancing crop productivity, improving soil nutrient use efficiency, and reducing farm input costs and the environmental impacts of artificial chemical applications, thus leading to better soil health and sustainable agroecosystems (Ellouze et al., 2014).

2.2. Crop rotations

Crop rotation is a traditional and practical way for managing agroecosystem biodiversity by enhancing soil health, repressing pests and disease outbreaks (Barbieri et al., 2019), and thus increasing yields. The value and efficiency of a crop rotation depends on several factors, including crop types used in rotation (Tiemann et al., 2015), rotating series and applied frequency of certain crops (Bainard et al., 2017b), rotating length (Bennett et al., 2012), agronomic history on farmland and soil characteristics (Li et al., 2019). These factors can influence soil health in many ways. For instance, crop rotations can provide better opportunities for some soil functional microorganisms growth and limit disease pressure by breaking down the life cycle of soil-borne pathogens associated with specific crop or crop genotype. Certain crops are better in rotation than others, making it difficult to determine the best rotation sequence to maximize soil benefits (Gan et al., 2003). For example, crop rotation with grain legumes can increase productivity and protein content of wheat as the following crop, due to increased soil available N from biological fixation after legumes (Gan et al., 2003). Different chickpea genotypes (cultivars) or legume crops (such as pea and chickpea) in rotation can modify soil functional microbial communities and influence the productivity of pulse crops and the following wheat crop (Yang et al., 2013). More specifically, different crops can produce various residues and root exudates to boost soil microbial diversity and activity, and increase soil microbial biomass and C and N cycling (Gurr et al., 2016; Li et al., 2019). Some non-mycorrhizal plants, such as canola and mustard, cannot establish symbiosis relationships with some functional rhizobacteria thus require more mineral fertilizer (Ellouze et al., 2014), which could change the soil physical–chemical structure in the long-term. Despite the benefits of these crops that bring to producers, including non-mycorrhizal crops in rotation can eliminate arbuscular mycorrhizal fungal populations and mycorrhizal formation in the growth of following crop (Njeru et al., 2014), and further restrict their bio-functions in soil.

Changes in rotation length and frequency of the same crop in rotation over time can affect the incidence of root rot diseases and enhance soil health and crop yield stability (Vilich, 1993). Rotations with short series are more sensitive to host specific disease and thus come with lower yields than these rotations with longer series (Bennett et al., 2012). For example, the wheat phase of a 5-year rotation had higher soil (bulk and rhizosphere) microbial biomass than the wheat phase of s 3-year rotation, which was related to crop residue compost and C inputs into the soil and lead to improved soil health and wheat yields (Lupwayi et al., 2018). In Western Canada, two phases of pea in 4-year rotation doubled soil N contents, while three legume phases significantly changed the composition and function of the rhizosphere bacterial community compared with continuous wheat growth (Hamel et al., 2018). However, increasing the frequency of the same crop in rotation can have negative impacts on soil health, as Bainard et al. (2017b) found that an increased pulse phase in rotation accumulated host-specific fungal pathogens in soil, which could reduce the rotational benefits for soil health and crop yield.

Soil physical–chemical parameters are an important consideration of rotation design as they will impact the abundance, diversity, and distribution of functional soil microorganisms (Allison and Martiny, 2008). For example, in a semi-arid area of Western Canada, producers have traditionally alternated cereals with summer fallow to keep soil bare by using tillage or herbicides. In recent decades, rotating crops including grain legumes (such as field pea, lentil and chickpea) and oilseeds (such as canola and mustard) were introduced in wheat-based rotations in semi-arid areas of Canadian prairie to replace summer fallow, which modified available soil nutrients, soil physical structure changes and soil moisture conservation (Gan et al., 2011). These changes of soil physical and chemical factors will further impact soil health in general.

Another important consideration for crop rotation design is whether the soil-borne pathogens can use alternative crops as a host or remain long-term dormant in soil, and how these crops respond to disease (Bennett et al., 2012). Applying non-host plants for soil-borne disease control in rotations is critical for reducing yield losses due to diseases, especially when considering some pathogens can exist in soil for long term in the form of spores or other dormant structures with the absence of their favored host plant (Merz and Falloon, 2009). For example, severe *Fusarium* root rot injury in pea grown in rotation in the Canadian prairie was related to a limited soil microbial community and lower abundance of beneficial bacteria and arbuscular mycorrhiza (AM) fungi (Nayyar et al., 2009). In other cases, continuous cropping with higher crop diversification increased amount of antagonistic soil microorganisms thus reduced soil pathogen populations, mitigating the “take-all” impact in wheat (Garbeva et al., 2004). In general, three and more crops should be included in a cropping design to improve soil health for better yield (Bennett et al., 2012).

2.3. Intercropping system

Intercropping practices can enhance soil health by reducing artificial chemical pollution (Lemaire et al., 2014), inhibiting soil disease (Vukicevich et al., 2016), increasing plant root function (Bukovsky-Reyes et al., 2019), enhancing soil nutrient and spatial use efficiency (Hinsinger et al., 2011) and promoting bio-functionalities of soil microorganisms (Sun et al., 2019). For example, a study in a semi-arid area in Gansu, China, found that intercropping systems, including corn, wheat, and faba beans, had about 23%, 4%, and 11% higher root biomass and organic C and N contents in the top 20 cm soil layer than those species in rotation (Cong et al., 2015). In Pernambuco, Brazil, intercropping cassava with pigeon pea and beans significantly reduced black root rot (*Scytalidium lignicola*) in cassava by up to 50% compared with cassava in monoculture (de Medeiros et al., 2019). In addition, the intercropping soil had higher organic C and other nutrients, microbial biomass, and enzyme activities, than the monoculture soil, which were correlated with a decline in disease severity (de Medeiros et al., 2019).

Although increased spatial plant diversity is typically associated with enhanced resource use in intercropping systems, substantial environmental benefits can be gained by intercropping with carefully chosen crop species (Matson et al., 1997). For example, grasses usually dominate in soils with high nitrogen availability, and legumes are advantageous for soils due to their symbiotic relationship with nitrogen-fixing bacteria; thus, grass–legume intercrops can self-regulate soil nitrogen levels to optimize soil nutrient use and reduce the carbon footprint (de Araújo Santos et al., 2019). However, the ecological influences and biological functions of these crops in intercropping systems are not well understood, as intercropping systems with higher yields do not necessarily reflect better soil health (Jungers et al., 2019). For example, total shoot biomass increased significantly in an intercropping practice using *Medicago sativa* and *Dactylis glomerata*, relative to sole cropping, but the N_2O production rate also increased, suggesting that understanding the nature of these intercropping designs is critical for soil and environmental health maintenance (Graf et al., 2019).

2.4. Prairie strip as a new cropping strategy for improving soil health

As a relatively new farmland conservation cropping practice applied in North America, prairie strips have already shown benefits for improving soil health, protecting the environment, and providing habitat for wildlife, while maintaining good yields (Schulte et al., 2017). A research team in the US has shown that including local prairie grass species into cropping with crop plants—in the form of in-field contour buffer strips and edge-of-field filter strips—can bring disproportionate benefits for environment in agroecosystems (https://www.nrem.iastate.edu/research/STRIPS/content/what-are-prairie-strips). Prairie strip cropping systems bring many more benefits than other perennial crop systems in North America due to the diversity of native plant species incorporated, their unique root morphologic structure to efficiently use water and nutrient resources, and strong stems that can hold up in heavy rain.

In agroecosystems, low-yielding farmlands are an excellent opportunity for integrating perennial vegetation with prairie strips. Prairie strips have the potential to generate many benefits for soil health (Batic, 2009). Compared with traditional methods, such as terraces and sediment-control basins, prairie strips not only control soil erosion and retain P and N in the soil system but also improve groundwater quality control with less N leaching, financial cost, and other environmental issues for local producers (Schulte et al., 2017; Tyndall et al., 2013). For example, converting 10% of a crop field (corn or soybean) to diverse, native perennial vegetation reduced sediment movement off-field up to 95% and total P and N lost through runoff up to over 85% (Schulte et al., 2017); the authors survey data analysis suggested that policies and programs designed in modern agriculture should prioritize some ecosystem services for prairie strips.

Compared with other cropping systems, prairie strips can improve soil water infiltration, soil organic matter content, and nutrient retention with fewer management challenges in agroecosystems (Poeplau and Don, 2015). While longer crop rotations can reduce soil disease levels and enhance financial impacts of some additional crops, such as small grains and forages, these require additional labor, equipment, and management practices. Therefore, prairie strip practices could be combined with other crop rotations to provide better ecosystem services for soil health (Schulte et al., 2017). For example, perennial native grass species grown with other crops in rotation offer substantial diversification opportunities to help meet both economic and environmental goals (Robertson et al., 2017; Werling et al., 2014), but the levels of benefits brought by prairie strips varies with crop species planted close to prairie strips and agronomic managements practiced in field (Brandes et al., 2016). Overall, prairie strips are a relatively low-cost approach with many benefits for improving soil health, requiring minimal changes to existing farming operations.

3. Soil-microbe-plant interactions in cropping practices and their effects on soil health

3.1. Co-evolution of plant microbes and signaling system development

Plants have co-evolved with microorganisms for more than 400 million years, since they left their aquatic environment to colonize the land to form very complicated soil–microbe–plant systems that preform many critical biological and ecological functions in nutrient cycling, carbon sequestration, soil fertility maintenance, and ecosystem resilience (Fierer, 2017; Remy et al., 1994). In agriculture, these soil-microbe-plant interactions are even stronger, considering that highly selected crop species are used in different cropping systems for food and fiber gains which also significantly enhance the “host effects” on soil microorganisms. As sessile organisms, plants developed multiple chemical signaling pathways during their co-evolution to invest and manage the root microbiome (Berg and Smalla, 2009; Fierer, 2017). Fig. 2 is an example of chemical signaling pathways as the driving power of some critical plant–microbe interactions. Different plants can select specific rhizosphere microbial communities for their benefit (Maarastawi et al., 2018). The composition of this specific microbial community, also called the 'root microbiome,' is constrained by the properties of the soil environment (Chen et al., 2019) and heavily shaped by host plants (Ellouze et al., 2014; Mhlongo et al., 2018). In particular, root exudates released by plants are important carbon and energy sources for soil microorganisms and can significantly change the soil physical–chemical properties, especially in the rhizosphere (Ji et al., 2015), thus modifying the microhabitats to which microorganisms are exposed (Maltais-Landry et al., 2014). Furthermore, these root exudates play critical roles in chemical signaling processes with soil microorganisms, which can further interfere with their eco-functions and soil health (Mhlongo et al., 2018). For example, plant hormones, such as strigolactones, salicylic acid, jasmonic acid, ethylene, gibberellic acid, auxin and cytokinin, are common signaling compounds produced by plants that regulate plant–microbe recognition processes (Bari and Jones, 2009). In particular, salicylic acid, jasmonic acids, and ethylene can trigger plant defense systems to prevent pathogen infections (Bari and Jones, 2009; Maruri-López et al., 2019). Strigolactones are involved in plant defense signaling as well as stimulating hyphal branching in the presymbiotic stage of AM symbioses (Kretzschmar et al., 2012) and triggering pathogen infection in plant root tissue with certain phenolic compounds (Steinkellner et al., 2007). Flavonoids initiate symbiosis formation in the signaling of recognition process with symbiotic diazotrophs (Miransari et al., 2013). Some peptides produced by plants are also involved in microbe–plant signaling and act as hormones (Bari and Jones, 2009) or enzymes (Fritig et al., 1998; Turrini et al., 2004) in defense of environmental stresses. For example, tryptophan dimers produced by plant roots can stimulate AM fungal growth under water stress (Horii et al., 2009). Some volatile organic compounds released from plant roots act as critical signaling compounds that can suppress the growth of pathogens, such as *Fusarium* spp. (Cruz et al., 2012).

The type and amount of root exudates can be affected by many environmental factors, depending on the environmental stress level and plant species involved (Preece and Peñuelas, 2016). In cropping systems, many factors can interfere with the soil–microbe–plant complex and thus influence its functionality. Soil type (Dai et al., 2012), organic carbon level (Wu et al., 2015), temperature and moisture (Yang et al., 2010), oxygen level (Maarastawi et al., 2018), electrical conductivity, calcium level and pH (Bainard et al., 2017a) are all factors that can change the composition and functionality of soil microbial communities. For example, insufficient soil P and N will enhance the production of strigolactones, which could further trigger AM fungi symbiosis and growth (Yoneyama et al., 2013). Low N availability in the soil can increase glyphosate levels, which will

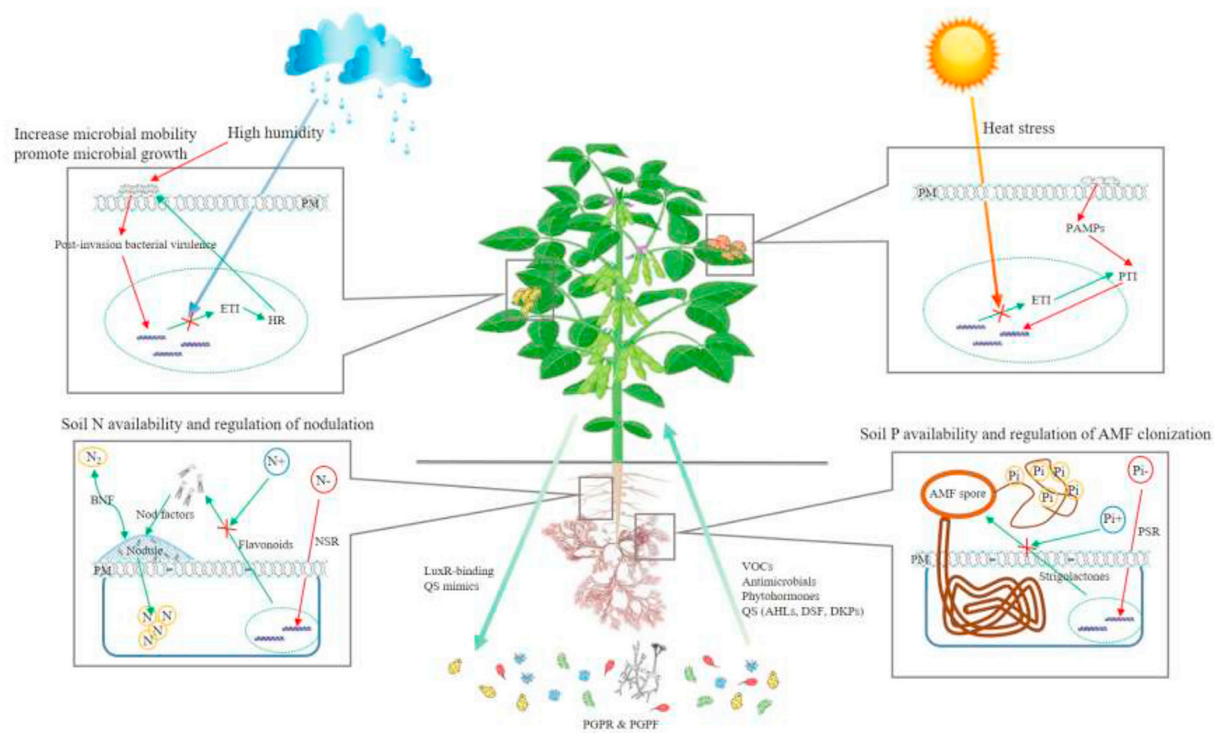

Fig. 2. Chemical signaling pathways in the plant–microbe–soil complex that are regulated by environmental factors (Cheng et al., 2019; Venturi and Keel, 2016). PM: phospholipid membrane; PAMPs: pathogen-associated molecular patterns; PTI: PAMP-triggered immunity; ETI: effector-triggered immunity; NSR: nitrogen starvation response; PSR: phosphate starvation response; BNF: biological nitrogen fixation; N+: N-sufficiency; N−: N-deficiency; P+: P-sufficiency; P−: P-deficiency; N_2: nitrogen gas; Pi: available P; AMF: arbuscular mycorrhizal fungi; VOCs: volatile organic compounds; QS: quorum sensing; AHLs: *N*-acyl homoserine lactones; DSF: diffusible signal factor; DKPs: diketopiperazines; PGPR/PGPF: plant growth promoting rhizobacteria/fungi.

increase the relative abundance of AM fungi and stimulate some related bacteria growth in the rhizosphere (Sheng et al., 2012). In general, environmental conditions modulate the strength and extent of plant–microbe signaling, which are considered important for managing soil microbial diversity to improve soil health.

Soil microorganisms also develop signaling pathways to actively interact with their host plants, which further impact soil health. For example, after legume crops produce flavonoids to trigger the *nod* gene in *Rhizobia* during nodulation, these bacteria will produce lipo-chitooligosaccharide (LCO) signals, which can trigger mitotic cell division in plant root tissues, leading to successful colonization and nodulation (Hayat et al., 2010). Soil microorganisms produce various signaling chemical compounds that are directly or indirectly involved in many critical eco-functions in soil, including C, N and P cycles, organic matter decomposition and plant growth regulation; this could be a key driver for plant diversification and community structure in terrestrial ecosystems (Van Der Heijden et al., 2008), which could further impact soil health.

3.2. Symbiosis microbiome and its relationship with soil health

In cropping systems, the symbiosis of diverse soil microorganisms has multiple benefits for crop plants (Fierer, 2017; Philippot et al., 2013). In particular, many bio-functions of agroecosystems rely on symbioses with functional microorganisms, including mycorrhizal fungi (Bolan, 1991), beneficial endophytic fungi (Rodriguez and Redman, 2008), and plant growth-promoting bacteria (PGPR) (Peoples and Craswell, 1992). Fig. 2 illustrates an AMF and rhizobia symbiosis. Plant–microbe symbionts can contribute to plant fitness, e.g., by improving nutrient status and increasing plant resistance to environmental stresses or disease defense.

The concept of a beneficial symbiosis microbiome was used to investigate the microbial community structure associated with host plants to understand and exploit their functionalities in sustainable agriculture. According to Vandenkoornhuyse et al. (2015), a 'pan-microbiome' comprises the microorganisms associated with one plant species, an 'eco-microbiome' comprises the microorganisms associated with a whole plant population in a specific environment, and a 'core-microbiome' comprises a subset of microorganisms always associated with one plant species. The core-microbiome concept is of interest in the context of agricultural production due to its consistency through time and space, which can be reliably managed through plant selection. By definition, the core microbes of a given plant species are always found with this plant species. However, the size of a functional core-microbiome in the rhizosphere can only be determined by a few key microorganisms. For example, among the 6376 bacterial and 679 fungal operational taxonomic units (OTU) recorded in the root microbiome of canola growing in the Western Canadian Prairie, only 14 bacterial and one fungal OTUs constituted the core-microbiome of canola roots; of these, only four bacteria and one fungus were positively correlated with canola yield (Lay et al., 2018).

Since symbiotic beneficial soil microorganisms are critical for soil health, understanding their taxonomic structure and phylogenetic information are essential for sustainable agriculture. However, linking taxonomic information to microbiome function and determining their value for agriculture is difficult (Fierer, 2017; Vandenkoornhuyse et al., 2015). Some positive correlations between certain microbial taxa and desirable plant traits, such as yield, do not necessarily reflect relationships among functional microbial groups and plant traits (Lay et al., 2018). For example, plant productivity and the proliferation of microorganisms with an r-strategist lifestyle were favored by high soil N fertility, while the plant and microbes were competing for the resource rather than helping each other. It is possible to link microbial community data to their bio-functions by assigning functional guilds to taxonomic structure using bioinformatics tools, such as FunGuild (Nguyen et al., 2016) and PICRUST2 (Douglas et al., 2019) which can infer eco-functions of these microorganisms based on their taxonomic placement. This is particularly useful for soil microorganism functional analysis, especially as a large proportion of root microbiome DNA sequences belong to microorganisms that cannot be classified. Shotgun metagenomics is another popular technology for drawing a global picture of microbial communities at both the taxonomic and function level.

3.3. Free-living microbiome and its relationship with soil health

While symbiotic soil microbes have tight relationships with their host plants and related eco-functions, free-living soil microorganisms also have potential benefits for plant growth and soil health in cropping systems (Müller et al., 2016). Beneficial free-living soil microorganisms that live outside plant cells are tightly associated with soil health for plant–microbe interactions in the rhizosphere. For example, some strains of *Azotobacter, Azospirillum, Bacillus*, and *Klebsiella* sp., which are associated with biological nitrogen fixation, have been inoculated globally to enhance plant productivity (Lynch, 1983). In addition, P-solubilizing microorganisms (such as *Bacillus* and *Paenibacillus*) have been used to improve soil P availabilities for plants to use in agroecosystems (Brown, 1974). A study found that wheat head numbers and potential yield increases are very likely due to the activities of some free-living microorganisms belonging to *Firmicutes* or *Actinobacteria* that accumulated in the previous pulse phase in rotation (Yang et al., 2012).

Generally, free-living soil microorganisms have the potentials to contribute to the establishment of sustainable agriculture in three ways: synthesizing particular compounds to support crops growth, enhancing certain nutrients uptake capabilities of crops from the soil, and preventing plant disease by competing either niches or nutrients with pathogens (Glick, 2003). In particular, free-living soil microorganisms can: (1) produce enzymes to reduce ethylene levels in plant tissue, thus increasing root development and plant growth; (2) produce hormones that can regulate plant growth; (3) antagonize phytopathogenic microorganisms by producing bio-control chemical compounds; (4) solubilize and mineralize soil mineral nutrients; (5) enhance resistance to environmental stresses such as drought and salinity (Hayat et al., 2010). Free-living microorganisms can also remediate contaminated soils (Zhuang et al., 2007). Therefore, it is important to develop the best combinations of beneficial soil microorganisms in sustainable agriculture to achieve good production with healthy soil systems.

4. Indicators for evaluating soil health in cropping systems

Apart from problems with defining soil health, its qualitative and quantitative assessment is somewhat overwhelming and poorly understood, as soil is an extremely complex bio-matrix whose functioning depends on myriad of soil organisms that live within a highly intricate soil architecture that can shift with cropping system. In any case, it is important to include physical, chemical, and biological properties when assessing soil health (Bünemann et al., 2018). Ideally, indicators of soil health should be related and/or correlated to soil processes and be responsive to changes in management and environmental conditions. Traditionally, physicochemical properties (texture, depth, bulk density, water holding capacity, porosity, pH, electrical conductivity, organic matter, cation exchange capacity, nutrient content) have been used as soil health indicators. Soil biological properties, particularly microbial properties, are becoming increasingly used owing to their ecological relevance, quick response, sensitivity, and capacity to integrate information and responses from various environmental factors (Barrutia et al., 2011; Galende et al., 2014; Mijangos et al., 2006). Soil parameters that provide information on the biomass, activity, and diversity of soil microorganisms are being used as bio-indicators of soil health (Epelde et al., 2010; Mijangos et al., 2006; Pardo et al., 2014), which is not surprising as soil microorganisms play a key role in many critical soil processes, such as organic matter decomposition and the accompanying recycling of nutrients related to primary biogeochemical cycles. Fig. 3 illustrates how soil microbial profiles are related to crop yield in various crop rotating systems.

Many other taxonomic groups of soil biota (e.g., members of soil macro- or meso-fauna, such as earthworms, enchytraeids, mites, springtails, and nematodes) can be used as bio-indicators of soil health (Bünemann et al., 2018). A drawback of all biological indicators of soil health is the lack of standardized and harmonized information, relative to soil physicochemical indicators, resulting in a lack of suitable reference values, which hinders the interpretation of soil biological parameters.

A particular disadvantage of using soil microbial parameters as indicators of soil health are the technical constraints when studying soil microbial communities. It is true that the development of advanced molecular methods, specifically next-generation sequencing techniques (e.g., amplicon sequencing and shotgun sequencing for structural and functional microbial diversity studies, respectively) has facilitated the study of the non-culturable fraction of soil microbial communities (yet, the majority of soil microorganisms do not grow on laboratory culture media). Nonetheless, these new techniques have limitations that must be considered when interpreting the data. It is undeniable that novel and powerful analytical techniques (not only molecular, but also biophysical, microscopic, etc.) are shedding light on the complex structural and

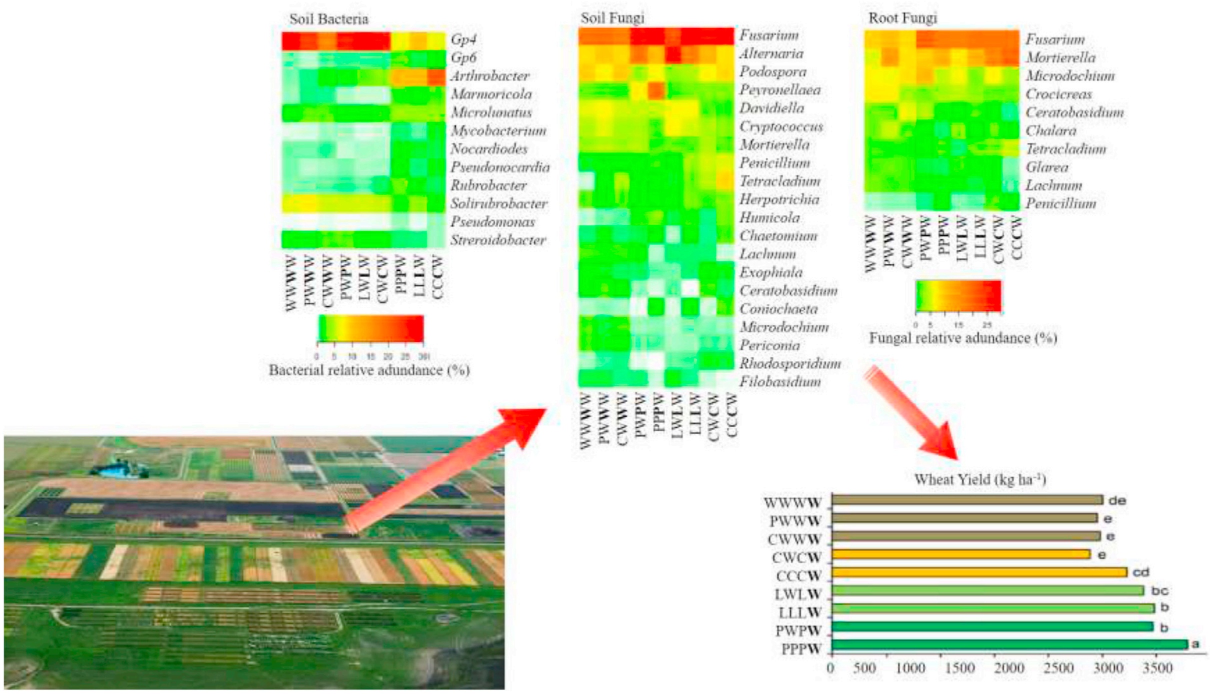

Fig. 3. Optimized soil microbial community promotes crop yield in cropping practices (Bainard et al., 2017b; Hamel et al., 2018; Niu et al., 2017). Capital letters for rotation abbreviations: W: durum wheat; P: pea; C: chickpea; L: lentil. Bold capital letters indicate the rotation stage of sampling. Different lower-case letters in the wheat yield graph indicate significant differences at the 5% similarity level.

functional aspects of soil microbial communities, and hence soil health. Another important limitation of using microbial parameters as indicators of soil health is that most microbial measurements are context-dependent (i.e., values strongly depend on sampling time, soil type and physicochemical variables, specific location, climate, soil history, etc.). In other words, while soil microorganisms have a key role in soil functioning and are, hence, *a priori* excellent indicators of soil health, the reality is that research is needed to fully understand the overwhelming complexity of microbial communities (in terms of both the countless components and innumerable interactions of most microbial networks), particularly those in soil due to the recognized difficulty of identifying soil ecosystem function with its marked spatial heterogeneity (at surface and at depth), temporal dynamicity, and vast biodiversity (related to the presence of a seemingly endless number of niches).

It is not surprising that various authors have proposed more general and integrative 'attributes' as indicators of soil health; for instance, (i) biodiversity, stability and self-recovery from stress (Parr et al., 1992); (ii) vigor, organization, stability, suppressiveness and redundancy (Garbisu et al., 2011); and (iii) ecosystem services (Velásquez et al., 2007). The determination of soil biodiversity is undoubtedly a key aspect when assessing soil health as, by definition, higher biodiversity offers superior potential for interactions and, in turn, a more intricate system of interactions frequently results in more resilience to disturbances. In any event, biodiversity and ecological stability (the term 'ecological stability' includes two concepts: *resistance* or the ability to continue to function without change when stressed by disturbance, and *resilience* or the speed and manner with which ecosystems recover after disturbance) should unquestionably be included in the list of important aspects for soil health.

Indicators of soil health can be used as individual properties or integrated into indices. Many soil health indices (simple and complex multi-parametric indices) have been proposed in the literature (Klimkowicz-Pawlas et al., 2019; Velásquez et al., 2007). As is often the case, the use of indices greatly facilitates interpretation and, above all, decision-making by soil managers, with the additional advantage that indices integrate information from several, or many, soil physicochemical and/or biological properties (in other words, they have an integrative character). By contrast, their use can imply the loss of valuable information (provided by each parameter when interpreted singly) and often leads to an oversimplification of the multifaceted responses of the extremely complex soil ecosystem against natural or anthropogenic disturbances (e.g., agricultural practices).

Finally, soil health monitoring networks are indispensable tools for gathering more data on the impact of natural or anthropogenic disturbances on soil health and, in general, for understanding the soil ecosystem better so that we can establish valid comparisons across variations in climate, soil types, management practices, etc.

5. Soil degradation from global cropping systems

Many anthropogenic activities that are used in various cropping systems, such as intensive tillage, fossil fuel consumption, draining of wetlands, adaptation of heavy equipment in farming practices, fertilization, and pesticide management, are factors that cause global soil degradation in agriculture. Other effects like erosion by water, erosion by wind, decline of organic matter in peat and mineral soils, compaction, sealing, contamination, salinization, desertification, flooding and landslides, and decline in biodiversity also threaten soil health (Stolte et al., 2015). Soil degradation is one of the most severe socioeconomic and environmental problems threatening our survival and well-being, mainly when analyzed for food security and safety. In this respect, it is unquestionable that feeding the rapidly growing human population is one of the most critical and disquieting challenges our society will face in the present 21st century, particularly in light of the existing situation with climate change and its expected strong negative impact on food production (Smith and Gregory, 2013).

Taking into consideration that most food and fiber resources come directly or indirectly from the soil (95% of the food and feed produced for humans and animals depends on soils) (Panagos et al., 2016), the degradation of soil, in particular agricultural soil under different cropping systems, is an environmental and socioeconomic problem that must be urgently, responsibly and exhaustively addressed. As reported by Bhattacharya (2019), soil degradation in agriculture is mainly due to inadequate and imbalanced fertilization, mineral nutrient leading, and the consequent problems developed during nutrient management. For example, the estimated supply−demand gap was about 1.8 million tons for N and P in 2012, and continues to increase. Global concern is due to low mineral fertilization use efficiency (N is around 50−60% in cereal crops, P is about 15−20% in most crops and K is 60−80%), as low nutrient recovery efficiency not only increases food costs but also reduces soil health and causes other environmental problems (Bhattacharya, 2019). Another factor that decreases soil health and quality in agriculture is tillage activities. Tillage is one of the most common agronomic practices used in agriculture for weed and some disease control. However, previous field studies, especially long-term studies, have shown a negative effect of tillage on soil health. For example, tillage can change the soil physical structure, which can further affect other soil health factors, such as pH, organic compounds, available N and C, and nutrient and micronutrient availabilities, such as Zn and Mn (Congreves et al., 2015; Grahmann et al., 2020), and increase soil degradation by water and wind erosion (Carr, 2017). These tillage related concerns on soil health, coupled with demands of a rapidly growing of food consumption, have challenged researchers and producers to develop alternative agronomic strategies to improve soil health and quality while maintaining the quantity and quality of crop products. Also, monoculture systems, which have been used in agriculture for many years, especially for cereal crops due to the reasonable grain price and market requirements (Angus et al., 2015), have adverse effects on soil health. Continuously growing the same crop in the same field leads to a low diversity of functional soil microbial community, accumulation of some host-specific soil-borne pathogens, and an imbalance of soil nutrient contents (Bai et al., 2019; Wang et al., 2018).

Therefore, sustainable and cost-effective measures for both the prevention of soil degradation and the recovery of degraded soils must be promptly implemented to minimize the manifold negative social, economic and environmental consequences associated with soil degradation, in terms of reducing their capacity to perform valuable functions and provide key sustainable ecosystem services.

6. Conclusion

Significant achievements, including refine content of soil health and the development of new evaluation standards for 'soil health and quality' by combining various soil health indicators (such as soil physicochemical properties, soil microorganisms status, and cropping practices) into indices in agroecosystems, can be used to evaluate and guide soil and crop management decisions. Enhancing the science-base for soil health assessment is the foundation for developing new tools and methodologies for quantifying soil biological properties and processes (such as genomic sequencing and mapping). Even though soil biology has been established and recognized as an important component of soil science for centuries, new research strategies and commercial investments regarding the impact of anthropogenic activities on soil health and quality are rousing topics. Future opportunities to advance soil health evaluation include the development of *in-situ* sensors that can provide efficient estimates for biotic and abiotic indicators, such as soil available carbon, bulk soil density, pH, soil water capacity, and soil microbial activities. We believe that these methods and techniques will significantly advance soil health assessments and improve our capacity to optimize soil health and quality sustainably. We also believe that global advancements in soil biology, new IT technology, and metadata analyzing techniques for interpreting and summarizing soil health indicators data under different environmental conditions will lead to more reliable guidance for sustainable land management, which will help to mitigate and prevent global soil degradation.

Declaration of competing interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Acknowledgment

We acknowledge technical assistance, database, and financial support from Agriculture and Agri-Food Canada, Environmental Canada, Saskatchewan Pulse Growers, and Agricultural Development Fund of Government of Saskatchewan (grant number J-001502.001.01 and J-001594.001.01). We grateful for Dr. Yantai Gan's help, and Dr. Hamel Chantal who kindly provided AMF photos for the use in our figure.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2020.e01118.

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Water Resources Research

RESEARCH ARTICLE
10.1002/2013WR015073

Key Points:
- Nitrate contamination has significantly expanded beneath irrigated cropland
- Increasing groundwater nitrate concentrations are rarely reversed
- Under most management scenarios nitrate inputs exceed aquifer concentrations

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Citation:
Exner, M. E., A. J. Hirsh, and R. F. Spalding (2014), Nebraska's groundwater legacy: Nitrate contamination beneath irrigated cropland, *Water Resour. Res.*, *50*, 4474–4489, doi:10.1002/2013WR015073.

Received 20 NOV 2013
Accepted 2 MAY 2014
Accepted article online 8 MAY 2014
Published online 29 MAY 2014

Nebraska's groundwater legacy: Nitrate contamination beneath irrigated cropland

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Abstract A 31 year record of ~44,000 nitrate analyses in ~11,500 irrigation wells was utilized to depict the decadal expansion of groundwater nitrate contamination ($N \geq 10$ mg/L) in the irrigated corn-growing areas of eastern and central Nebraska and analyze long-term nitrate concentration trends in 17 management areas (MAs) subject to N fertilizer and budgeting requirements. The 1.3 M contaminated hectares were characterized by irrigation method, soil drainage, and vadose zone thickness and lithology. The areal extent and growth of contaminated groundwater in two predominately sprinkler-irrigated areas was only ~20% smaller beneath well-drained silt loams with thick clayey-silt unsaturated layers and unsaturated thicknesses >15 m (400,000 ha and 15,000 ha/yr) than beneath well and excessively well-drained soils with very sandy vadose zones (511,000 ha and 18,600 ha/yr). Much slower expansion (3700 ha/yr) occurred in the 220,000 contaminated hectares in the central Platte valley characterized by predominately gravity irrigation on thick, well-drained silt loams above a thin (~5.3 m), sandy unsaturated zone. The only reversals in long-term concentration trends occurred in two MAs (120,500 ha) within this contaminated area. Concentrations declined 0.14 and 0.20 mg N/L/yr ($p < 0.02$) to ~18.3 and 18.8 mg N/L, respectively, during >20 years of management. Average annual concentrations in 10 MAs are increasing ($p < 0.05$) and indicate that average nitrate concentrations in leachates below the root zone and groundwater concentrations have not yet reached steady state. While management practices likely have slowed increases in groundwater nitrate concentrations, irrigation and nutrient applications must be more effectively controlled to retain nitrate in the root zone.

1. Introduction

Nitrate is the most common chemical contaminant in the world's aquifers [*Spalding and Exner*, 1993; *Thorburn et al*., 2003; *Jalali*, 2005; *Batlle Aguilar et al*., 2007] and a major drinking water impairment in the United States. As early as the 1940s, *Comly* [1945] linked the ingestion of nitrate-contaminated private well water by infants and children to methemoglobinemia, an acute and potentially fatal condition in which blood hemoglobin is altered and the tissues are deprived of oxygen. The condition was not observed in infants consuming water with less than 10 mg NO_3-N/L [*Walton*, 1951]. The U.S. Public Health Service adopted the 10 mg NO_3-N/L standard in 1962 with the issuance of the first nitrate drinking water standard [*U.S. Public Health Service*, 1962] and 10 mg N/L became the maximum contaminant level (MCL) for nitrate under the 1974 Safe Drinking Water Act. In 1991, a 1 mg/L MCL was promulgated for nitrite-N (NO_2-N) and the 10 mg N/L MCL was revised to include both nitrate and nitrite (Federal Register, 56, 3526 (1 January 1991)). Both standards are based solely on protecting infants from methemoglobinemia [*Fan and Steinberg*, 1996]. The causal role of nitrate in certain cancers [*Freedman et al*., 2000; *Weyer et al*., 2001; *Rhoades et al*., 2013], adverse reproductive outcomes [*Croen et al*., 2001; *Brender et al*., 2004], and other chronic health effects is inconclusive [*Ward et al*., 2005; *U.S. Environmental Protection Agency*, 2007]. The latest review of the National Primary Drinking Water Regulations found the MCLs for nitrate and nitrite remain appropriate (Federal Register, 75, 15519 (29 March 2010)).

A highly soluble and mobile anion, nitrate is readily transported with recharge through oxic soils to groundwater. Nitrate occurs naturally in groundwater at concentrations <2 mg N/L [*Mueller and Helsel*, 1996]. Concentrations above a 3–4 mg N/L threshold reflect anthropogenic contributions [*Nolan et al*., 2002]. While many nitrogen sources contaminate groundwater, agricultural use of commercial and animal waste fertilizers and septic systems in densely populated areas have had the greatest impact on groundwater quality

[*Nolan et al*., 1997]. Commercial N fertilizer is the major source of groundwater N-contamination nationwide [*Rupert*, 2008; *Burow et al*., 2010] and has long been recognized as the major source of contamination in Nebraska's aquifers [*Exner and Spalding*, 1979; *Gormly and Spalding*, 1979]. National assessments of nitrate's occurrence in groundwater [*Spalding and Exner*, 1993; *Burow et al*., 2010] report that the most wide-spread contamination is beneath densely irrigated areas. The heavier N fertilization requirements of irrigated crops; irrigation of predominately well to excessively well-drained soils; and application of water in excess of crop needs likely exacerbate the N flush to groundwater [*Schepers et al*., 1991a; *Bruce et al*., 2003]. Nonlinear regression models have delineated many of the largest irrigated areas in the United States as highly vulnerable to contamination [*Nolan and Hitt*, 2006]. In the western United States, nitrate loss via denitrification in the vadose zone beneath irrigated fields is minimal. Sprinkler irrigation aerates the already oxic groundwater used for irrigation and the aerated sprinkler return flows oxygenate the soils which are generally low in organic matter [*Burow et al*., 2010].

Long-term nitrate concentration trends have been reported for only a few aquifers contaminated by agricultural leachates. Statistically significant decadal changes occurred in nitrate concentrations at eight of 25 National Water-Quality Assessment Program well networks in predominately agricultural areas. Statistically significant increases in concentrations occurred at six networks. All wells were sampled once during 1988–2000 and once during 2001–2010 [*Lindsey and Rupert*, 2012]. After a decade of implementing voluntary beneficial or best management practices (BMPs), nitrate concentrations in the young groundwater of Canada's Abbotsford-Sumas aquifer increased [*Wassenaar et al*., 2006]. Enhanced N leaching of inorganic fertilizer during fall and winter rains negated the assumed BMP of partially replacing some animal waste, which was the prevalent nitrate source, with inorganic N fertilizer. The authors concluded that voluntary BMPs were ineffectual and that nitrate loading to the vadose zone or the receiving environment should be monitored to timely identify nutrient management practices that do not reduce leaching. Agricultural management in Denmark induced a trend reversal in groundwater nitrate concentrations which had increased between 1950 and 1980 [*Hansen et al*., 2011]. Improved manure and animal waste management between 1970 and 1980 contributed greatly to the early reductions in nitrogen loading. Danish environmental action plans implemented in 1985 regulate nutrient applications and have significantly lowered nitrate application rates on crops and reduced N in leachates an estimated 33%. While government-sponsored controls in the United Kingdom have similarly reduced nitrate in soil, high nitrate concentrations in deep well abstractions have not improved and necessitated long-term resource reductions, decreased operational flexibility, and increased consumer cost for water [*Knapp*, 2005]. In the United States, 16 years (1988–2003) of nutrient and irrigation management in an intensively irrigated corn-growing area of Nebraska's Central Platte Natural Resources District Ground Water Quality Management Area saw a significant ($p < 0.0001$) decrease in groundwater nitrate concentrations albeit at the slow rate of 0.26 mg N/L/yr. Average concentrations peaked at 26.8 mg N/L in 1988 after increasing at rates of 0.8–1 mg N/L since 1974 [*Exner et al*., 2010].

The statutes of most central and western states that rely heavily on groundwater as a potable water source promote its protection for existing and future beneficial uses; have an antidegradation clause; and propose a framework for addressing nonpoint source (NPS) contamination. The states' approaches to reducing NPS nitrate are varied but, in general, each has criteria and procedures for designating areas for management; protocols and guidelines for preparation and implementation of a plan to mitigate the contamination; and a mechanism for evaluation of the effectiveness of the adopted recommendations. In some states, following designation as a groundwater management area (MA) by the appropriate state agency, a local committee together with state agencies may develop an action plan. Usually, it has a strong education and outreach component and encourages adoption of BMPs. Soil and water testing and data analysis are conducted by the appropriate state agency. Voluntary compliance is preferred [*Idaho Groundwater Quality Council*, 1996; *Oregon Department of Environmental Quality*, 2011; *Washington Administrative Code*, 2013] but may be enforced if concentration criteria are not met [*Idaho Ground Water Quality Council*, 1996]. Management areas may also be established by existing state government subdivisions charged with protecting natural resources [*Bishop*, 1996]. Since 1986 Nebraska's Natural Resources Districts (NRDs) have had legislative authority to establish groundwater management areas primarily to protect groundwater quality and, in addition to the existing quantity control measures, could require use of BMPs and attendance at education programs [*Exner and Spalding*, 1987]. Legislation passed in 1991 required NRDs revise their existing groundwater management plans to more adequately address water quality concerns. The Central Platte NRD's

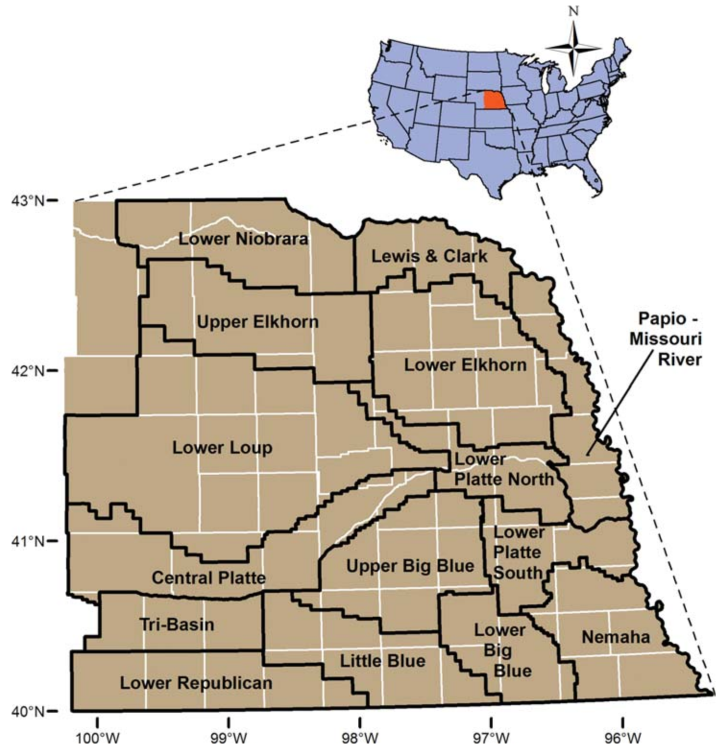

Figure 1. Location of the study area within Nebraska and associated natural resources districts.

management plan, implemented in 1987, became the model for other NRDs. Each NRD has as many as four groundwater quality management tiers based on nitrate concentrations. Specific management and reporting regulations become increasingly stricter in each tier. Usually, entire NRDs are tier 1 MAs and focus only on education and demonstration.

In Nebraska, irrigated corn is the largest consumer of nitrogen fertilizer and receives heavier N fertilizer applications than nonirrigated corn. Corn is grown on $\sim$70% of Nebraska's 3.4 Mha of irrigated row crops [*U.S. Department of Agriculture*, 2009]. Approximately 80% of the irrigated corn hectares are in central and eastern Nebraska [*U.S. Department of Agriculture*, 2009]. Extensive NPS nitrate contamination of groundwater occurs primarily in eastern and central Nebraska while contamination in western Nebraska is limited to groundwater beneath alluvial deposits in narrow river valleys [*Spalding and Exner*, 1993]. Nebraska is one of only a few states with a long-term ($>$30 years) public record of groundwater nitrate concentrations. The study objectives are to examine decadal changes in the areal expanse of nitrate-contaminated (NO_3-N $\geq$10 mg/L) groundwater beneath irrigated cropland and the relationship between vadose zone characteristics and areas of emerging contamination in central and eastern Nebraska (Figure 1) and, in the contaminated areas, to analyze concentration trends in wells with long-term nitrate records and their response to regulated management.

2. Methods

2.1. Groundwater Nitrate Data

Groundwater nitrate concentrations were obtained from actively pumping irrigation wells during the irrigation season (June, July, and August). Irrigation wells usually tap the more transmissive zones of an aquifer and integrate nitrate concentrations from the more productive vertical horizons of the aquifer. Thus, they are better indicators of nitrate conditions in NPS-contaminated areas than are monitoring or domestic wells [*Zlotnik et al.*, 1993]. The nitrate data were obtained from the Quality-Assessed Agrichemical Contaminant Database for Nebraska Groundwater [*University of Nebraska-Lincoln*, 2000]. These publicly available data from federal, state, and local agencies and University of Nebraska monitoring and research projects have met the minimum criteria for each of seven essential elements (well location, well depth, sample date, sampling procedure and sample preservation, analytical method, and field and laboratory quality assurance practices). About 44,000 nitrate analyses in 11,465 irrigation wells were available for the period (1981–2011) covered by this study. Personnel licensed by the State of Nebraska conducted the irrigation well sampling. The sample usually was obtained from a faucet at the wellhead. Irrigation wells that were not in continuous operation were pumped for at least 2 h [*Schepers et al.*, 1991b]. Samples were collected in polyethylene bottles and immediately put on ice until submitted for laboratory analysis. Occasionally samples were preserved with acid. With the exception of Lower Loup NRD samples prior to 2002, all samples were analyzed by the EPA-approved cadmium reduction method and concentrations reported as NO_2-N plus NO_3-N.

The distribution of nitrate concentrations was mapped using ArcGIS 10.1 conversion and cartography toolsets. The highest nitrate concentration in each well during the decade was averaged across 2 km by 2 km grid cells using the point-to-raster tool. The raster-to-polygon tool was used on grid cells with an average concentration $\geq$10 mg N/L. During conversion, the polygons were left orthogonal and not simplified. A polygon union was performed with no gaps allowed to fill in any open grid cells that were surrounded on all sides by $\geq$10 mg N/L. The data were consolidated into contiguous contaminated areas with the aggregate-polygons tool and major rivers as aggregation barriers. During all decades, the polygon aggregation was not forced to preserve orthogonal shapes. For 1981–1990 and 1991–2000, the aggregation distance was 6 km and the minimum hole size was 3000 ha. The wider geospatial distribution of the data during 2001–2010 necessitated increasing the aggregation distance and minimum hole size to 7.2 km and 4000 ha, respectively. The aggregated polygons for each decade were smoothed using Polynomial Approximation with Exponential Kernel (PAEK) and a smoothing tolerance of 4 km. In no instances were the endpoints for rings preserved during the smooth polygon process. The entire procedure was repeated using the median nitrate concentration in each well during the decade.

For the nitrate trend analyses, individual irrigation wells with nitrate data for at least half the years of the trend interval were selected. Additionally, data were required for the first year and either of the last 2 years of the trend analysis time frame. If more than one concentration was reported in a well in a year, the concentrations were averaged. Average annual nitrate concentrations were calculated for years in which the number of sampled wells was greater or equal to half the maximum number sampled in any year of the trend interval. Concentration trends were determined using linear regression. Statistical significance was described by the p value for a 2-tailed test. p values $<$0.05 were considered statistically significant.

2.2. Depth to Water and Saturated Thickness

The depth to water map was constructed using the ArcGIS 10.0 topo-to-raster tool for 72,620 wells completed after 1989 and with static water levels reported as greater than zero (http://www.dnr.ne.gov/groundwater-data). Flow line and lake layers from the National Hydrography Dataset (http://www.dnr.ne.gov/national-hydrography-dataset) were used to accommodate water level changes in highly sloped areas surrounding surface water bodies. The modeled depth to water was determined for all irrigation wells with a nitrate analysis between 2001 and 2010 using the ArcGIS 10.0 extract values-to-points tool. The difference between the well depth as given in the Agrichemical Contaminant Database and the modeled depth to water is the saturated zone well penetration depth.

3. Results and Discussion

3.1. Areal Distribution of Contamination

During each of the previous three decades, the area underlain by groundwater nitrate concentrations $\geq$10 mg N/L in the 11.2 Mha of central and eastern Nebraska nearly doubled. Using maximum nitrate concentrations the areas increased from 0.41 to 0.85 to 1.3 Mha (Figure 2). While the contaminated area delineated using median concentrations was less expansive in each decade, the decadal trends were similar with the contaminated areas increasing from 0.35 to 0.73 to 1.0 Mha. The contaminated areas are intensively irrigated (Figure 3a) and cropped to continuous corn or, more recently in some areas, corn in rotation with soybeans (Figure 3b). In the last decade, $\sim$30% of the irrigated area was underlain by nitrate-contaminated groundwater. Extensive production of nonirrigated row crops (Figure 3a), largely corn and soybeans in rotation (Figure 3b), also occurs in the study area. Groundwater beneath these areas seldom exceeds the MCL (Figure 3).

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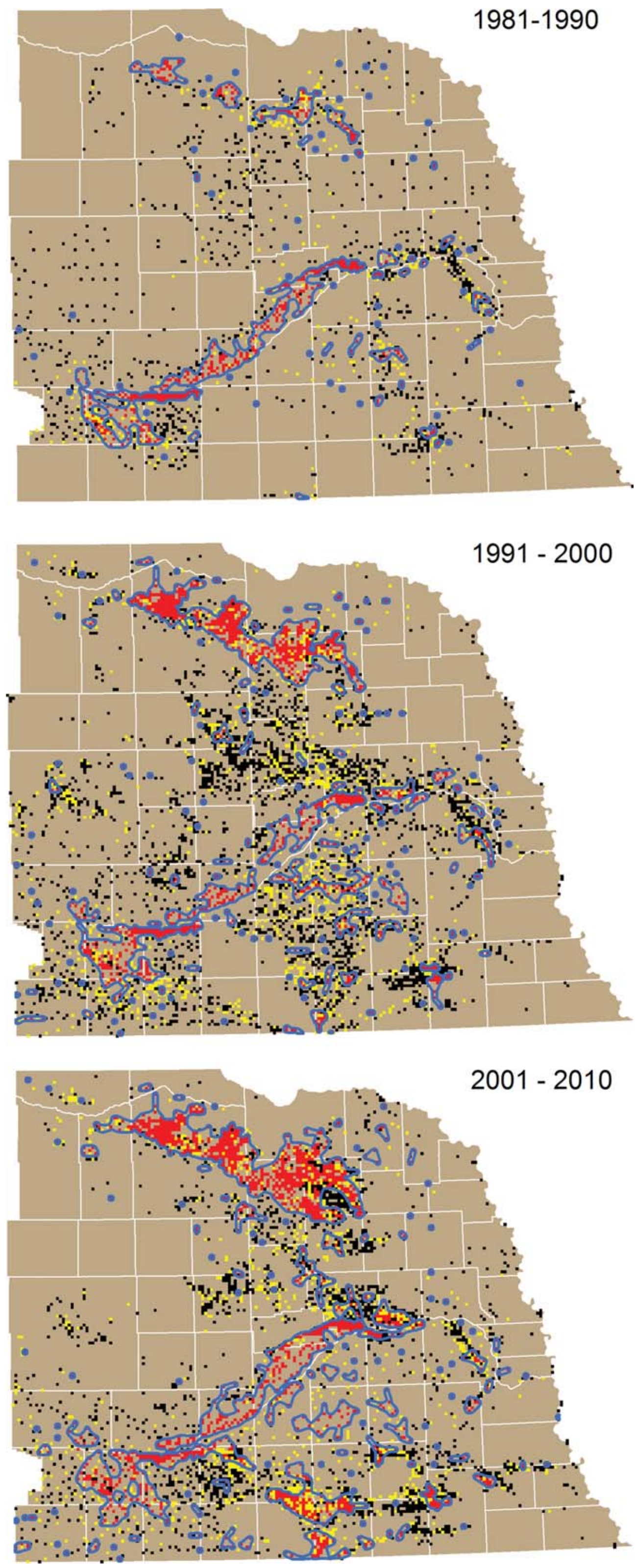

Figure 2. Decadal emergence of contaminated (≥10 mg N/L) groundwater. In each decade, the highest nitrate concentrations in irrigation wells within 2 km by 2 km grid cells were averaged. Black cells depict average concentrations <5 mg N/L, yellow cells 5 to <10 mg N/L, and red cells ≥10 mg N/L. The red grid cells were the basis for modeling the ≥10 mg N/L contaminated areas outlined in blue.

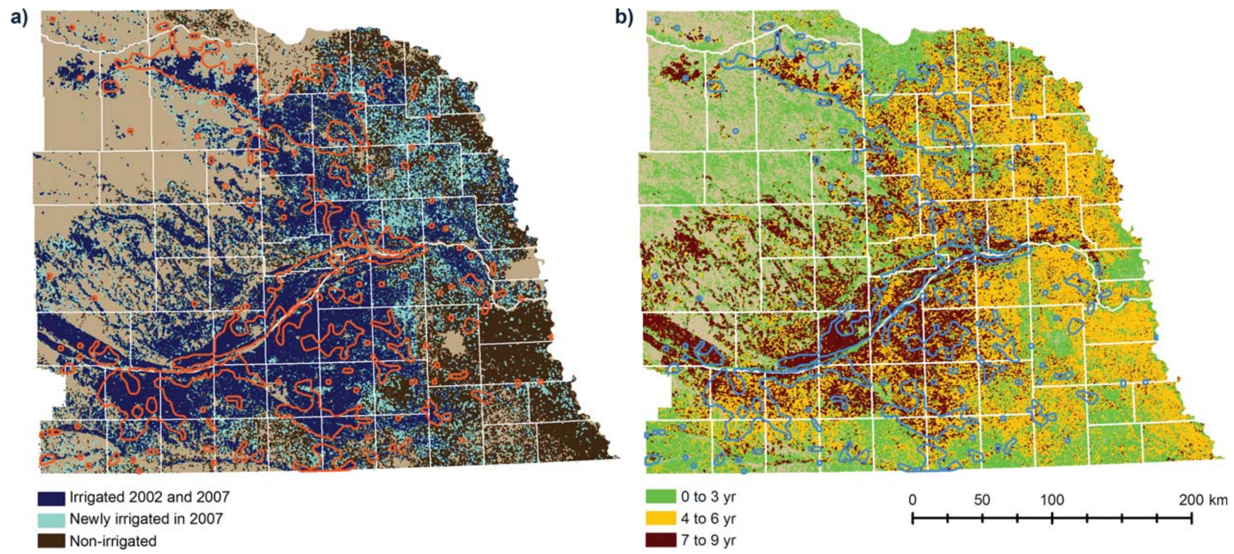

Figure 3. Distribution of (a) irrigated and nonirrigated row crops and (b) years of corn production between 2002 and 2010. Irrigated areas were drafted from the MIrAD-US project under the USGS Early Warning and Environmental Monitoring Program (http://earlywarning.usgs.gov/USirrigation/). Nonirrigated areas are those cropped to dryland corn and dryland soybeans on the 2005 Nebraska Land Use Map (http://www.calmit.unl.edu/2005landuse/statewide.shtml). The number of years in corn production was assessed by stacking raster layers of annual data from the National Agricultural Statistics Service (NASS) Cropland Data Layer (http://nassgeodata.gmu.edu/CropScape/). Groundwater nitrate concentrations in the outlined areas were $\geq$10 mg N/L during 2001–2010.

Contaminated groundwater in the predominantly nonirrigated southeastern, southwestern, and extreme northern parts of the study area occurs in small pockets of irrigated cropland (Figure 3a).

3.2. Characterization of Contaminated Areas

Major differences in agricultural practices and hydrology necessitated grouping the larger contaminated groundwater areas with intensive irrigation according to irrigation method (Figure 4a), soil drainage characteristics (Figure 4b), vadose zone thickness (Figure 5), and sediment lithology. The large, contiguous contaminated area north of the Elkhorn River (444,000 ha) and the two contiguous areas south of the

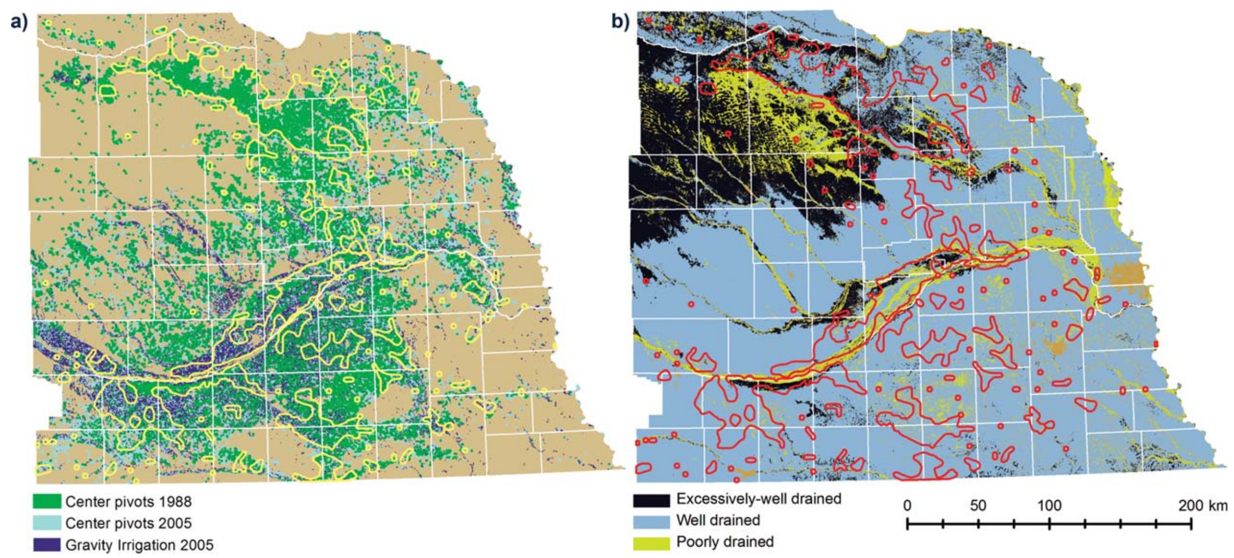

Figure 4. (a) Irrigation application methods and (b) soil drainage capacities. The irrigation methods are from the University of Nebraska-Lincoln Conservation and Survey Division 1988 Center Pivot Inventory (http://snr.unl.edu/data/geographygis/NebrGISwater.asp#pivot) and the Center for Advanced Land Management Information Technologies 2005 Nebraska Land Use map (http://www.calmit.unl.edu/2005landuse/statewide.php). The seven drainage classifications of the Soil Survey Geographic Database (http://www.dnr.state.ne.us/databank/ssurgo2.html) were consolidated into three groups. Groundwater nitrate concentrations in the outlined areas were $\geq$10 mg N/L during 2001–2010.

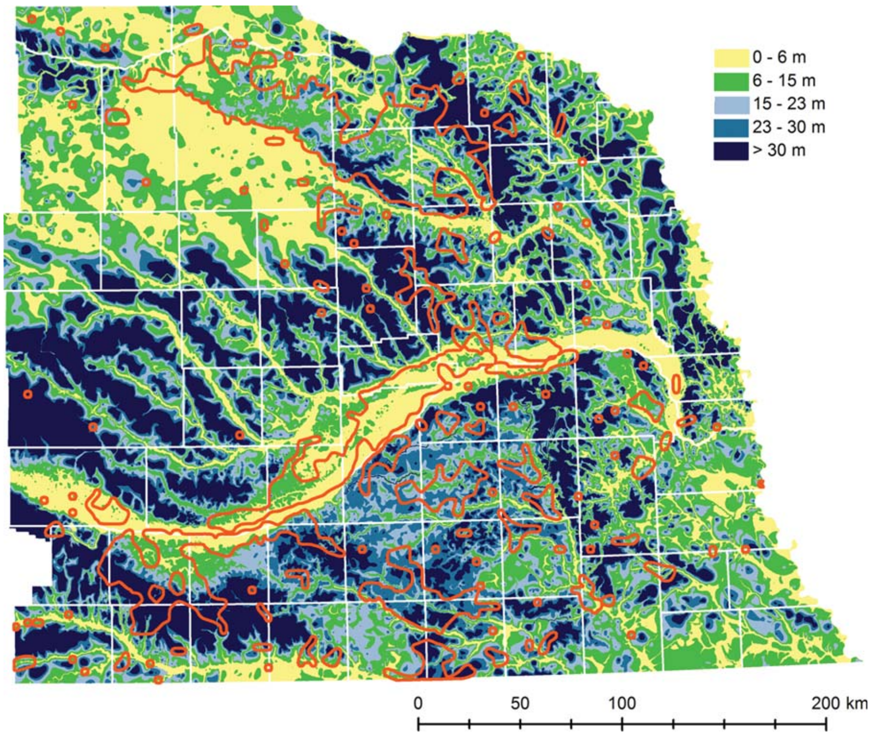

Figure 5. Depth to water. Groundwater nitrate concentrations in the outlined areas were ≥10 mg N/L during 2001–2010.

Platte (43,800 ha) and Loup Rivers (23,600 ha) comprise Group A (Figure 6). Group B occupies 220,000 ha along and north of the Platte River. Many discontinuous contaminated areas between the Platte, Republican, and Big Blue Rivers comprise the 400,000 ha of Group C. About 13% of the 1.3 million contaminated hectares were not classified. They are small emerging areas and are primarily south of the Platte River (Figure 2).

3.2.1. Group A

Well and excessively well-drained soils (Figure 4b), very sandy vadose zones, and spray application of irrigation water via center-pivot systems (Figure 4a), characterize the three Group A areas depicted in red in Figure 6. The unsaturated zone is >15 m thick in 46% of the 444,000 contiguous hectares contaminated north of the Elkhorn River and in 14% of the area is >30 m thick (Figure 5). Test hole drilling in Antelope County, located in the center of the contiguous area, showed a high level of sediment heterogeneity with layers of eolian sands, sandy silts, and silty sands [*Souders and Shaffer*, 1969]. The presence of continuous, confining clay lenses was not reported and suggests that

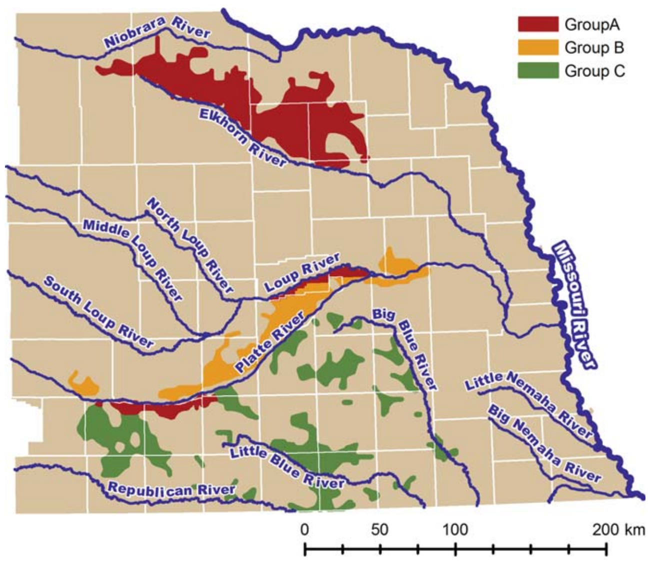

Figure 6. Contaminated groundwater during 2001–2010 classified according to soil drainage, vadose zone lithology and thickness, and irrigation practice. Major rivers are depicted.

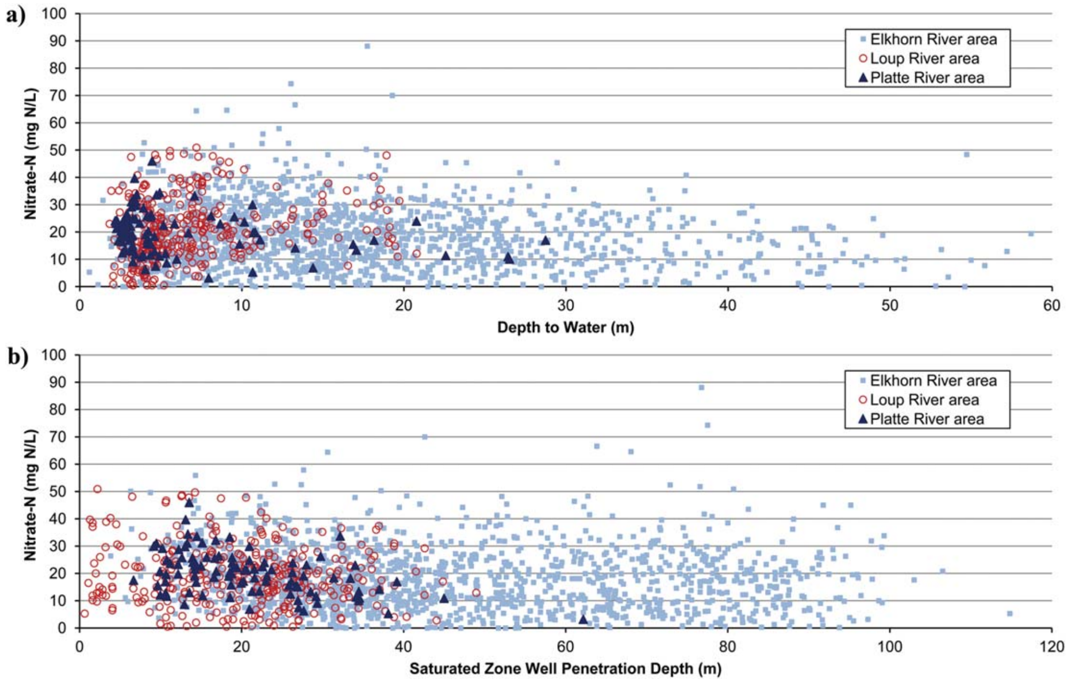

Figure 7. Nitrate-N concentration distribution in Group A contaminated groundwater with (a) depth to water and (b) saturated zone well penetration depth. Nitrate concentrations were the highest value in each irrigation well between 2001 and 2010.

vertical flow through the unsaturated zone is relatively uninhibited. Shallower and less variable depths to water occur in the smaller contaminated area south of the Loup River (Figures 5 and 6). The unsaturated thickness averages 6 m and in 95% of the sampled irrigation wells ranges from 1.8 to 15 m (Figure 7a). Similar depths to water occur in the contaminated area south of the Platte River where the unsaturated thickness averages 6 m and ranges from 2 to 22 m in 95% of the sampled wells (Figure 7a). These thin ($<$6 m), sandy, unsaturated zones cause both areas to be extremely vulnerable to nitrate leaching. Both small Group A areas are remnants of The Sandhills, a north-central Nebraska landmark occupying about one third of the state. Low organic matter soils and sandy vadose zones in the three Group A areas combined with oxygen-enriched irrigation return flows from spray applications strongly suggest that nitrate loss via denitrification is highly unlikely during downward transport.

The Ogallala aquifer is beneath the contiguous, four-county Group A contaminated area north of the Elkhorn River. It is relatively heterogeneous although predominantly sandstone with saturated thicknesses reaching 150 m [*Souders and Shaffer*, 1969]. The saturated zone penetration depth averages 45 m in the sampled wells and ranges from 4 to 91 m in 95% of the wells (Figure 7b) while in the Loup and Platte River areas the penetration depths average 20 and 21 m, respectively (Figure 7b). High nitrate concentrations occur at all depths (Figure 7b). Densely spaced, high-capacity irrigation wells likely increase vertical mixing of groundwater [*Spalding et al.*, 2001]. Gravel-packing the $\sim$1 m diameter well bores below the water table creates vertical conduits for water to circulate within the aquifer and could partially account for nitrate in the deeper screened wells. Sealing the boreholes between highly transmissive zones would reduce vertical movement. The occurrence of nitrate in deep wells beneath densely irrigated areas also has been reported in Washington [*Wassenaar et al.*, 2006] and the southern Great Plains [*Bruce et al.*, 2003]. In the last two decades, the areal growth of the Group A contaminated area was 18,600 ha/yr. Median nitrate concentrations yielded a substantial but slower growth rate of 14,800 ha/yr.

The management areas shown in Figure 8 encompass $\sim$50% (228,000 ha) of the contiguous contaminated area. Those with sufficient data for trend analysis are located in Antelope and south central Holt counties in the Upper Elkhorn NRD (UENRD), in Knox County in the Lewis and Clark NRD (LCNRD), and in western and north-central Holt County in the Lower Niobrara NRD (LNNRD). In 1998, average concentrations ranged from slightly above the MCL (11.3 mg N/L) in the Antelope MA to more than twice the MCL (25.7 mg N/L) in

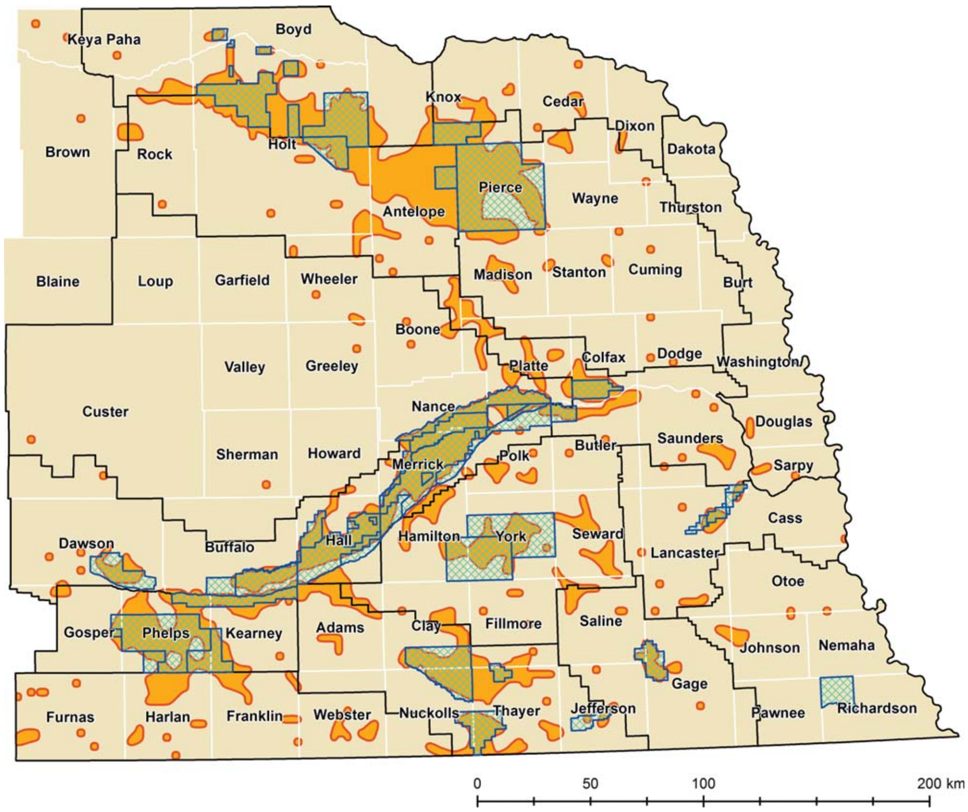

Figure 8. Tier 2 and 3 management areas and contaminated (≥10 mg N/L) groundwater. Management areas as of 31 December 2011 are shown as hatched pattern. Concentrations in orange areas were ≥10 mg N/L during 2001–2010.

the western Holt MA (Figure 9a). Average concentrations >20 mg N/L were reported in the latter area as early as 1976 and coincided with heavy irrigation development [*Exner and Spalding*, 1979]. Average annual N concentrations in the Antelope and Knox MAs increased ~0.20 mg N/L/yr ($p = 0.0017$ and $p = 0.025$, respectively) during the 14 year period. Significant concentration trends were not evident in the other three MAs.

For approximately 25 years, similar average nitrate concentrations in the Group A contaminated groundwater in the Lower Loup NRD (LLNRD) and Tri-Basin NRD (TBNRD) MAs south of the Loup and Platte rivers, respectively, have increased at almost identical rates (Figure 9b). Average annual nitrate concentrations in the MAs south of the Loup and Platte rivers increased from 14.5 to 20.3 mg N/L and from 13.6 to 20.7 mg N/L, respectively, at average rates of 0.26 mg N/L/yr ($p < 0.0001$) and 0.23 mg N/L/yr ($p < 0.0001$), respectively. The rate of increase in the Lower Loup MA calculated from the database records is identical (0.26 mg N/L/yr, $p < 0.0001$) to that calculated using the LLNRD's 27 year record of average annual concentrations for a much larger number of wells [*Lower Loup Natural Resources District*, 2012].

3.2.2. Group B

Gravity irrigation (Figure 4a) of corn and soybeans (Figure 3b) grown on ~1.5 m thick, well-drained, silt loam soils (Figure 4b) positioned above a thin, sandy unsaturated layer (Figure 5) characterizes the 220,000 ha of Group B contaminated groundwater (Figure 6). A 200,000 ha contaminated area was delineated using median nitrate concentrations. The small difference between the maximum and median nitrate concentration delineated areas is likely related to long-term (>35 years) [*Gormly and Spalding*, 1979] localization of the majority of the contamination by the lack of infiltration through bordering poorly drained bottomland soils (Figure 4b), low (<1 mg N/L) nitrate inflow from the Platte River, and reduced aquifer loading as a result of adoption of better management practices [*Spalding et al*., 1978; *Exner et al*., 2010]. Soil drainage heterogeneity is greater in the eastern Central Platte NRD (CPNRD) than in the other contaminated areas of the NRD. The very short (<1 m) distance to groundwater in many areas of the eastern CPNRD coupled with

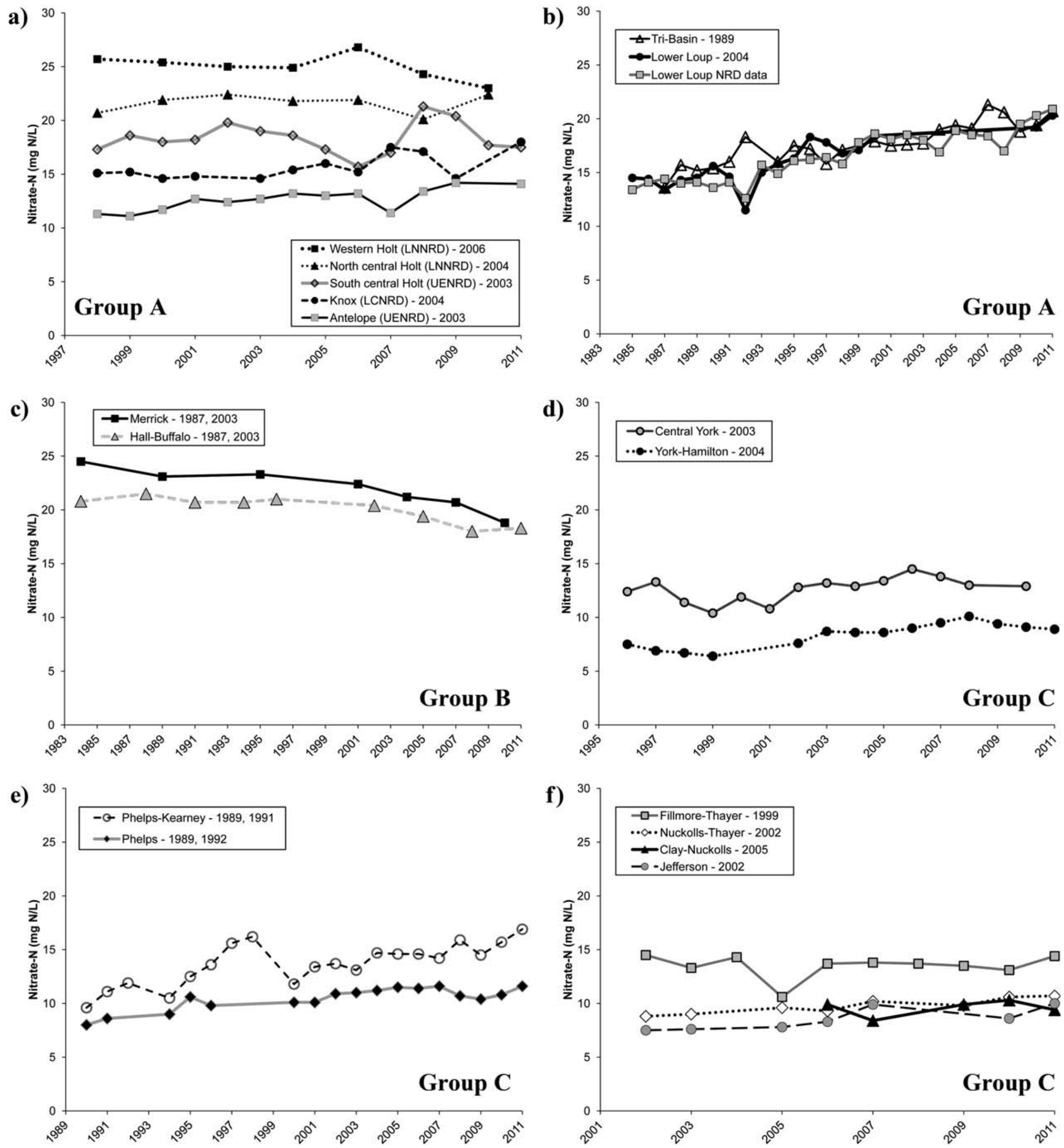

Figure 9. Nitrate-N concentration trends in management areas within Groups A, B, and C. Group A trends (a) north of the Elkhorn River and (b) south of the Platte and Loup rivers; Group B trends in the (c) two largest contiguous MAs in the Central Platte NRD; and Group C trends in (d) the Upper Big Blue NRD, (e) the Tri-Basin NRD, and (f) the Little Blue NRD. Regulations were implemented in the year in the legend. Small areas were annexed in the second year shown.

the application of anhydrous N fertilizer using knives that can intercept the water table likely affect vulnerability more than transport through the well to poorly drained soils. Within this area of the NRD, however, the incidence of very high nitrate concentrations (30–60 mg N/L) was greatest beneath excessively well-drained, intensely irrigated soils [*Spalding et al*., 1978]. Depth to groundwater is $<$6 m in 77% of the contaminated area which has an average unsaturated thickness of 5.3 m (Figure 10a).

The primary aquifer is composed of relatively homogeneous sands and gravels. The average saturated thickness penetrated by the sampled irrigation wells is 19 m (Figure 10b). The Ogallala, a deep secondary aquifer,

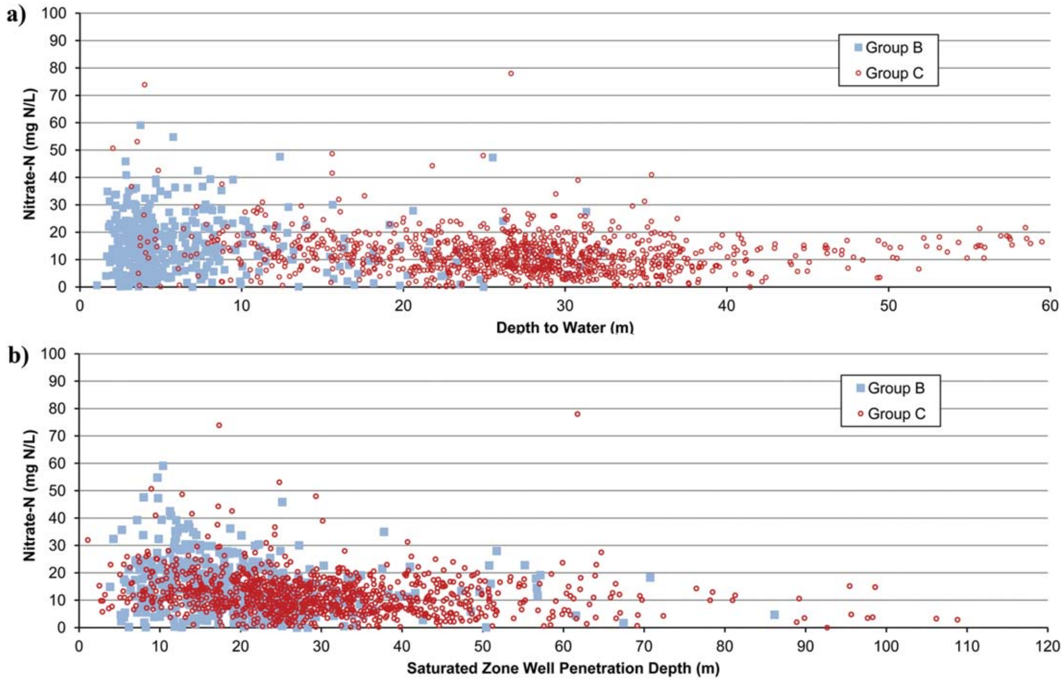

Figure 10. Nitrate-N concentration distribution in Groups B and C contaminated groundwater with (a) depth to water and (b) saturated zone well penetration depth. Nitrate concentrations were the highest value in each irrigation well between 2001 and 2010.

underlies the westernmost part of the contaminated area. A relatively thick aquitard protects the Ogallala from downward transport of the nitrate in the primary aquifer. During the last two decades, the rate of growth in the Group B area averaged 3700 ha/yr using the maximum nitrate concentration method and 3300 ha/yr with the median nitrate concentration method.

The contaminated groundwater is almost entirely contained within the 266,000 ha under management (Figure 8). Average nitrate concentrations in the two largest contiguous MAs—a 63,500 ha band stretching from central Buffalo County through Hall County and a 57,000 ha band through the center of Merrick County—were more than double the MCL in 1984 (Figure 9c). In the Merrick MA average concentrations decreased from 23.1 mg N/L in 1989 to 18.8 mg N/L in 2010 at an annual rate of 0.20 mg N/L ($p = 0.015$) and in the Hall-Buffalo MA concentrations declined from 21.5 mg N/L in 1988 to 18.3 mg N/L in 2011 at a rate of 0.14 mg N/L/yr ($p = 0.0012$).

3.2.3. Group C

Group C is characterized by well-drained silt loams (Figure 4b) positioned on a thick eolian clayey-silt unsaturated zone. Depths to groundwater >15 and >30 m (Figure 5) comprise 82% and 31%, respectively, of the 400,000 contaminated hectares (Figure 6). All the contaminated areas are located south of the Platte River and mostly in relatively flat uplands. With the exception of stream valleys where the unsaturated zone has thinned as a result of erosion, the clayey silts in the upper vadose zone are 15–21 m thick [*Spalding and Kitchen*, 1988]. Depth to water in the Group C irrigation wells averaged 23.7 m and in 95% of the wells ranged from 3.8 to 45.3 m (Figure 10a). N profiles in cores taken from the upper vadose zone of irrigated, N-fertilized research plots in the southwestern Upper Big Blue NRD showed nitrate had leached 20 m [*Spalding and Kitchen*, 1988]. Vadose zones beneath excessively fertilized plots had the greatest quantities of nitrate. Matching the high nitrate peaks with those in cores taken at the same locations 5 years later indicated that the nitrate moved $\sim$0.75 m/yr [*Bobier et al*., 1993]. Additional coring in the Upper Big Blue, Little Blue, and Central Platte NRDs has shown that excess nitrate commonly occurs in thick vadose zones beneath N-fertilized, irrigated corn and corn/soybean fields (R. F. Spalding, unpublished data, 2004, 2010–2013). Thus, nitrate can leach though fine-textured eolian sediments and threaten groundwater quality. The saturated thickness penetrated by the wells in this study averaged 27.7 m and in 95% of the wells ranged from 3.1 to 62 m (Figure 10b). The Group C contaminated areas emerged in the last two decades and are increasing at an average rate of 15,000 ha/yr. The average expansion rate of 10,600 ha/yr calculated using median nitrate concentrations is considerably lower. More variability is expected as concentrations in these small emerging areas increase. As many of the numerous small emerging areas (Figure 2) merge and form large areas, nitrate concentrations likely will become more homogeneous as has occurred in Group B and is occurring in Group A contaminated areas.

Group C contaminated groundwater occurs as several discontinuous areas with average annual nitrate concentrations that are generally lower than in Groups A and B. Eight MAs encompass most of the larger areas of contamination and have sufficient data for trend analysis (Figures 8 and 9d–9f). Average nitrate concentrations increased at rates between 0.13 and 0.25 mg N/L/yr in six of the eight MAs and in five of the six average concentrations met or exceeded the MCL in 2011. In the central York and York-Hamilton MAs (Figure 8) average annual concentrations rose 0.14 ($p = 0.043$) and 0.20 ($p < 0.001$) mg N/L/yr, respectively, since 1996 (Figure 9d). Average groundwater nitrate concentrations are increasing in the two largest MAs that include most of the Group C contaminated groundwater in the Tri-Basin NRD. In the Phelps MA and the Phelps-Kearney MA that abuts it on the east and southeast (Figure 8), average concentrations rose to 11.6 and 16.9 mg N/L in 2011, respectively, at rates of 0.13 mg N/L/yr ($p = 0.0001$) and 0.23 ($p = 0.0001$), respectively (Figure 9e). The groundwater nitrate records in the Little Blue NRD MAs are relatively short (Figure 9f). Average annual concentrations in the Nuckolls-Thayer and Jefferson MAs increased 0.20 and 0.25 mg N/L/yr ($p = 0.0009$ and 0.034), respectively, to concentrations that met or exceeded the MCL. Only the Fillmore-Thayer MA concentrations averaged considerably above the MCL ($\sim$14 mg N/L) and, with the exception of 2005, were quite stable during the 10 year record. Average N concentrations in the Clay-Nuckolls MA remained at or below the MCL during the 6 year record.

3.3. Management Area Regulations and the Impact on Concentrations

The 17 MAs in the nine NRDs with relatively large Group A, B, or C groundwater areas (Figure 8) have similar requirements. Producers in all MAs must attend education programs and be certified to apply commercial N fertilizer, adopt N budgeting on regulated fields, and complete an annual report that details the N budget for each regulated field. Budgeting begins with a N fertilizer recommendation. Most districts use a University of Nebraska formula that is based on residual soil N and organic matter and a yield goal which is usually 105% of several previous years' production. Requirements for crediting N inputs from irrigation water, each manure source (e.g., hogs, cattle), and previous legume crops in the budget as well as the density and depth of soil samples varies with the NRD. Scheduling of irrigation water applications is required only in the Upper Big Blue and Little Blue NRDs' MAs. Typically scheduling is encouraged as is monitoring the amount of irrigation water applied. While all management plans address practices on irrigated corn, NRDs may regulate other irrigated row crops and some regulate nonirrigated row crops. Table 1 summarizes the management practices for irrigated corn producers in the tier 2 and 3 MAs whose nitrate concentration trends are depicted in Figure 9.

Increasing or decreasing groundwater nitrate concentrations in the MAs reflect the impact of BMPs on vadose zone N leachates. Higher nitrate concentrations in leachates below the root zone than in the aquifer cause groundwater concentrations to increase. Conversely, lower N concentrations in the leachate reduce groundwater nitrate levels. A trend of decreasing groundwater nitrate concentrations reflects the impact of reduced N loads in the leachate. Increasing groundwater concentrations indicate that a steady state concentration between vadose zone pore water and groundwater has not been attained. Age-dating has shown that groundwater beneath thin, permeable vadose zones is rapidly impacted by changes in vadose zone pore water concentrations [*Spalding et al*., 2001].

3.3.1. Group A

Tier 2 and 3 MA regulations in the seven Group A MAs have not effected a significant ($p < 0.05$) trend reversal in average nitrate concentrations (Figures 9a and 9b). The seven MAs have the similar budgeting requirements and all require submission of an annual report (Table 1). Differences lie in the timing and application of commercial N fertilizer. The Tri-Basin NRD MA south of the Platte River is the oldest Group A MA. It moved to tier 3 after N concentrations did not decline during the first 15 years in tier 2. In tier 3 commercial N fertilizer applications are banned in fall and winter. Commercial N fertilization is banned until spring in the Lower Loup MA at which time the application must be split between pre-emergence and

Table 1. Prescribed Management Practices for Irrigated Corn as of 31 December 2011[a]

MA	Tier	Year	NRD	Commercial N Fertilizer Application Restrictions (kg N/ha)			N Budget Credits				Annual Report
				Fall (9/1 to 11/1)	Winter	Spring (After 3/1)	Analyses				
							Soil Composite (Depth / Frequency) m/ha	Irrigation Water (Frequency) Years	Manure	Previous Legume Crop	
Group A											
Western Holt	2	2006	Lower Niobrara[b]	0			0.6/16	4	R		R
North-central Holt	2	2004	Lower Niobrara[b]	0			0.6/16	4	R		R
South-central Holt	2	2003	Upper Elkhorn[c]	0			0.6/16	4			R
Antelope	2	2003	Upper Elkhorn[c]	0			0.6/16	4			R
Knox	3	2004	Lewis & Clark[d]	0	0		0.9/16	2		R	R
South of Loup River	3	2004	Lower Loup[e]	0	0	split or use N inhibitor	0.9/32	1	R		R
South of Platte River	2	1989	Tri-Basin[f]	0	0[g]		0.8/32	1			R
South of Platte River	3	2006	Tri-Basin[f]	0	0		0.8/32	1			R
Group B											
Merrick	3	1987	Central Platte[h]	0	0	split or use N inhibitor	0.9/32	1	R	R	R
Hall-Buffalo	3	1987	Central Platte[h]	0	0	split or use N inhibitor	0.9/32	1	R	R	R
Group C											
Central York	2	2003	Upper Big Blue[i]	0 (1996)	0[j] (1996)		0.6/16	0[k,m]	R[l]	R	R
York-Hamilton	2	2004	Upper Big Blue[i]	0 (1996)	0[j] (1996)		0.6/16	0[k,m]	R[l]	R	R
Phelps-Kearney	2	1989	Tri-Basin[f]	0	0[g]		0.8/32	1			R
Phelps	2	1989	Tri-Basin[f]	0	0[g]		0.8/32	1			R
Phelps	3	2006	Tri-Basin[f]	0	0		0.8/32	1			R
Fillmore-Thayer	3	1999	Little Blue[n]	0			0.9/16	0[k]	R		R
Nuckolls-Thayer	2	2002	Little Blue[n]	0			0.9/16[m]	0[k,m]	R[m]		R
Jefferson	2	2002	Little Blue[n]	0			0.9/16[m]	0[k,m]	R[m]		R
Clay-Nuckolls	2	2005	Little Blue[n]	0			0.9/16[m]	0[k,m]	R[m]		R

[a]MA, management area; NRD, natural resources district; R, required.
[b]*Lower Niobrara Natural Resources District* [2003].
[c]*Upper Elkhorn Natural Resources District* [1997].
[d]www.lcnrd.org/groundwater/bgma.
[e]*Lower Loup Natural Resources District* [2002].
[f]*Tri-Basin Natural Resources District* [1992].
[g]On sandy soils.
[h]*Central Platte Natural Resources District* [2003].
[i]*Upper Big Blue Natural Resources District* [1995].
[j]Liquid and dry N forms.
[k]Require irrigation scheduling.
[l]NRD specifies credit amount for each manure source.
[m]Demonstration field only.
[n]www.littlebluenrd.org/Water/management_areas.html.

postemergence and a nitrification inhibitor which prevents rapid conversion of ammonium-N to nitrate-N used if more than half ($>$90 kg N/ha) of the application is applied before the crop emerges. Fall fertilization is prohibited in all the MAs along the Elkhorn River while the Knox MA also prohibits winter applications. Spring preplant and pre-emergent fertilizer applications are not restricted in this highly contaminated area.

Average annual concentrations in the western Holt MA, which averaged $\sim$25 mg N/L for almost a decade, appear to be trending downward toward a steady state concentration while the relatively recently developed areas in the Antelope and Knox MAs have a significant upward trend ($p < 0.05$) and concentrations in the leachate and groundwater have not yet attained a steady state. Concentrations in the south central Holt MA have fluctuated about a steady state concentration during the period of record. The large unsaturated and saturated thicknesses penetrated by the irrigation wells and the high levels of aquifer heterogeneity in the five MAs likely retard the observable effects of management practices on groundwater nitrate concentrations.

Trend reversals anticipated in MAs with short distances to groundwater ($\sim$6 m) and thin saturated thicknesses (20–21 m) have not occurred in the MAs south of the Platte and Loup rivers (Figure 9b). Average concentrations in both MAs increased to $\sim$21 mg N/L in 2011 and will continue to increase until N concentrations in the leachate and groundwater establish steady state concentrations.

3.3.2. Group B

The two large contiguous MAs in the Central Platte NRD (Figure 8) are the only MAs where nitrate concentrations are declining (Figure 9c). Tier 3 prohibitions against fall and winter N fertilization of all soils, preplant and pre-emergent fertilization restrictions including the use of a nitrification inhibitor if $>$90 kg N/ha is applied before emergence, and very detailed N budgeting have effected a decrease in leachate N concentrations and reversed the $\sim$0.4–1 mg N/L/yr increase in groundwater concentrations that occurred between 1974 and 1984 [*Spalding and Exner*, 1993]. The rate of decrease has been greater in the Merrick MA where concentrations peaked at 24.5 mg N/L, about 4 mg N/L higher than in the Hall-Buffalo MA, in 1984. Concentrations in both MAs average 18–19 mg N/L.

The high density of irrigation wells pumping from a relatively thin ($<$20 m) and homogeneous saturated thickness promote vertical mixing of the reduced nitrate load in the leachates [*Spalding et al*., 2001]. Unlike most MAs in this study, irrigation water has been applied largely via furrows rather through a sprinkler system (Figure 4a). Even water distribution is much more difficult with furrow irrigation. Since N cannot be applied to the corn crop at the time of maximum uptake as is possible with sprinkler irrigation, the crop's N needs during the entire growing season must be anticipated and applied early in the growing season.

3.3.3. Group C

Average nitrate concentrations in the eight Group C MAs have not undergone a trend reversal and in 6 MAs concentrations have increased at rates of 0.13–0.25 mg N/L/yr ($p < 0.05$; Figures 9d–9f). Each of the three NRDs encompassing the Group C MAs has different N fertilizer regulations (Table 1). Fall N fertilization is prohibited in all the MAs. It has been banned in the central York and York-Hamilton MAs as part of a district-wide regulation since 1996. Winter application of liquid and dry N fertilizers, but not anhydrous N, requires the use of a nitrification inhibitor in the central York and York-Hamilton MAs while winter commercial N fertilizer applications are banned on sandy soils in the Phelps-Kearney MA and on all soil types in the Phelps MA. None of the MAs restrict spring fertilizer applications. The Little Blue and Upper Big Blue NRDs are unique in that they require irrigation scheduling in existing MAs. Concentration triggers for the Little Blue NRD MAs are the lowest of the Group C MAs.

Despite more than 20 years of N fertilizer restrictions, nitrate concentrations in the aquifer beneath the Phelps-Kearney and Phelps MAs are at their highest levels and will continue to increase until N input concentrations decrease and begin to dilute the existing high concentrations. N inputs have been regulated for a shorter time ($<$15 years) in the Upper Big Blue and Little Blue NRDs' MAs and the impacted leachates likely have not yet reached the aquifer.

Presently, nitrate concentrations in leachate below the root zone of irrigated corn grown using recommended BMPs exceed the MCL [*Klocke et al*., 1999; *Spalding et al*., 2001] and can be attained only by serious concessions to yield goals and by the elimination of overly optimistic yield goals [*Schepers et al*., 1991b]. Even with decreased inputs of both water and nitrogen, leaching beneath high N demand row crops is subject to weather-related phenomena. Nitrate leaching increased after spring rains leached preplant N below undeveloped corn root systems [*Spalding et al*., 2001; *Helmers et al*., 2007]. Hail-damaged corn or persistent cloudy conditions during the growing season can result in higher soil N concentrations available for leaching [*Spalding et al*., 2001]. Lysimeter data indicate that leachate nitrate concentrations were not reduced when corn and soybeans were rotated [*Klocke et al*., 1999; *Tarkalson et al*., 2006]. As *Twomey et al*. [2010] report the possibility of small towns and municipalities obtaining groundwater with concentrations at or below the MCL is shrinking while the likelihood of costly treatment options is growing.

4. Conclusion

Known areas of groundwater nitrate contamination with average concentrations above the MCL are expanding and new areas continue to emerge beneath Nebraska's irrigated cropland. Increasing concentration trends have been reversed only in two MAs in the Central Platte NRD where after more than two decades of commercial N fertilizer application restrictions and adoption of N budgeting, concentrations average 18–19 mg N/L. While fertilizer BMPs in the MAs likely have slowed the increases in groundwater concentrations, irrigation has obviously exacerbated leaching and water use must be effectively managed and monitored to limit nitrate leaching below the root zone. Whether N and water management will decrease N fertilizer and water application rates to sufficiently lower groundwater nitrate concentrations is doubtful. Groundwater nitrate contamination likely will expand as marginal cropland is developed for irrigated corn production as a consequence of the United States's reliance on ethanol as a gasoline additive and alternative fuel.

Acknowledgments
This project was supported by Hatch projects NEB 38-067 and NEB 22-326. All data are publicly accessible through cited websites.

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2021 NCF-Envirothon Nebraska

Current Issues Study Resources

Key Topic #2: Agriculture and Local Communities

5. Evaluate the effect of agriculture on local economies.
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Study Resources

Natural Resource Amenities and Nebraska's Economy – ECONorthwest, 2006 (Page 32 - 48)

The REAL Cost of Soil Erosion – *NRCS Nebraska, 2019* (Page 49 - 50)

Understanding Nebraska's Water Supply – *Nebraska American Water Works Association, published in Nebraska Farmer, 2017* (Page 50 - 55)

Study Resources begin on the next page! ➡

Natural-Resource Amenities and Nebraska's Economy:

Current Connections, Challenges, and Possibilities

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August 2006

EXECUTIVE SUMMARY

Natural resources do not have to be converted into crops, electricity, or other commodities to support economic growth. Instead, growth can occur when natural resources provide recreational opportunities (bird-watching, fishing, boating, etc.) and other amenities consumers find desirable. This process is called amenity-driven growth.

This report examines the current status of, and potential for natural-resource-related, amenity-driven growth in Nebraska. Resource-related amenities may be able to stimulate economic growth in the state through four mechanisms:

1. **Improve the Quality of Life.** Nebraskans may be able to improve the economy by making the state more attractive, especially to highly productive people. Areas with abundant amenities tend to attract people—especially entrepreneurs and those with high levels of education—and to experience faster growth in jobs and income.
2. **Encourage Feedback to the Farm Sector.** Nebraskans may be able to improve the economy by capitalizing on natural-resource amenities in ways to bolster the farm sector. Amenity-driven growth may increase off-farm job opportunities for members of farm and ranch families. Some farms and ranches may increase earnings by using natural resources for agritourism activities. Practicing environmentally sound farm practices, such as irrigating with no more water than crops need, may increase many farms' net earnings.
3. **Expand Recreation and Other Commercial Uses of Natural Resources.** Nebraskans may be able to improve the economy by stimulating growth in the recreation industry. Americans spend a lot on resource-related recreation. National expenditures in 2001 on three activities, fishing, hunting, and wildlife-watching, averaged $81, $103, and $103, respectively per trip, and totaled $35.6, $20.6, and $38.4 billion for the year. Some recreational activities important in Nebraska, such as bird-watching, are growing rapidly.
4. **Protect Environmental Values.** Nebraskans may be able to improve the economy by reducing damage to the environment. Ecosystems provide many valuable goods and services. Some sustain species and special landscapes, others knit together the web of life, mitigate floods, control pests, … the list is perhaps endless. Impairing these goods and services can retard growth by causing communities to rely on more costly substitute services, and by triggering changes in economic behavior, either voluntarily or through regulation.

The economic forces underlying amenity-driven growth are powerful. Spatial differences in amenities, of all types, account for about half the interstate differences in job growth. Natural-resource amenities are especially important. Most studies, though, have focused on mountains, ocean beaches, and other amenities absent in Nebraska, raising the possibility that it lacks what is needed to have any hope of using natural-resource amenities to generate jobs, incomes, and community stability.

Evidence indicates, however, that Nebraska has its own, distinctive style of amenities potentially capable of generating amenity-driven growth: rivers and reservoirs; agricultural as well as undeveloped landscapes; opportunities for fishing, hunting, and wildlife-watching; trails; state parks; and areas with aesthetically pleasing topography and scenery. Nearly all Nebraskans indicate that the state's natural resources are important to the quality of life they enjoy living in Nebraska.

These feelings notwithstanding, the four mechanisms of amenity-driven growth currently sometimes work to Nebraska's disadvantage.

Quality of Life. Nebraska has some serious economic challenges, some of which seem to stem from its inability to compete successfully with other states for productive households. Much of the state exhibits slow or even negative growth: between 2000 and 2004, for example, only one county (Sarpy) experienced population growth faster than the national average. Moreover, the state has demonstrated a tendency to lose highly-educated people. Between 1995 and 2000 it had a net loss of more than 4,500 young people with at least a bachelor's degree; between 1985 and 1999, it lost $246 million in personal income—about 1.1 percent of the state's total—because of the brain drain.

These challenges have many roots, among them limited public access to amenities, and perceptions that natural resources are degraded. About 97 percent of Nebraska is privately owned and typically managed for purposes other than providing the public with recreational and other amenities. News items about environmental degradation are abundant, among them: surface waters typically contain 10 – 14 herbicides or related chemical compounds; the width of the Platte River has been reduced 40 – 90 percent above Grand Island; manipulation of the Missouri River Basin has reduced populations of invertebrate species important to the food web by about 70 percent. To the extent that people perceive Nebraska's natural resources to be degraded and difficult to reach, these resources are likely to exert a negative, not positive, influence on household-location decisions.

Farm Sector. Agriculture is an economic powerhouse in Nebraska. Even so, some farmers and ranchers face challenges that amenity-driven growth might ease. Some landowners might earn additional revenues through agritourism: those who lease land for hunting, for example, earn $10 – $20 per acre. Others might reduce their costs: research in the Upper Big Blue Natural Resources District, for example, found that, with more efficient use of water and fertilizer, some farmers with 500 acres could realize annual savings of $23,600, reduce pollution, and leave water for other uses. And amenity-driven growth might generate new off-farm job opportunities for some who depend on income from off-farm sources to sustain not just their standard of living but their ability to remain on their farms and ranches.

Recreation Industry. Recreationists took almost 8 million trips to fish, hunt, and watch wildlife in Nebraska in 2001, and spent $46, $90, and $59 per trip, respectively. Nonetheless, the state's recreation industry is one of the smallest in the United States. In contrast to other western states, little land and water is open to public access. Also important is a prevailing attitude among landowners, which sees land and water primarily, if not exclusively, as economically important only when they are used as inputs to the production of commodities—crops, livestock, and electricity—or when they absorb pollutants. Some evidence indicates this attitude is changing. A growing number of farmers are expressing interest in agri-tourism, for example, as a way to augment farm earnings. Several communities are leading the way to capitalize on natural-resource amenities: attracting business and residential investment to the riverfront in Omaha, rafters to the Niobrara River in Valentine, and bird-watchers to the central Platte. Much potential remains untapped, however.

Environmental Values. Past actions have reduced the ecosystem's ability to provide valuable goods and services. Groundwater pollution threatens water supplies of the state's major cities, for example, the state has lost many of its wetlands, and more than 600 species face significant risk of extirpation in the state, with 80 of these among those most at risk of extinction globally or nationally. As the ecosystem's ability to provide goods and services declines, society must do without or develop more costly substitutes.

The value of lands used to produce recreational and other amenities compares favorably with, and sometimes exceeds, the value of lands used to produce crops and livestock. Areas providing high-quality recreational opportunities probably can support fishing, hunting, and wildlife-watching activities with an annual value greater than $120 per acre, whereas the annual rent in Nebraska for agricultural production is $97 per acre for cropland and $12 per acre for pasture. Overall willingness to pay for preserving areas capable of producing recreational and other amenities, including the protection of rare species, can be as high as $3,000 – 7,000 per acre. In contrast, the average price of agricultural land in Nebraska is $1,430 per acre for cropland and $310 per acre for pasture.

The economic output of activities linked to the amenities derived from the state's natural resources is smaller than the output linked to the commodities, but it is nonetheless significant. The 2002 agricultural census, for example, found that farms and ranches in Nebraska produced crops and livestock with a commercial net value, exclusive of government subsidies, of about $890 million. In comparison, a 2001 survey found that the resources supporting fishing, hunting, and wildlife-watching activities in the state had a net value of about $350 million.

Many Nebraskans have demonstrated a willingness to promote amenities, such as bird migrations, seeing their actions as a contribution to the quality of life not just for themselves but also for others. The information presented in this report indicates that greater contributions to the state's economy are possible. They typically would originate from the interests of landowners, and be linked to private and public investments in access and ancillary facilities (roads, motels, etc.). Some efforts to capitalize on amenities might entail converting land and water resources from the production of commodities (corn, cattle, etc.) to the production of amenities (recreational opportunities, fish and wildlife habitat, etc.). Others would not: with appropriate marketing and ancillary investments a farmer or rancher might enjoy higher earnings by producing commodities and amenities rather than commodities alone.

Unless Nebraskans act more aggressively to capitalize on them, the economic forces underlying amenity-driven growth are likely to work to the state's disadvantage. Some amenities in other states can generate economic growth even when trampled, hard to reach, and overlooked, but Nebraska doesn't have this luxury. Amenities similar to Nebraska's are found elsewhere in the Great Plains, and, if Nebraska is to realize the full benefits of amenity-drive growth, it must distinguish itself from the crowd. To do so, Nebraskans must ensure their amenities have higher quality and better access, and they must have a clear vision of how to make the most of them. These are some of the areas with untapped potential for amenity-driven growth:

Omaha's riverfront	Missouri River trails	National wildlife refuges
Niobrara River-Valentine	Ponca State Park	Pine Ridge region
Middle Platte River	Wetlands	Lake McConaughy

The forces underlying amenity-driven growth affect the potential effectiveness of economic–development strategies that receive a lot of attention. A strategy to invest in education may have limited success unless the state becomes more attractive to highly-educated individuals and entrepreneurs. Relaxing environmental standards for some industries might increase the costs other industries and households incur to cope with environmental degradation and reinforce the perceptions that encourage some highly productive households to locate elsewhere. Intensifying the application of natural resources to agricultural production might boost that industry's output but slow overall economic growth unless the agricultural sector can reverse its declining ability to support farm families and avoid spillover costs that retard growth in other, faster-growing sectors.

None of this is intended to diminish in any way the economic importance of agriculture or other natural-resource industries, nor is it intended to disparage those who own and manage the state's land and water. Rather, the core message of this report is that the economic forces underlying amenity-driven growth exert a powerful influence on Nebraska's economy. The state possesses resources that could be used to take advantage of these forces, but so far Nebraskans have not fully seized these opportunities. This report makes no recommendations; it only provides background information for Nebraskans to consider as they make resource-management decisions in the future.

I. INTRODUCTION

Nobody can reasonably doubt the economic importance of Nebraska's land and water resources. Nor can anyone reasonably doubt the economic importance of the industries and activities that for so long have dominated these resources. Agricultural activities on 53,000 farms and ranches occupy 46.4 million acres, or 94 percent, of the state's land.[1] To produce crops, farmers irrigate about 7.5 million acres with 1.2 million acre-feet of surface water and 5.8 million acre-feet of groundwater.[2] Ranchers divert about 160,000 acre-feet of water from the state's streams, and pump 122,000 acre-feet of groundwater each year.[3] The agricultural use of these land and water resources generates annual sales of crops and livestock totaling about $10 billion.

Efforts to wring jobs and incomes from the state's resources involve more than just farming. Businesses and households save money by relying on the state's waterways to carry downstream about 203,000 acre-feet of municipal sewage and industrial waste,[4] as well as pollutants from agricultural operations. More than 2,150 state-regulated dams store water and alter stream flows for miles downstream.[5] Some of these dams store water for irrigation, but much of the water also produces electricity with a retail value of about $1.5 billion.[6] About 16.8 million acre-feet pass through hydroelectric generators use each year; thermal power plants use 2.6 million acre-feet.[7] The operation of federal dams on the Missouri River support barging activities with a gross value of about $7 million per

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[1] Nebraska Agricultural Statistics Service. 2002. *2002 Nebraska Agricultural Statistics*. http://www.nass.usda.gov/ne/2002book/pag_001.pdf (accessed December 1, 2005).

[2] Nebraska Natural Resources Commission and U.S. Geological Survey. 1998. *Estimated Water Use in Nebraska: 1995*. April, pp. 23-29. http://www.dnr.state.ne.us/otherresources/waterreport95.html (accessed January 6, 2006). An acre-foot is about 326,000 gallons, or the amount of water that would cover one acre of land one foot deep.

[3] Nebraska Natural Resources Commission and U.S. Geological Survey. 1998. *Estimated Water Use in Nebraska: 1995*. April, pp. 30-32. http://www.dnr.state.ne.us/otherresources/waterreport95.html (accessed January 6, 2006).

[4] Nebraska Natural Resources Commission and U.S. Geological Survey. 1998. *Estimated Water Use in Nebraska: 1995*. April, p. 33. http://www.dnr.state.ne.us/otherresources/waterreport95.html (accessed January 6, 2006).

[5] Association of State Dam Safety Officials. "Nebraska Dam Safety Program." http://www.damsafety.org/layout/subsection.aspx?groupid=1&contentid=182 (accessed December 1, 2005).

[6] U.S, Department of Energy, Energy Information Administration. 2004. *State Electricity Profiles 2002*. February, pp. 122-126. http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html (accessed January 6, 2006).

[7] Nebraska Natural Resources Commission and U.S. Geological Survey. 1998. *Estimated Water Use in Nebraska: 1995*. April, pp. 32-33. http://www.dnr.state.ne.us/otherresources/waterreport95.html (accessed January 6, 2006).

year, and provide benefits of about $242 million to Nebraska's municipal-industrial water users.[8]

These economic benefits come at a price, however. Nebraska has some serious economic challenges, and mounting evidence suggests they stem, at least in part, from current uses of the state's natural resources. Some of the most notable challenges are:

- ***Rural flight.*** More than 50 of the state's counties lost population in the 1990s. In the first years of this century, population in only one county (Sarpy) grew faster than the national average. As rural communities and economies shrink, so too does their ability to provide roads, schools, and other essential public services without supplemental support from urban firms and households.
- ***Brain drain***. More young college graduates are moving out of the state than moving in, weakening Nebraska's ability to build and sustain innovative, competitive firms that can generate new jobs and incomes in the future.
- ***Insecure farm earnings.*** Half of the principal operators of Nebraska's farms and ranches earn income from off-farm work, and 30 percent work more than 200 days per year at off-farm jobs.[9] There are no obvious opportunities that will enable all farm and ranch families to rely solely on agricultural income in the foreseeable future.
- ***Stagnant industries.*** The state's economy has a heavy concentration of industries, especially resource-related industries, exhibiting no more than a tepid ability to generate new jobs and incomes. Overall job growth in Nebraska frequently lags behind the national average.[10]
- ***Deficit production.*** Many of Nebraska's farms and ranches operate at a loss: their costs to produce crops or livestock exceed the prices they receive for these products. To offset these losses, farmers and ranchers received more than $7 billion in federal subsidies for producing some commodities over the past decade.[11] Areas heavily dependent on farm subsidies tend to have economies less robust than other areas. If adopted—many believe the question is when, not if—proposals to curtail subsidies to farm production might depress farm-related jobs and incomes even further.

[8] National Research Council, Committee on Missouri River Ecosystem Science. 2002. *The Missouri River Ecosystem: Exploring the Prospects for Recovery*. Washington, D.C.: National Academy Press, pp. 92-94.

[9] U.S. Department of Agriculture, National Agricultural Statistics Service. 2004. *2002 Census of Agriculture: State Summary Highlights*. June. http://www.nass.usda.gov/census/census02/volume1/ne/index2.htm (accessed January 6, 2006).

[10] Wilkerson, C. 2005. "What Do Expected Changes in U.S. Job Structure Mean for States and Workers in the Tenth District?" *Economic Review: Federal Reserve Bank of Kansas City*: 59-93.

[11] Environmental Working Group. 2006. *EWG's Farm Subsidy Database*. http://www.ewg.org/farm/regionsummary.php?fips=31000 (accessed January 6, 2006).

As farm families, business leaders, and public officials grapple with these challenges, many have suggested Nebraskans could generate additional jobs, higher incomes, and more robust communities by diversifying uses of the state's resources. For the most part, these suggestions involve shifting some resources away from sole production of agricultural and other commodities in areas with low economic return toward uses that would protect and enhance the natural character of the environment. These suggestions have been fueled by the experiences of communities elsewhere, many of which have found that land and water can generate more jobs and income when they provide recreational opportunities, scenic vistas, and other amenities for consumers than when they produce only agricultural goods and other commodities.

Some researchers use the term, amenity-driven growth, to describe the ability of healthy, attractive natural resources to generate jobs and incomes. Much of the research on this process, however, focuses on amenities absent in Nebraska: snow-topped mountains, ocean beaches, and warm winter climates. This research raises these questions: What are the forces underlying amenity-driven growth and how do they affect Nebraska? Does Nebraska have the types of natural-resource amenities needed to generate jobs, incomes, and community stability?

This report addresses these and related questions. We prepared it with support from a coalition of individuals representing these state agencies, offices, and private entities: American Rivers; the Center for Rural Affairs; Nebraska Department of Economic Development (Division of Business Development and Division of Travel and Tourism); Nebraska Game and Parks Commission; the Office of U.S. Senator Ben Nelson; the Office of U.S. Representative Jeff Fortenberry; and the University of Nebraska–Lincoln Water Center.

We separate our presentation into five parts. In Section II, we explain a conceptual framework for understanding the process by which natural-resource amenities accessible to the public (or lack thereof) can have a positive (negative) effect on economic growth. In Section III, we describe the occurrence of natural-resource-related, amenity-driven growth in the U.S., as well as the underlying forces and trends that make it powerful. In Section IV, we assess the applicability of the amenity-driven-growth process in Nebraska. In Section V, we briefly describe some of the lessons learned as states and communities elsewhere have attempted to capitalize on the amenity-driven-growth process. In Section VI, we highlight some of the state's natural-resource amenities, their current economic linkages, and their economic potential.

We emphasize that our focus is descriptive, not prescriptive. By explaining the current and potential interactions between Nebraska's economy and amenity-driven growth we are not saying that Nebraskans should make this or that decision regarding the management of resources, either in general or in particular. This report aims only to provide information regarding the role of amenity-driven growth in the state.

II. NATURAL-RESOURCE AMENITIES AND ECONOMIC GROWTH: A CONCEPTUAL FRAMEWORK

Decades ago, the relationship between Nebraska's natural resources and its economy was straightforward. The major demands were limited: farmers and ranchers wanted land and water for growing crops and livestock, utilities wanted water to generate hydropower, and farms, industries, and municipalities wanted potable-water supplies and a cheap way to dispose of their wastes.

Today, though, things are much more complex. More people and industries demand land and water. Cities spread to farmland and compete more extensively with irrigators for water. Households increasingly seek both goods, such as clean water, and services, such as recreational opportunities. Additional demands have materialized with the concerns of scientists and the public about the environment. Water supplies also have changed. Variation in climate recently brought on a deep drought, conditions many fear will occur more frequently in the future, than they have in the recent past. Dams and irrigation systems have altered the spatial and temporal distribution of water. Farming has replaced a native ecosystem of many species with one that has far fewer.

The relationship between Nebraska's natural resources and its economy has evolved into one where a complex web of demands compete for scarce resources whose quantity and quality vary in complicated ways over space and time. This evolving competition embodies the values that individuals, households, businesses, and communities place on the state's natural resources. Hence, to understand the contributions—current and potential—natural resources make to the state's economy, one must understand the essential characteristics of the competition for these resources. Toward that end, we observe that the competition for natural resources typically does not stem from demands for the resources, themselves, but from demands for the many goods and services derived from the resources. The next section provides more detail.

A. The Value of Nebraska's Natural Resources Stems from the Goods and Services They Produce

From an economics perspective, Nebraska's land and water resources are important not in and of themselves but because they both produce things that benefit people, impose costs on them, and compose the environment.

Describing the economically important products derived from the state's natural resources is not a straightforward task. One widely accepted approach combines economic with ecological concepts, as shown in Figure 1. Its central feature is the ecosystem's production of *ecosystem goods and services*, which are important to people and, hence, have economic value. Sometimes this value materializes in market prices, as sellers and buyers trade a good or service, or a product derived from it. The absence of a market price, however, does not mean that a good or service has no value. Instead, as we discuss below, a good or service can have value even though it is not traded in markets. The economic importance of a good or service may arise when it is extracted, as when farmers divert water from a river to irrigate a crop, or when it remains *in situ*, as when anglers fish on the water left in the river. The ecosystem produces goods and services through processes, known as ecosystem functions, that derive from the ecosystem's structure.

The left side of Figure 1 highlights the importance of human actions that influence the ecosystem's structure and functions and, hence, its production of goods and services. The right side shows that sometimes humans place values on the structure of the ecosystem, e.g., the character of the landscape, rather than on the goods and services it produces. To simplify things, however, we use the terms, goods and services, to represent all those resource-related things that have economic value.[12]

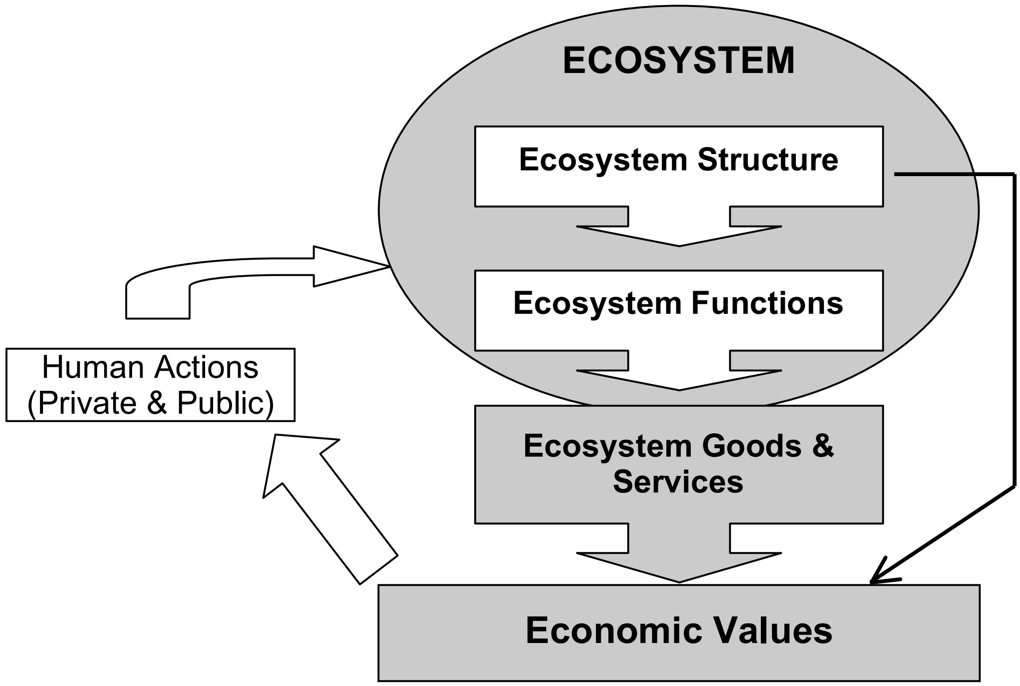
The list of resource-related goods and services is long and growing, as ecological scientists learn more about the inner workings of ecosystems and people find new ways to derive benefits from them. Table 1 offers a representative list. Some of the goods and services in Table 1 will be unfamiliar to those who see natural resources as having economic value only in terms of their most visible uses: irrigation, industrial processing, municipal uses, and recreation. Indeed, some of them would have been unrecognized by many economists just a few years ago. The economic importance of the full slate of goods and services is now widely recognized, however.[13]

The systems that manage Nebraska's resources were established when the levels of understanding of ecosystems and the economy were more limited than they are today and, hence, they often failed to recognize goods and services whose importance is just emerging. The first focus was on marketed goods and services and it took decades for this focus to widen enough to include nonmarketed goods and services. For example, management of surface water stems from the state's 1895 adoption of a

[12] We also use "goods and services" to include things, such as damaging floods, that are economically important in a negative rather than positive sense.

[13] *See*, for example, National Research Council, Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems. 2004. *Valuing Ecosystem Resources: Toward Better Environmental Decision-Making*. National Academies Press.

Figure 1. Connections between the Ecosystem and Economic Values



Source: ECONorthwest, adapted from National Research Council, Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems. 2004. *Valuing Ecosystem Services: Toward Better Environmental Decision-Making*. National Academies Press.

doctrine that appropriates water using the rule, first-in-time-first-in-right. The most senior claims on water are therefore associated primarily with the production of marketed crops and livestock. It was not until 1984 that the doctrine was expanded to include instream flows and then only for flows to maintain existing recreational uses or the needs of fish and wildlife species. Water uses associated with other goods and services, such as the formation of soil or the regulation of climate, have not been folded into the doctrine.

One should not, however, take the exclusion of a good or service from the resource-appropriation doctrine to mean that its importance is zero. Also, one should not conclude that those goods and services included in the doctrine are necessarily more valuable than those that are excluded. Instead, it is important to recognize that, given the current state of documentation and understanding, it is generally impossible to know with precision all the values of the different goods and services that can be derived from a given natural resource. To have the best possible understanding of these values one must look to all the relevant information—quantitative and qualitative, local and distant.

Table 1. Functions, Goods, and Services of Nebraska's Ecosystem

Functions		Examples of Goods and Services Produced
1	Production and regulation of water	Natural and human-built features capture precipitation; filter, retain, and store water; regulate levels and timing of runoff and stream flows; influence drainage; and provide water for diverse human uses.
2	Formation & retention of soil	Wetlands and biota accumulate organic matter, and prevent erosion to help maintain productivity of soils.
3	Regulation of atmosphere & climate	Biota produce oxygen, and help maintain good air quality and a favorable climate for human habitation, health, and cultivation.
4	Regulation of disturbances	Wetlands and reservoirs reduce economic flood damage by storing flood waters, reducing flood height, and slowing velocity of flood.
5	Regulation of nutrients and pollution	Wetlands and riparian vegetation improve water quality by trapping pollutants before they reach streams and aquifers; natural processes improve water quality by removing pollutants from streams.
6	Provision of habitat	Prairies, wetlands, riparian vegetation, streams, and reservoirs provide habitat for economically important fish and wildlife.
7	Food production	Biota convert solar energy into plants and animals edible by humans.
8	Production of raw materials	Streams and biota generate materials for construction, manufacturing, fuel, and fodder; streams possess energy convertible to electricity.
9	Pollination	Insects facilitate pollination of economically important wild plants and agricultural crops.
10	Biological control	Birds, bats, fish, and microorganisms control pests and diseases.
11	Production of genetic & medicinal resources	Genetic material in wild plants and animals provide potential basis for drugs and pharmaceuticals.
12	Production of ornamental resources	Products from plants and animals provide materials for handicraft, jewelry, worship, decoration, and souvenirs
13	Production of aesthetic resources	Landscapes, wetlands, streams, and reservoirs provide basis for enjoyment of scenery from roads, housing, parks, trails, etc.
14	Production of recreational resources	Streams, reservoirs, fish, birds, mammals, and other wildlife provide basis for outdoor sports, eco-tourism, etc.
15	Production of spiritual, historic, cultural, and artistic resources	Landscapes, streams, and reservoirs serve as basis for spiritual renewal, focus of folklore, symbols of group identity, motif for advertising, etc.
16	Production of scientific and educational resources	Land and water provide inputs for research and focus for on-site education.

Source: Adapted by ECONorthwest from De Groot, R., M. Wilson, and R. Boumans. 2002. "A Typology for the Classification, Description and Valuation of Ecosystem Functions, Goods and Services." *Ecological Economics* 41: 393-408; Kusler, J. 2003. *Assessing Functions and Values.* Institute for Wetland Science and Public Policy and the Association of Wetland Managers, Inc.; and Postel, S. and S. Carpenter. 1997. "Freshwater Ecosystem Services." in *Nature's Services: Societal Dependence on Natural Ecosystems*. Edited by G.C. Daily. Washington, D.C.: Island Press, pgs. 195-214.

B. Competing Demands Shape the Benefits and Costs Nebraska Derives from Its Natural Resources

In most times and places, Nebraska contains insufficient land and water to satisfy all the demands for all the goods and services shown in Table 1. Hence, when these resources produce one set of goods and services, the demands for others go unmet. In other words, there is competition for the state's natural resources. Because this competition both reflects and shapes the economic values of the different goods and services derived from these resources, an understanding of the essential characteristics of this competition can provide useful insights into the values that exist today and how they change over time.

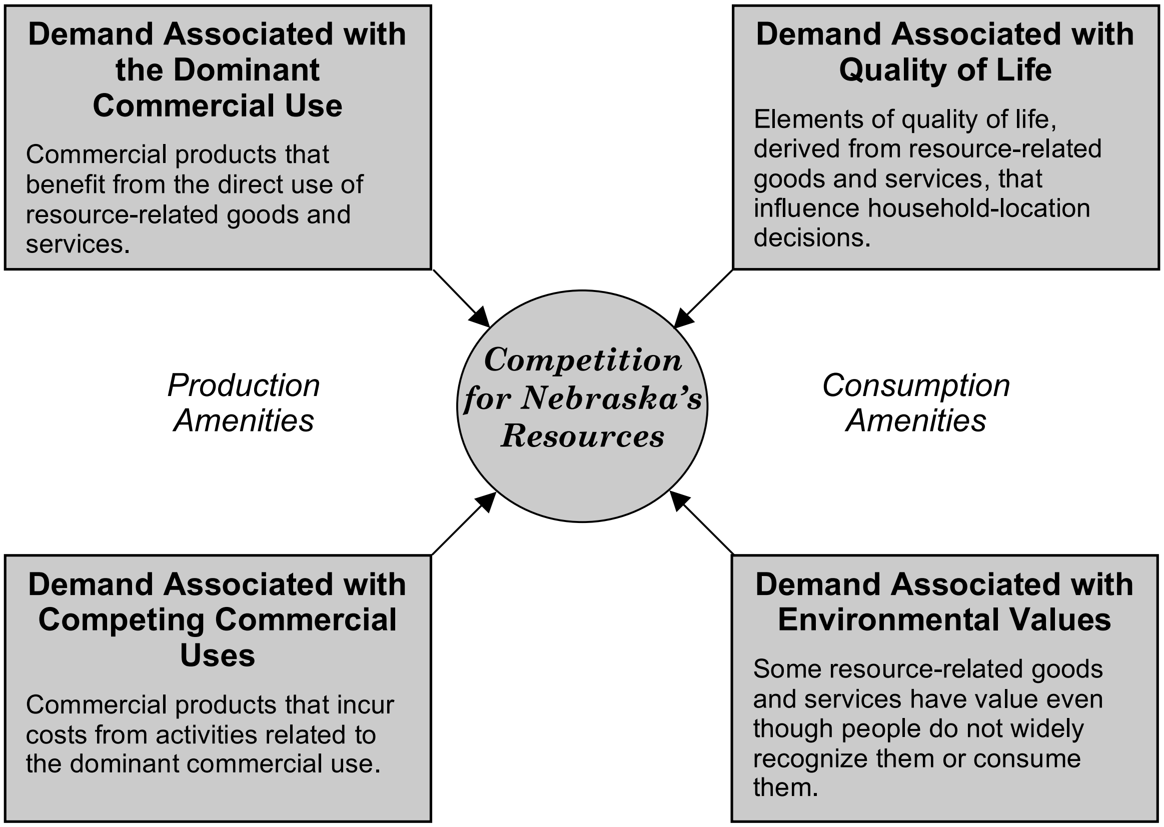
One could categorize the competition in any of a number of ways, but we employ a taxonomy that distinguishes among the four types of demand illustrated in Figure 2. Two of these, which we call demands for production amenities, include demands for those goods and services that are, or could be, inputs to a process that produces other goods and services. The other two, which we call demands for consumption amenities, include demands for goods and services that directly enhance the well-being of consumers.

To facilitate the discussion, we assume that one type of demand, which we call the dominant commercial demand, prevails and then look at the consequences for the others. Moreover, we initially describe the consequences by portraying the competitors in the classic posture, with insular and adversarial interests, so that when one successfully secures the use of a natural resource, others are left wanting. From this perspective, Nebraskans face stark either-or choices: they can use natural resources to produce either the goods and services associated with agriculture, hydropower, and other commodities or the goods and services associated with clean water, recreational opportunities, and other amenities, but not both.

In some circumstances, such tradeoffs dominate. In others, however, they do not. Hence, later in our discussion we recognize that the competing demands often overlap, with individuals, families, businesses, and communities wanting more than just one good or service from natural resources. Farm families, for example, typically want to use their land and water to produce both crops (or livestock) and a healthy, pleasant environment. Many urban residents want both clean water in streams and irrigation water to support a healthy agriculture industry. In this context, some landowners and water managers may be able to use these resources to produce multiple outputs, some of which are linked to commodity-driven growth and others to amenity-driven growth.

Against this backdrop, we now describe the different types of competing demands for natural resources.

Figure 2. The Competing Demands for Nebraska's Natural Resources



COMPETITION FOR PRODUCTION AMENITIES

On the left side of Figure 2 we place the competing demands for production amenities, i.e., elements of Nebraska's ecosystem that facilitate commercial production. Farming, ranching, sand and gravel mining, and urban development are the most important of these demands. Demand for the state's production amenities comes from private and public enterprises, which we define broadly, to include farming, ranching, private corporations, incorporated cities, and public agencies, as well as some households, such as those that develop new housing.

Dominant Commercial Uses. We separate the demands for production amenities into two groups. One of these, shown in the upper left of Figure 2, directly use land and/or water; and they have dominant resource-use characteristics. This type of demand usually is associated with a familiar industry, such as farming or ranching, or with common urban-development activities. In general, only one product benefits from a particular use of a resource, but sometimes there may be more. A dam and reservoir may benefit anglers, irrigators, and consumers of hydroelectricity, for example.

Competing Commercial Uses. Sometimes, the dominant commercial use of resource-related goods and services imposes costs on other enterprises, which are represented in the bottom left of Figure 2. When irrigators deplete stream flows or reservoirs and reduce fish habitat, for example, they may reduce the production of irrigators downstream who now have less water for their fields, or impose costs on fishing guides who now have fewer prime fishing spots for their customers.

We purposefully separate the demands on the left side of Figure 2 into two boxes to drive home the message that there may be competition, within the commercial sectors, for Nebraska's land and water resources. We do so because often people perceive that the competition for natural resources occurs only between a single commercial interest and environmental-protection interests. By highlighting the existence of competition within the commercial sectors, we emphasize the point that the positive consequences arising from one set of commercial activities frequently have offsetting, negative effects on others.

COMPETITION DIRECTLY FROM CONSUMERS

On the left side of Figure 2, Nebraska's natural resources are economically important because they are inputs in the production of other things, such as beef and hydroelectricity, that consumers want to have. On the right side, consumers' connection to these resources is more direct. That is, the resources are economically important for how they directly contribute to consumers' well-being. In economics parlance, such contributions are called consumption amenities. There are two types of demand for Nebraska's resource-related consumption amenities: one affects residential location decisions; the other does not.

Consumption Amenities and Residential Location. Some resource-related goods and services, such as recreational opportunities and scenic vistas, contribute directly to the well-being of people who have access to them. Their contribution to consumers' well-being makes them economically important in their own right, but they are more important when they also influence the location decisions of households and businesses. We show the demands for consumption amenities that influence location decisions in the upper right portion of Figure 2.

Economists' explanation of why some consumption amenities can influence location revolves around the concept of *consumer's surplus*. Whenever a consumer derives benefits (increases in well-being) from a good or service that exceed the costs he or she pays to obtain it, the net benefit represents a net increase in well-being. This increment is called consumer's surplus.

In general, the nearer that people live to resource-related amenities, the better their access, and the lower their cost of taking advantage of them. Thus, consumers can increase their consumer's surplus—their economic well-being—by living near locations that offer recreational opportunities, pleasant scenery, wildlife viewing, and other amenities. This consumer's surplus is, in effect, a *second paycheck* residents receive from living in a place where they have easy access to these amenities. Thus, the total welfare of residents near them is the sum of this second paycheck plus the purchasing power of the money income they receive from their first paycheck. Spatial differences in the size of the second paycheck affect behavior by influencing households to locate in one place rather than in another.

Quality-of-life values can be powerful. As we describe below, many Nebraskans say the primary reason they live in the state is to enjoy its quality of life. Some undoubtedly could enjoy higher earnings (their first paycheck) living elsewhere, but choose not to do so because their total welfare (the sum of the first and second paychecks) is higher here. Some aspects of this quality of life—the strength of its communities, schools, and churches, for example—are not directly related to natural resources. But others are: the open space, outdoor way of life, and opportunities for fishing and hunting, to mention a few. All else equal, if the state's resource-related consumption amenities improve, some people already in Nebraska will have a greater tendency to stay and additional people will tend to move in. Degradation of the amenities will have the reverse impacts.

Because quality-of-life values do not materialize in easily recognizable forms they are often overlooked. Studies that measure the output, jobs, incomes, and taxes generated when resources are used to produce crops and other commodities, for example, generally are blind to the output, jobs, incomes, and taxes that could have been generated, had the resources been used to produce quality-of-life amenities that attract households. By their nature, such studies focus on the value of marketed goods and services (crops, livestock, etc.) and on the first paychecks commodity-oriented industries pay workers. Calculating the economic importance of quality-of-life amenities, in contrast, requires a different approach using different data and different analytical techniques. First, they must examine the value of the nonmarketed goods and services (scenic views, fish habitat, etc.) that constitute the amenities. That is, they must determine the size of the second paycheck enjoyed by nearby residents. Second, they must determine the extent to which the amenities influence household-location decisions. Third, they must examine the extent to which the influence on households stimulates commercial output, jobs, incomes, and the like.

Environmental Values. The lower right portion of Figure 2 represents demands associated with economic values that do not necessarily entail a conscious, explicit use of Nebraska's natural resources. We call these environmental values. There are two general categories: nonuse values and values of goods and services that generally go unrecognized.

Nonuse values arise whenever individuals want to maintain some element of the environment, even though they do not directly or personally use it and have no intention to do so.[14] Sometimes this value is linked to the existence of a species, a scenic landscape, or other resource. It also can be associated with maintaining a particular cultural or ecological characteristic of a resource. Nonuse values also arise when people place a value on ensuring that a particular resource will be available for future generations. For example, a person might be willing to pay some amount to ensure that their grandchildren will have the same opportunities they've had to enjoy a free-flowing river, to see an open prairie or a traditional ranching landscape, or to go fishing. Similarly, some may desire that soils and water resources be used in a sustainable manner, so future generations will have opportunities to farm or ranch and pass along a legacy comparable to what exists today.

Ecosystems can provide goods and services that people consume without being aware of them. Some of these are part of the so-called web of life: operating at local, regional, and global scales, they help sustain human and other life in Nebraska and elsewhere. Others have a more direct link to the well-being of the state's residents, as when the microorganisms of an out-of-sight aquifer help purify water before it reaches the intake of a municipality's water utility. Even though people might not consciously consider the benefits of these services on a day-to-day basis, they probably would do so if they had a better understanding of them or if the services were to become threatened or noticeably diminished. Many people today, for example, consciously consider the economic values associated with the services produced by the global climate, in ways that were unknown, except to scientists, just a few years ago. Some scientists and economists believe many more services have great economic value although this value and, hence, the demands for the services are not visible.[15]

Unlike the other types of demand in Figure 2, demands related to environmental values do not necessarily affect population growth, jobs, income, or other indicators of economic activity in Nebraska. Residents of Omaha and Seattle, for example, might place a value on and, hence, express a demand for protecting the existence of the pallid sturgeon, a fish at significant risk of extinction in Nebraska's rivers, but this demand might never result in any discernible change in economic activity. Then again, some changes might occur. Those wanting to ensure the sturgeon's existence might trigger protective actions by donating money, pressing for the expenditure of public funds, or lobbying for regulations toward that end. The resulting investments in fish habitat would generate jobs and

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[14] These values are also known as passive-use values or intrinsic values.

[15] *See*, for example, Daily, G.C. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington, D.C.: Island Press.

News Release

The REAL Cost of Soil Erosion

Email This Page

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Do you know what ‘menace’ Nebraska farmers are still battling? Soil erosion. Even after widespread adoption of no-till and other modern farming methods, soil erosion is still a big problem in many areas.

Hugh Hammond Bennett was the first Chief of the USDA Soil Conservation Service (now called the Natural Resources Conservation Service or NRCS). He is widely known as the “Father of Soil Conservation,” and is credited with creating a strong public interest in reducing the problem of soil erosion back in the 1930s.

Erosion happens when soil is not adequately covered to protect it from water and wind. When uncovered soil particles become detached and are washed or blown away, soil health declines, and other resources are negatively impacted such as water and air quality. Bennett observed how soil erosion reduced the ability of land to sustain agricultural productivity, and that is still a problem for many producers today.

Farmers in south central Nebraska saw first-hand the results of soil erosion after heavy rain storms this spring. On May 6, a storm dumped up to 10 inches of rain in a single event in a 10-county band from Hastings to Nebraska City. Heavy rain caused severe soil erosion and flooding throughout the area, especially around Hebron in Thayer County. But not all fields were impacted the same.

Aaron Hird, NRCS Resource Conservationist in Hebron reported that fields where the soil had been tilled showed visible signs of excessive soil erosion. In contrast, fields with high amounts of crop residue or cover crops and no tillage had noticeably less erosion or no visible erosion at all.

So what’s being done to help farmers combat the impact of soil erosion? With the help of NRCS and other conservation partners; quite a lot.

NRCS has been in the soil saving business for over 80 years. In 1935, Congress created the USDA Soil Conservation Service to address the national Dust Bowl crisis stating, "the wastage of soil and moisture resources on farm, grazing, and forest lands . . . is a menace to the national welfare."

Since then, the Natural Resources Conservation Service (as we’re now called) has continued to provide voluntary conservation assistance to farmers and ranchers who want to improve natural resources on their land.

We’ve been making tons of progress – literally. The NRCS Conservation Effects Assessment Report from 2012 shows that farmers have reduced soil loss through the adoption of conservation practices by as much as 5 tons per acre.

While soil erosion in much of the Midwest region has decreased, the cost of soil loss is still very significant. An NRCS report of their Environmental Quality Incentive Program from 2002 and 2010 indicated that each ton of soil eroded contains the equivalent of 2.32 pounds of nitrogen and 1 pound of phosphorus. The cost per pound for nitrogen and phosphorus were 0.63 and 0.64 respectively. Mike Duffy, Extension Economist with Iowa State University, published “Value of Soil Erosion to the Landowner” in 2012 that suggested the real cost to the farmer based on those estimates was a loss of fertilizer at $2.10 per ton of soil loss per acre.

To illustrate a point about the substantial costs associated with soil erosion, let’s look at the May 6 storm in Thayer County. According to the USDA Census of Agriculture, Thayer County has approximately 326,000 acres of cropland. If we assume that half of the cropland in Thayer County was impacted by the heavy rainfall, (160,000 +/- acres) and that the average soil loss was 2 tons per acre, the total soil loss would be 320,000 tons. At a cost of $2.10 per ton for nitrogen and phosphorus alone, the estimated loss from the May 6 storm would be $672,000. Assuming a similar loss in the 10-county storm-impacted area, the estimated loss would be $6,720,000 - and that doesn’t even consider the costs of seed and fuel and the time required to replant some of those acres.

The ‘real’ cost of soil erosion goes beyond just the cost of lost fertilizer. The additional costs associated with soil erosion include loss in crop production; loss of land value from long-term excessive erosion; damage to real property, roads, bridges and other infrastructure; and environmental damages to streams, rivers and lakes.

To help combat the economic and environmental impacts of soil erosion, NRCS is available to help farmers and ranchers apply effective soil conservation practices such as contour farming, terraces and grassed waterways. NRCS programs are voluntary and offered free of charge. Financial assistance is available through NRCS conservation programs to help farmers install soil saving conservation practices like planting cover crops.

NRCS has identified four key principles to healthy soil: 1) keep soil covered, 2) disturb soil less, 3) feed soil with living plants as much as possible, and 4) increase plant diversity. Following these principles will reduce soil degradation, improve soil productivity, and increase soil resilience to extreme weather.

These soil health principles are in line with what Hugh Hammond Bennett believed. He said, “Everything we do, all we share, even whatever we amount to as a great enduring people, begins and rest on the sustained productivity of our agricultural land.”

To learn how you can help sustain the productivity of your agricultural land by protecting one of its most valuable assess – its soil – visit your local USDA Service Center. Conservation professionals can work with you to develop a conservation plan custom-made for your farming operation.

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NebraskaFarmer


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MUTUAL BENEFIT: An adequate and safe water supply is fundamental for a strong economy and for the public's health and safety. Total Water Solutions is working with interested groups and individuals to build relationships with all Nebraska water stakeholders, particularly those in agriculture.

Understanding Nebraska's water supply

Commentary: Water quality and quantity have much in common for both agriculture and municipal water interests; Nebraskans benefit when agriculture and municipal water interests work together.

Mar 02, 2017

How many Nebraskans know the source of their drinking water?

The general public's accuracy in being able to answer this question is of concern to both agricultural producers and Nebraska municipal water supply operators and managers. While both groups represent diverse interests, an adequate and safe water supply is fundamental for a strong economy and for public health and safety. Water quality and quantity do hold much in common for agricultural and for drinking water and municipal supply systems.

Water, energy, nutrients and economics are central themes for both agriculture and municipalities. The same issues for Nebraska agricultural and municipal water interests are seen to exist globally. Worldwide interest and priorities are evolving for water policy and technology. As seen elsewhere, Nebraskans benefit when agriculture and municipal water interests work together on quality and quantity.

The Nebraska Section of the American Water Works Association has traditionally focused upon the needs, trends and technology relating to municipal public water supply systems. In 2014, the Nebraska Section formed the Total Water Solutions subcommittee. A primary goal of TWS is building understanding and positive collaborative working relationships with all Nebraska water stakeholders, especially agriculture.

This article seeks to further describe a number of practices in which municipalities manage water. Most Nebraska municipal systems derive their source of supply from groundwater. Regardless of size, communities' land uses within an individual watershed have a direct effect on quality and quantity of supply.

Nebraska's economy relies directly upon agricultural land uses and the farm economy. A healthy agricultural economy benefits municipal business, industry and government. For example, commercial and residential construction within larger Nebraska municipalities was robust in 2016. In contrast, farm producer commodity prices were severely reduced in the same year. With reduced farm income, the state of Nebraska experienced a tax revenue shortfall of $2 billion.

Water supply

As a point of interest, irrigated agriculture measures quantities of water use in acre-feet, while municipal use is typically tracked in gallons. As an example, in a dry year the city of Lincoln delivers 14 billion gallons of water to its customers, which is about 8.7 inches (annually) for the area served by the municipal water system; 14 billion gallons is equivalent to 43,000 acre-feet. In addition, about 80% of the water use in Lincoln is returned through the wastewater system as treated effluent. Some of this water is a direct return of the potable water supply, and some portion is extraneous water from infiltration.

Relatively small individual household water savings can represent significant conservation for municipal systems, given the number of customers. Examples of reduced residential water usage in municipal systems include flow restriction devices on water fixtures, shower heads, sinks and toilets. Nationally, these practices have produced major reductions in water used for municipal systems. Lincoln has decreased per capita water use by 25% since the early 1980s.

Significant reductions have also occurred as a result of increased water efficiencies in manufacturing and industry, municipal water rate structures to discourage wasteful use and target summer turf irrigation, and an overall emphasis and awareness on the value of water from organizations such as AWWA and the Nebraska Water Balance Alliance (NEWBA).

A large portion of peak summer water uses for agricultural producers and municipalities goes to plant and landscape production. Water conservation for agriculture and municipal users requires making use of drought-tolerant plants and metering of water use. Significant improvements in agricultural irrigation efficiencies on crops have also been made as a result of producer awareness and technology. Examples of agricultural water efficiency include a producer's use of soil moisture probes and weather station information in making decisions as to when to irrigate.

Electrical costs in operating a center pivot may typically fall in the $1,500 to $2,000 range per revolution in irrigating a quarter section. Saving that application benefits water levels and costs. Not overwatering may actually enhance crop production and water quality. Nebraska nurseries and the University continue working together in developing water conserving plant materials and options.

A fundamental tool for municipal water conservation is having rate-based delivery of water to customers. Moreover, rate plans where the per unit cost of water increases with increased use have an even higher impact on reducing water use. These rate plans not only recognize that a customer should pay for the amount of water they use, but also for the incremental cost associated with having a supply, treatment and distribution system to deliver water during the high summer demand period as a result of turf and landscape irrigation. The two largest municipalities in Nebraska use this type of increasing water rate structure.

Water quality

Water quality has and will continue to be an important and ever emerging issue for water utilities. While water supply quality has been strictly regulated in the states, people will continue to have impact on water supply quality. Customers' expectations and awareness are ever increasing, especially with events like Flint, Mich., and Des Moines, Iowa. In Nebraska, water supply quality can be influenced by both municipal and agricultural activities.

Municipalities are meeting increasingly stringent water treatment quality requirements for wastewater treatment facilities. Increasingly treated effluent is evaluated as a useful commodity or resource. Examples of the resource nature of treated effluent include landscape irrigation, wastewater plant internal water demands and as a heating-and-cooling source. Also, processed solids from treatment plants may be used to produce methane gas that is converted to electricity. These solids may also be used as an agronomic source of nutrients on farmland.

Rainwater management

Rainwater that falls within communities must have adequate drainage systems and may require monitoring. Land development and construction projects must plan sedimentation and erosion, ensuring that soils are not eroded away from the project site.

Residential development of crop land results in considerably more runoff for a given rain event. The increased hard surface with streets, driveways and roofs may result in as much as 75% more rainwater leaving a development. A common practice is to require developers to provide storage of stormwater as part of their land development plan. Therefore, water quality is better ensured, waterway erosion is minimized and downstream flooding is reduced. To the extent to which this extra water could be considered as an opportunity in a potentially water-short area might change how it is managed.

Working together

Nebraska municipalities are working with local natural resource districts in developing integrated management plans. These plans examine agricultural and municipal water quantity and quality conditions for the district.

How can we better connect in building collaboration on water quality and quantity across all users within Nebraska? The Total Water Solutions looks for opportunities to work with the Nebraska Farmer and interested groups and individuals to further build an understanding and collaboration within our drainage basins.

This article was written by the Total Water Solutions Committee of the Nebraska American Water Works Association. For more information, contact Steve Owen with the TWS at sowen@lincoln.ne.gov .

Source URL: https://www.farmprogress.com/water/understanding-nebraskas-water-supply

2021 NCF-Envirothon Nebraska
Current Issue Study Resources

Key Topic #3: Assessing Environmental Impacts with Data

9. Analyze groundwater data and identify trends.
10. Identify and describe data collection techniques.
11. Identify what types of data are needed to answer different scientific questions.

Study Resources

2020 Nebraska Groundwater Quality Monitoring Report – *Nebraska Department of Environment and Energy, 2020* (Page 57 - 78)

Study Resources begin on the next page! ➡

2020 Nebraska Groundwater Quality Monitoring Report

Prepared Pursuant to Neb. Rev. Stat. §46-1304 (LB329 – 2001)

NEBRASKA

Good Life. Great Resources.

DEPT. OF ENVIRONMENT AND ENERGY

Groundwater Section

November 2020

2020 Nebraska Groundwater Quality Monitoring Report

Introduction

The 2001 Nebraska Legislature passed LB329 (Neb. Rev. Stat. §46-1304) which, in part, directed the Nebraska Department of Environment and Energy (NDEE) to report on groundwater quality monitoring in Nebraska. Reports have been issued annually since December 2001. The text of the statute applicable to this report follows:

"The Department of Environment and Energy shall prepare a report outlining the extent of ground water quality monitoring conducted by natural resources districts during the preceding calendar year. The department shall analyze the data collected for the purpose of determining whether or not ground water quality is degrading or improving and shall present the results to the Natural Resources Committee of the Legislature beginning December 1, 2001, and each year thereafter. The districts shall submit in a timely manner all ground water quality monitoring data collected to the department or its designee. The department shall use the data submitted by the districts in conjunction with all other readily available and compatible data for the purpose of the annual ground water quality trend analysis."

The section following the statute quoted above (§ 46-1305), requires the State's Natural Resources Districts to submit an annual report to the legislature with information on their water quality programs, including financial data. That report has been prepared by the Nebraska Association of Resources Districts and is being issued concurrently with this groundwater quality report.

Groundwater in Nebraska

Groundwater can be defined as water that occurs in the open spaces below the surface of the earth (Figure 1). In Nebraska (as in many places worldwide), useable groundwater occurs in voids or pore spaces in various layers of geologic material such as sand, gravel, silt, sandstone, and limestone. These layers are referred to as aquifers where such geologic units yield sufficient water for human use. In parts of the state, groundwater may be encountered just a few feet below the surface, while in other areas, it may be a few hundred feet underground. This underground water "surface" is usually referred to as the water table, while water which soaks downward through overlying rocks and sediment to the water table is called recharge as shown in Figure 2. The amount of water that can be obtained from a given aquifer may range from a few gallons per minute (which is just enough to supply a typical household) to many hundreds or even thousands of gallons per minute (which is the yield of large irrigation, industrial, or public water supply wells).

Boyd County (Connie McCarthy, Lower Niobrara NRD)

Depth & Velocity of Groundwater

The depth to groundwater plays a very important role in Nebraska's valuable water resource. A shallow well is cheaper to drill, construct, and pump. However, shallow groundwater is more at-risk from impacts from human activities. Surface spills, application of agricultural chemicals, effluent from septic tank leach fields, and other sources of contamination will impact shallow groundwater more quickly than groundwater found at depth. The map in Figure 3 shows the great variation of depth to water across the State.

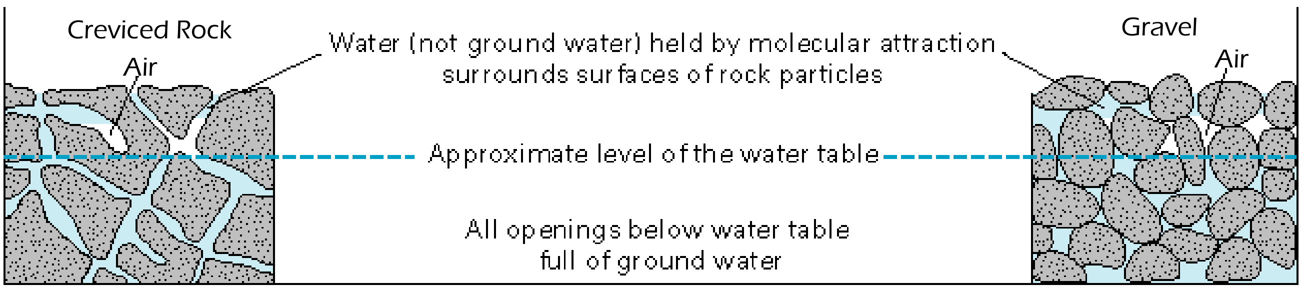


Figure 1. Basic aquifer concepts (U.S. Geological Survey).

In general, groundwater flows very slowly, especially when compared to the flow of water in streams and rivers. Many factors determine the speed of groundwater and most of these factors cannot be measured or observed directly. Basic groundwater features are shown in Figures 1 and 2. The most important geologic characteristics that impact groundwater movement are as follows:

- The sediment in the saturated zone of the aquifer. Groundwater generally flows faster through gravel sediments than clay sediments.
- The 'sorting' of the sediment. Groundwater in aquifers with a mix of clay, sand, and gravel (poor sorting) generally does not flow as fast as in aquifers that are composed of just one sediment, such as gravel (good sorting).
- The 'gradient' of the water table. Groundwater flows from higher elevations toward lower elevations under the force of gravity. In areas of high relief, groundwater flows faster. A typical groundwater gradient in Nebraska is 10 feet of drop over a mile (0.002 ft/ft).
- Well pumping influences. In areas of the State with numerous high capacity wells (mainly irrigation wells), groundwater velocity and direction can be changed seasonally as water is pumped.

Ultimately, groundwater scientists have determined that groundwater in Nebraska can flow as fast as one to two feet per day in areas like the Platte River valley and as slow as one to two inches per year in areas like the Pine Ridge in northwest Nebraska or the glacially deposited sediments in southeast Nebraska.

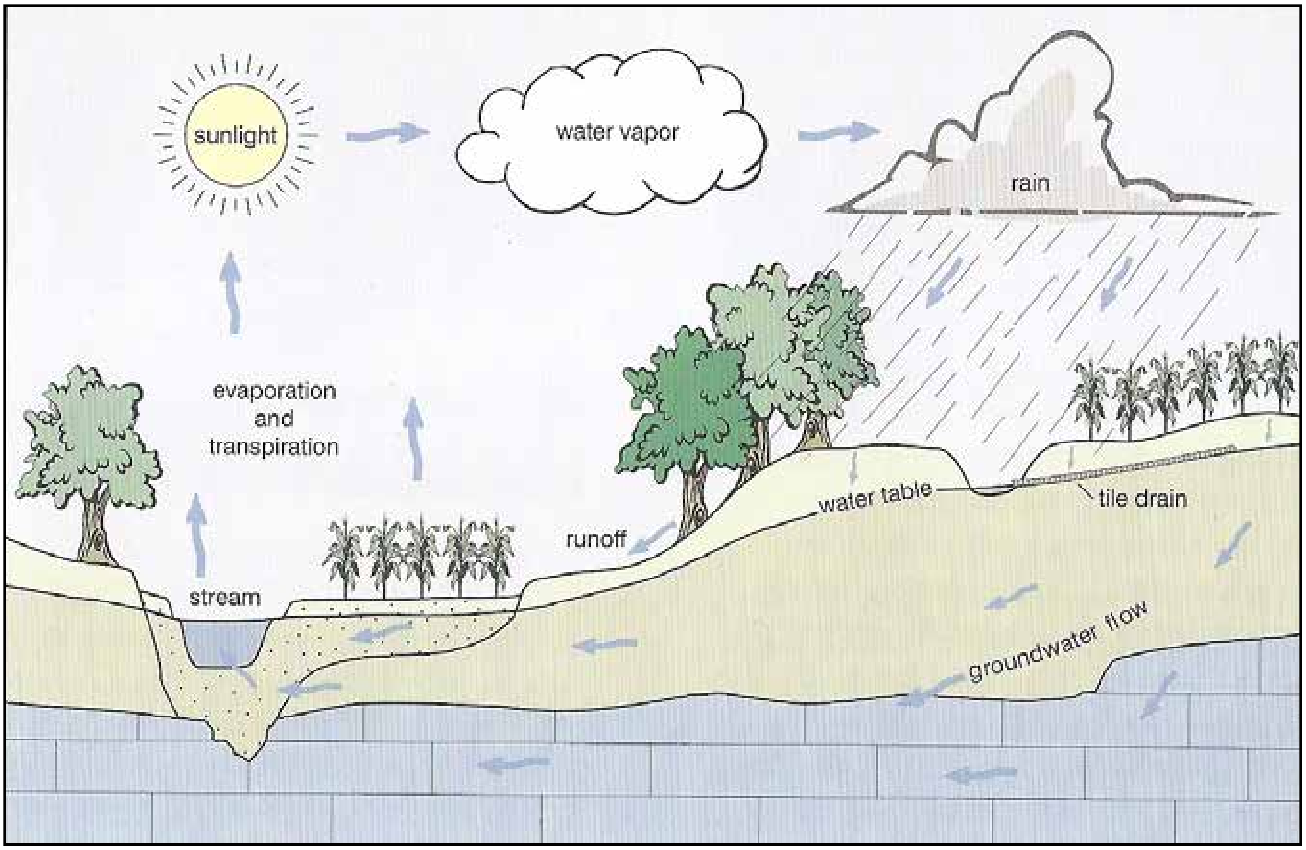


Figure 2. Generalized hydrologic cycle. (Prior, 2003).

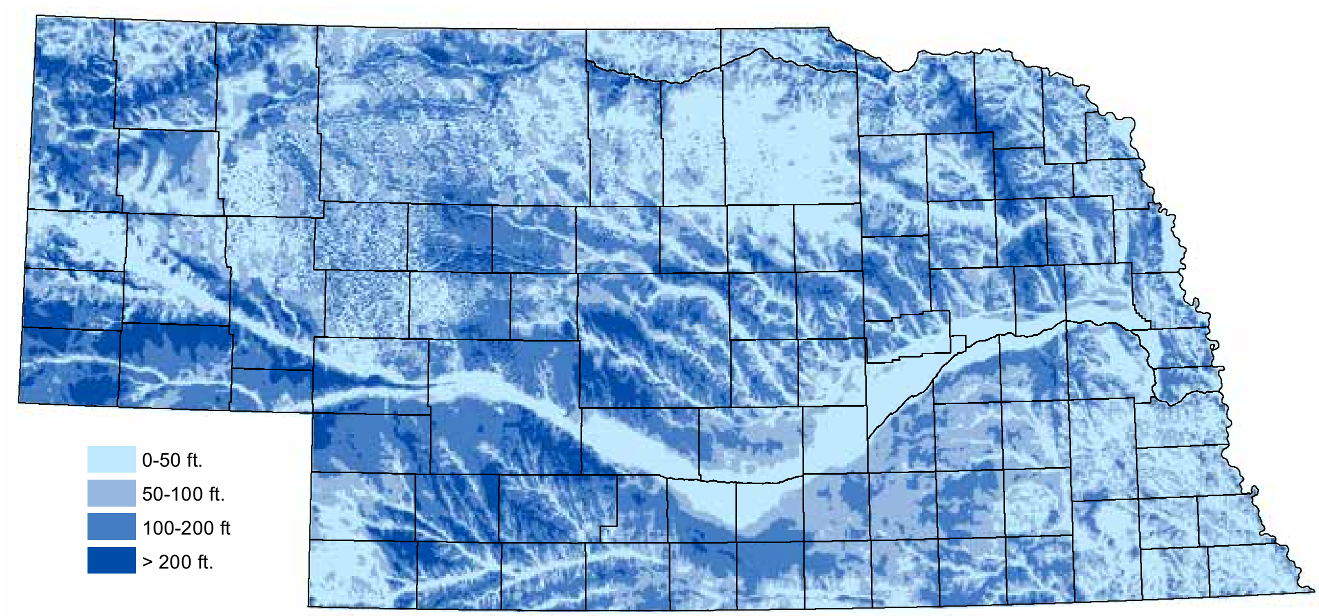


Figure 3. Generalized depth to groundwater.
(Source: University of Nebraska, Conservation and Survey Division, 1998)

Geology and Groundwater

Nebraska has been "underwater" most of its history. Ancient seas deposited multiple layers of marine sediments that eventually formed sandstone, shale, and limestone. These geologic units are now considered "bedrock" and underlie the entire State. Limited fresh water supplies can be found in this bedrock mainly in the eastern portion of the State. After the seas retreated, huge river systems deposited sand and gravel eroded from mountain building to the west to form groundwater bearing formations such as the lower Chadron, Ogallala (Figures 4 and 5) and Broadwater. Next, the combination of erosion (statewide) and glaciation in the east introduced new material that was deposited by wind, water, and ice to form the remainder of the High Plains Aquifer (Figure 4 and 5).

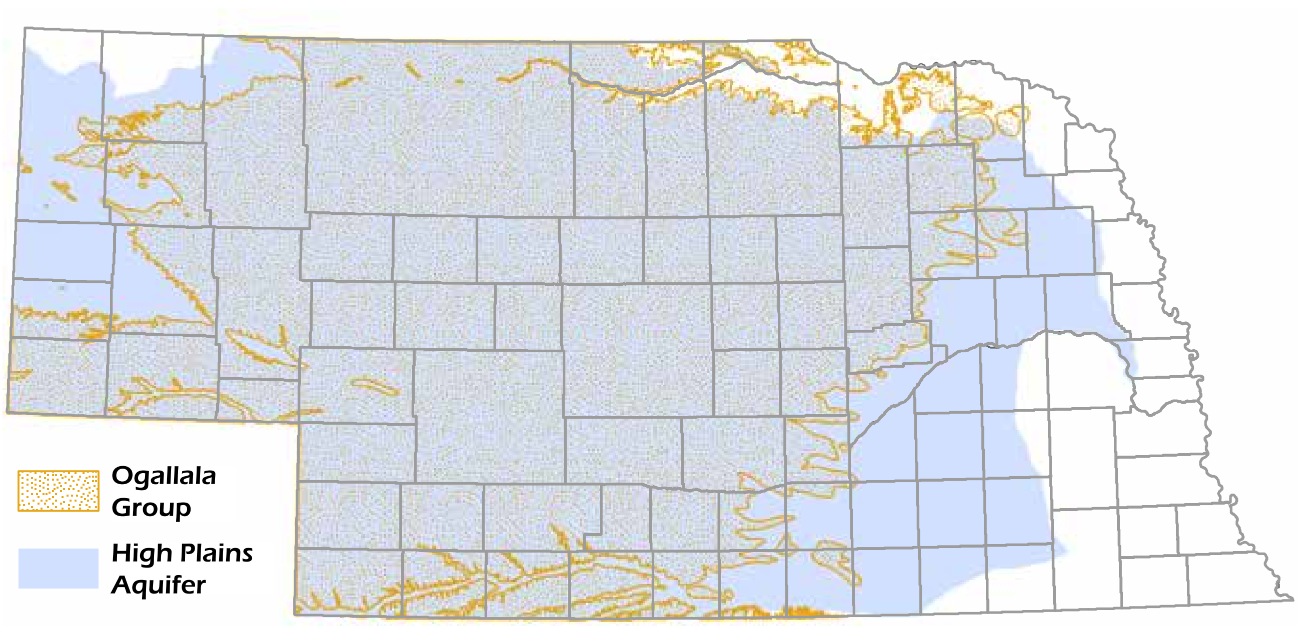


Figure 4. Map of the High Plains aquifer identifying the Ogallala Group. (Source: University of NE, Conservation and Survey Division, 2013)

The High Plains Aquifer is a conglomeration of many separate groundwater bearing formations such as the Brule, Arikaree, Ogallala, Broadwater, and many more recent unnamed deposits (including the Sand Hills). Many of the unnamed deposits are found mainly within the stream valleys (recent or ancient) and are a common source of groundwater (Figure 6, left pane). No single formation completely covers the entire state. However, when these numerous formations and deposits are combined, they form the High Plains Aquifer, covering almost 90% of Nebraska.

There are parts of eastern Nebraska where the High Plains Aquifer is not present. These areas rely heavily on groundwater from buried ancient river channels (paleovalleys) or recent alluvial valleys (Missouri, Platte, and Nemaha Rivers) (Figure 6, right pane).

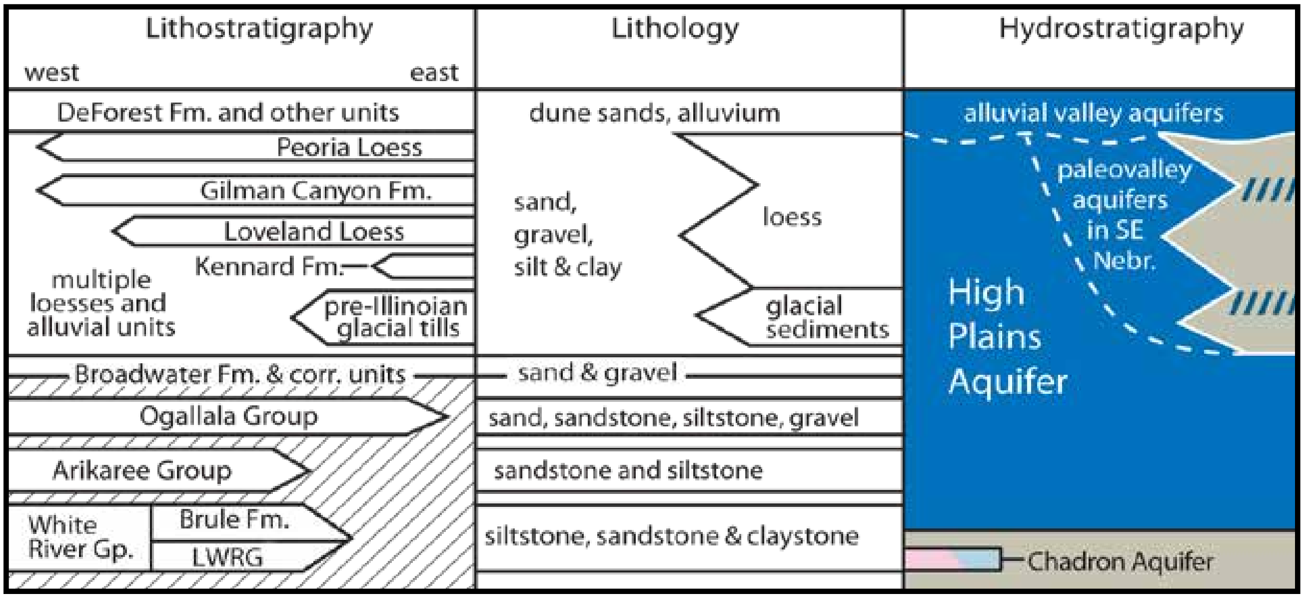


Figure 5. Excerpts from the generalized geologic and hydrostratigraphic framework of Nebraska. (Source: University of Nebraska, Conservation and Survey Division, 2013)

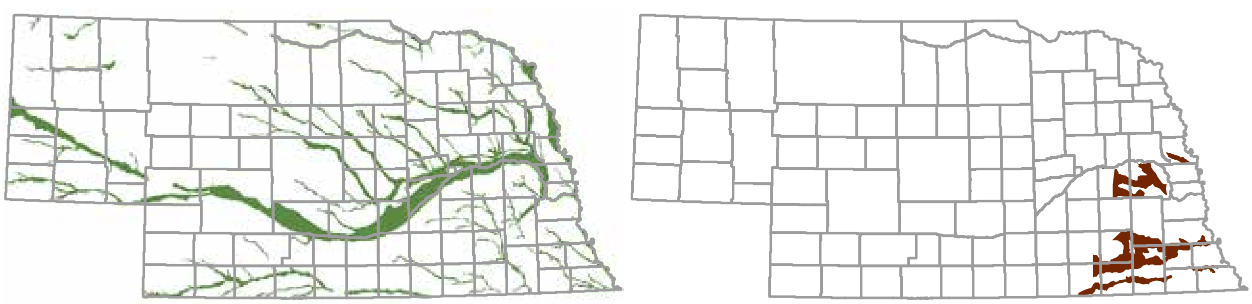
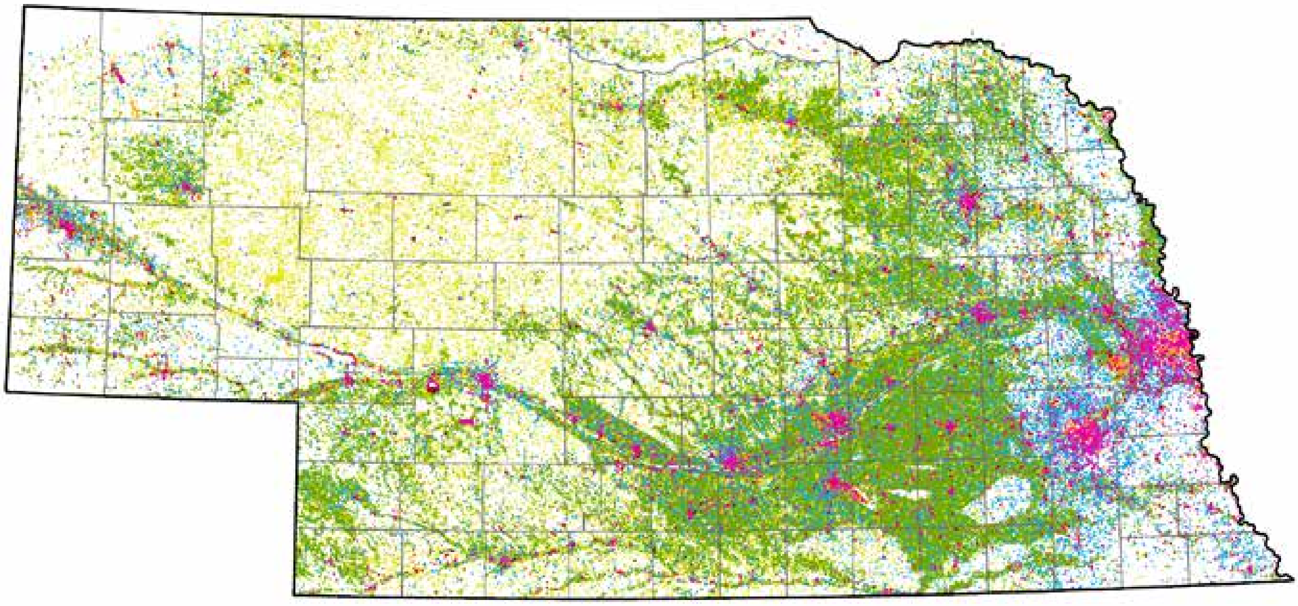


Figure 6. Map of the valleys topographic region (left) and paleovalley aquifers (right). (Source: University of Nebraska, Conservation and Survey Division, 2013)

Importance of Groundwater

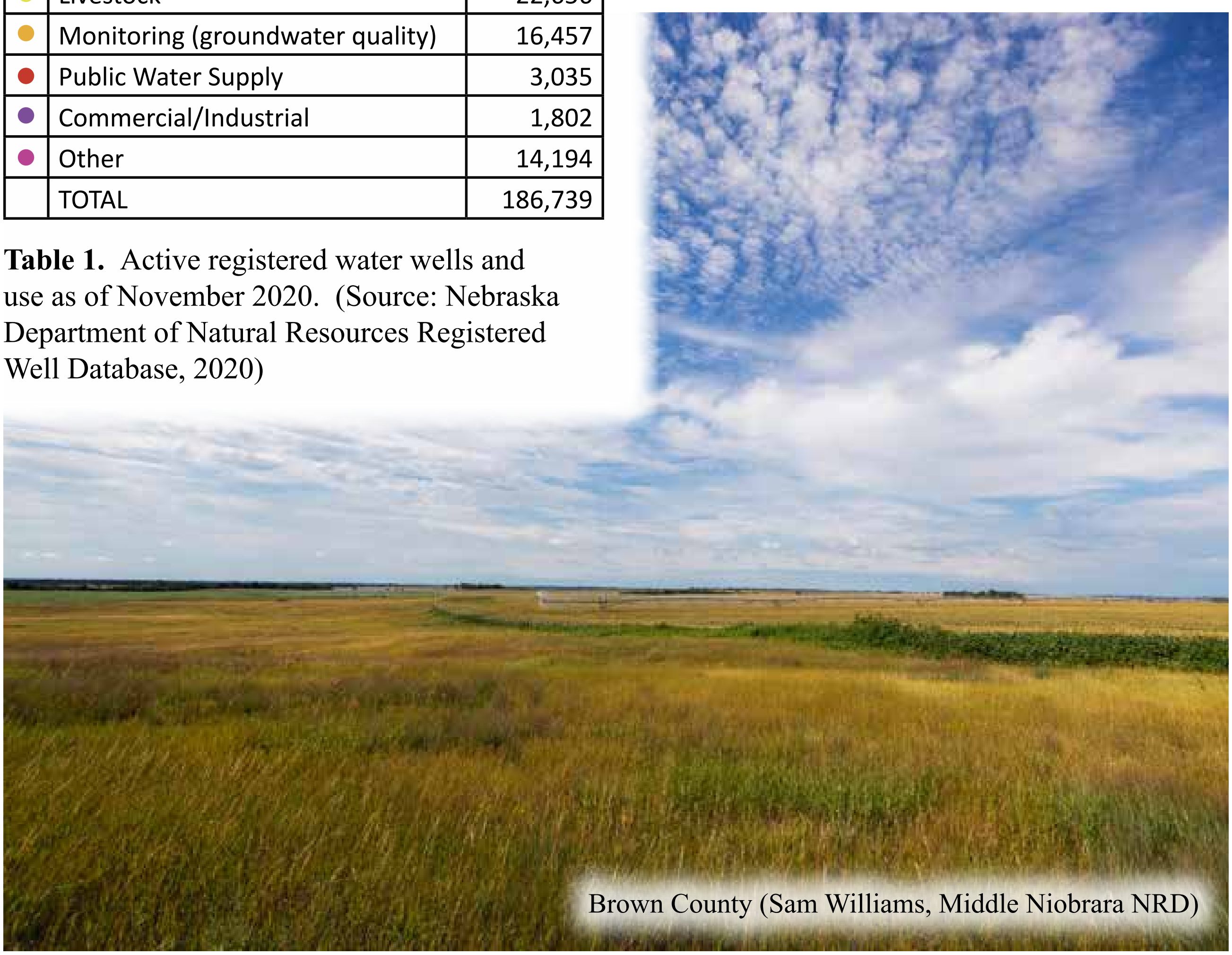
Nebraska is one of the most groundwater-rich states in the United States. Approximately 88% of the state's residents rely on groundwater as their source of drinking water. If the public water supply for the Omaha metropolitan area (which gets about a third of its water supply from the Missouri River) isn't counted, this rises to nearly 99%. Essentially all of the rural residents of the state use groundwater for their domestic supply. Not only does Nebraska depend on groundwater for its drinking water supply, the state's agricultural industry utilizes vast amounts of groundwater to irrigate crops and water livestock. Nebraska experiences variable amounts of precipitation throughout the year, so irrigation is used, where possible, to ensure adequate amounts of moisture for raising such crops as corn, soybeans, alfalfa, and edible beans. As of November 2020, the Nebraska Department of Natural Resources (NeDNR) listed 96,263 active irrigation wells and 32,332 active domestic wells registered in the state. Domestic wells were not required to be registered with the state prior to September 1993, therefore thousands of domestic wells exist that are not registered with the NeDNR. Figures 7 and 8 and information shown in Table 1 help illustrate this.



	Water Use	Active
●	Irrigation	96,263
●	Domestic	32,332
●	Livestock	22,656
●	Monitoring (groundwater quality)	16,457
●	Public Water Supply	3,035
●	Commercial/Industrial	1,802
●	Other	14,194
	TOTAL	186,739

Table 1. Active registered water wells and use as of November 2020. (Source: Nebraska Department of Natural Resources Registered Well Database, 2020)

Figure 7. Active registered water wells as of November 2020. (Source: Nebraska Department of Natural Resources Registered Well Database, 2020)



Brown County (Sam Williams, Middle Niobrara NRD)

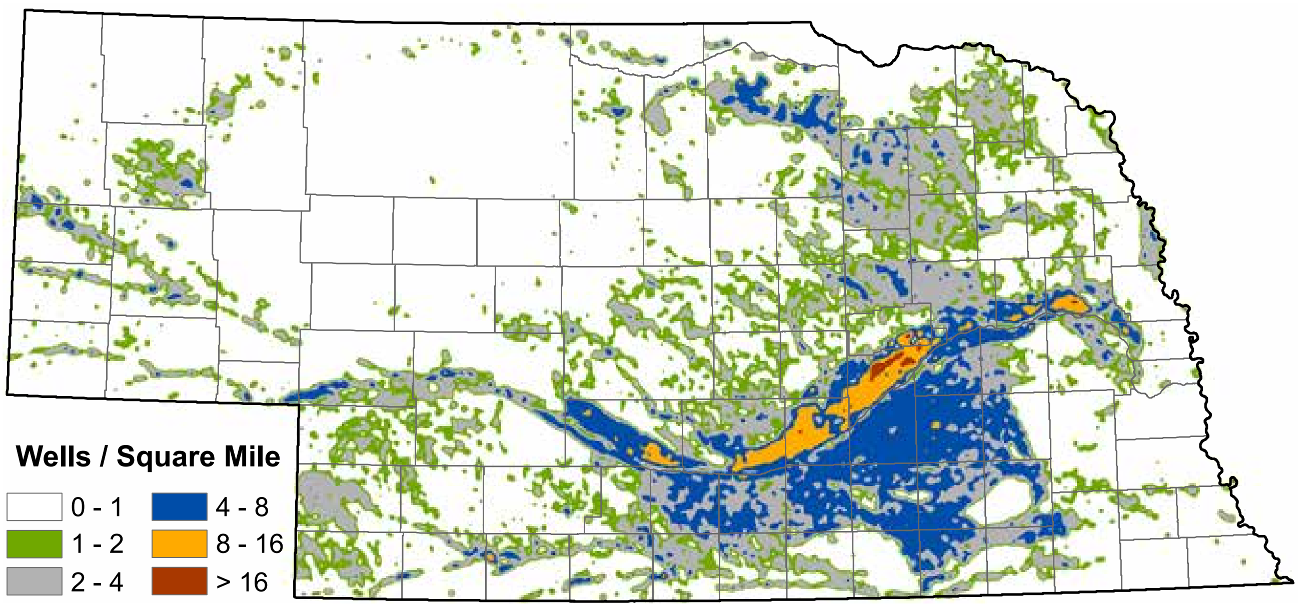


Figure 8. Density of active registered irrigation wells as of November 2013. (Source: Nebraska Department of Natural Resources Registered Well Database, 2013)

Groundwater Monitoring

The previous information shows that groundwater is vital to the well-being of all Nebraskans. Fortunately, our state has a long tradition of progressive action in monitoring, managing, and protecting this most precious resource. Many entities perform monitoring of groundwater for a variety of purposes.

Those entities include:

- Natural Resources Districts (23)
- Nebraska Department of Agriculture
- Nebraska Department of Environmental Quality
- Nebraska Department of Health and Human Services
- Public Water Suppliers
- University of Nebraska-Lincoln
- United States Geological Survey

Groundwater monitoring performed by these organizations meets a variety of needs, and therefore is not always directly comparable. For instance, the state's 23 Natural Resources Districts (NRDs) perform groundwater monitoring primarily to address contaminants over which they have some authority; mainly nitrates and agricultural chemicals. In contrast, the state's 1340 public water suppliers monitor groundwater for a large number of possible pollutants which could impact human health. These include basic field parameters (pH, conductivity, and temperature), agricultural compounds, and industrial chemicals. Not only are these samples analyzed for many different parameters, the methods used for sampling and analysis vary as well.

Kyle Temple sampling, Cherry County (Sam Williams, Middle Niobrara NRD)

Partly in response to this situation, the Nebraska Departments of Agriculture (NDA) and Environmental Quality and the University of Nebraska - Lincoln (UNL) began a project in 1996 to develop a centralized data repository for groundwater quality information that would allow comparison of data obtained at different times and for different purposes. The result of this project is the Quality-Assessed Agrichemical Contaminant Database for Nebraska Groundwater (referred to as the Database in this publication). The Database brings together groundwater data from different sources and provides public access to this data.

The Database serves two primary functions. First, it provides to the public the results of groundwater monitoring for agricultural compounds in Nebraska as performed by a variety of entities. At present, agricultural contaminants (mainly nitrate and pesticides) are the focus of the Database because of their widespread use, and also because historical data suggests that these compounds pose the greatest threat to the quality of groundwater across Nebraska. Second, the Database provides an indicator of the methodologies that were used in sampling and analysis for each of the results. UNL staff examine the methods used for sampling and analysis to assign a quality "flag" consisting of a number from 1 to 5 to each of the sample results. The flag depends upon the amount and type of quality assurance/quality control (QA/QC) that was identified in obtaining each of the results. The higher the "flag" number, the better the QA/QC, and the higher the confidence in that particular result.

During the past several years, UNL staff have worked to establish contact with all the entities performing groundwater monitoring of agricultural chemicals (nitrate and pesticides) in Nebraska. Groundwater data is submitted to UNL by these entities each year, where it is assigned a quality "flag" and entered into the Database. The updated information is then forwarded to the NeDNR, which places the data on its website (http://dnr.nebraska.gov/ or more specifically http://clearinghouse.nebraska.gov). The Database can be accessed and searched at NeDNR's website for numerous subsets of data, sorted by county, type of well, Natural Resources District, etc. (refer to Appendix C).

Groundwater Quality Data

Groundwater quality data presented in the remainder of this report reflect the data present in the Database as of October 1, 2020. The dates for these data range from mid-1974 to 2019. Groundwater results from some of the agencies working in Nebraska have not been submitted to UNL to be entered into the Database, but NDEE is confident that the information presented represents the majority of sample results available. Table 2 lists each agency producing groundwater quality data for this report.

Agency	
Central Platte NRD	Nebraska Department of Environment and Energy
Hastings Utilities	Nebraska Department of Health and Human Services
Lewis & Clark NRD	Nemaha NRD
Lincoln-Lancaster County Health Department	North Platte NRD
Little Blue NRD	Papio-Missouri River NRD
Lower Big Blue NRD	South Platte NRD
Lower Elkhorn NRD	Tri-Basin NRD
Lower Loup NRD	Twin Platte NRD
Lower Niobrara NRD	U.S. Geological Survey
Lower Platte North NRD	University of Nebraska
Lower Platte South NRD	Upper Big Blue NRD
Lower Republican NRD	Upper Elkhorn NRD
Middle Niobrara NRD	Upper Loup NRD
Middle Republican NRD	Upper Niobrara-White NRD
Nebraska Department of Agriculture	Upper Republican NRD

Table 2. Various agencies providing groundwater analyses in Nebraska to be used in the Database. (Source: Quality-Assessed Agrichemical Database for Nebraska Groundwater, 2019)

Types of Wells Sampled

The data summarized in Table 3 represent the quantity of water samples analyzed from a variety of well types. Historically, most wells that have been sampled are irrigation or domestic supply wells. Irrigation and domestic wells are constructed to yield adequate supplies of water, not to provide water quality samples (longer screens across large portions of the aquifer). However, in recent years, monitoring agencies have been installing increasing numbers of dedicated groundwater monitoring wells designed and located specifically to produce samples (shorter screens in distinct portions of the aquifer). By utilizing such varied sources, groundwater data from a range of geologic conditions can be obtained.

Well Type	Number of Analyses
Monitoring	260,065
Irrigation	125,776
Domestic	77,711
Public Water Supply	41,809
Commercial/Industrial	2,582
Livestock	2,170
Heat Pump (GW Source)	8
Total	510,121

Table 3. Total number of groundwater analyses by well type. (Source: Quality-Assessed Agrichemical Database for Nebraska Groundwater, 2020)

Steffan Silva (left) and Kaleb Puncochar (right) sampling, Cherry County (Sam Williams, Middle Niobrara NRD).

Monitoring Parameters

As already mentioned, numerous entities across Nebraska have been monitoring groundwater quality for many years, for a wide variety of possible contaminants. However, much of this monitoring has been for area-specific (part of an NRD), or at most, regional purposes (entire NRDs), and it has been difficult to assess data on a statewide basis for more than a short period of time. Creation of the Database has provided an important tool for such analysis. Appendix A lists the compounds for which groundwater has been sampled and analyzed since 1974. Table 4 lists the compounds from Appendix A for which at least 50 samples exceeded the **Reporting Limit***. This gives an indication of which compounds are most commonly detected in Nebraska's groundwater. Only 12 of the 241 compounds sampled met the criteria.

**__Reporting Limit__ refers to the concentration a laboratory has indicated their analysis method can be validated. For example, if a contaminant were at a level below the reporting limit, the laboratory's analysis method could not detect it and the concentration would be reported as "below the reporting limit".*

Throughout this report, the number of sample analyses for any one contaminant refers only to the number of analyses as reported in the Quality-Assessed Agrichemical Contaminant Database for Nebraska Groundwater, and not for the total number of analyses for that contaminant measured in the state. As already mentioned, data which are currently in the process of being submitted to UNL to be entered into the database are not reflected in this report. In addition, there are undoubtedly samples for various contaminants taken by entities other than the agencies referred to in this report (for instance, private consulting firms, or other programs within some of the reporting agencies), which are not included in the Database.

The table in Appendix A shows a wide variety of compounds for which groundwater samples have been analyzed, all of which are used in agricultural production. As mentioned previously, there is also an effort in monitoring groundwater for other, non-agricultural contaminants. Examples of such compounds include petroleum products and additives, industrial chemicals, hazardous wastes, contaminants associated with landfills and other waste disposal sites, and effluent from wastewater treatment facilities. Such issues are beyond the scope of §46-1304, and information about such monitoring data is not contained in any centralized database at present.

Compound	Total Samples Collected	Number of Samples that exceed the Reporting Limit	Percent of Samples that exceed the Reporting Limit
nitrate-N	130,713	120,127	91.90%
alachlor ethane sulfonic acid	136	71	52.21%
deethylatrazine	5,970	1,572	26.33%
atrazine	10,904	2,295	21.05%
metolachlor	9,974	1,065	10.68%
deisopropylatrazine	5,281	383	7.25%
cyanazine	10,436	422	4.04%
alachlor	10,473	305	2.91%
propazine	5,863	119	2.03%
simazine	6,445	125	1.94%
prometon	6,217	55	0.88%
metribuzin	10,330	59	0.57%

Table 4. Compounds more commonly found in wells monitored in Nebraska. More than 50 samples analyzed for each compound were greater than the reporting limit. (Source: Quality-Assessed Agrichemical Database for Nebraska Groundwater, 2020)

Discussion and Analysis

The information presented previously in this report shows the amount of effort that has gone into monitoring groundwater quality in Nebraska since the mid-1970s, especially in areas that are heavily farmed. A comparison of Appendix A and Table 4 shows that only a small percentage of parameters analyzed have been detected above the Reporting Limit (12 of 241). However, these same data show that several contaminants have been detected in numerous samples throughout the monitoring period. Levels and distribution of these compounds are issues of concern to Nebraskans.

As Table 4 shows, the compounds that have been detected above the Reporting Limit more than 50 times throughout the monitoring period include nitrate-nitrogen (nitrate-N), atrazine, metolachlor, and degradation products of atrazine, alachlor, and metolachlor. Nitrate is a form of nitrogen common in human and animal waste, plant residue, and commercial fertilizers. Atrazine, alachlor, and metolachlor are herbicides used for weed control in crops such as corn and sorghum while deethylatrazine, deisopropylatrazine, alachlor ethane sulfonic acid are degradation products or metabolites of atrazine and alachlor. Cyanazine is a trizine herbicide similar to atrazine, but its use has been discontinued. In addition to atrazine and metolachor, the Nebraska Department of Agriculture identified two other priority compounds (alachlor and simazine) for development of pesticide State Management Plans, following guidance produced by the U.S. Environmental Protection Agency.

Cover Crops, Cedar County (Becky Ravenkamp, Lewis & Clark NRD)

Nebraska Sandhills, Arthur County (Sidney Norris, Twin Platte NRD)

Occurrence of elevated levels of nitrate and herbicides in groundwater has been associated with the practice of irrigated agriculture, especially corn production (Exner and Spalding 1990). The Natural Resources Districts have instituted Groundwater Management Areas (GWMAs) over all or parts of nearly all of the 23 districts based on NRD and NDEQ groundwater sampling. The NRDs' implementation of these GWMAs indicates a concern and recognition of nonpoint source groundwater contamination. Additionally, NDEQ's Groundwater Management Area program has completed 20 studies across the state since 1988, identifying areas of nonpoint source contamination mainly from the widespread application of commercial fertilizer and animal waste.

The State of Nebraska has a geographic area of over 77,000 square miles. Accurately characterizing the quality of Nebraska's groundwater in a complex aquifer system has always been difficult. The acquisition of more data is increasing the validity of a trend analysis. However, it is still common practice to sample the "problem areas", which skews the data and makes it very difficult to show the areas in Nebraska where the contaminant levels are decreasing through better management and farming practices.

Another difficulty is obtaining the resources and the logistics of collecting groundwater samples. There are over 186,000 active registered wells in Nebraska and there have been only enough resources to collect samples from 3,600 (1.9%) to 5,400 (2.9%) annually (since 2000). Also, not all samples collected are evenly distributed throughout the state (Appendix B).

Nitrate Trends Utilizing the Database

Nitrate monitoring data have been collected from wells for many years, and the purpose of collection has varied by the agency or organization performing the work. For instance, public water supply operators sample their drinking water wells to ensure that the public is offered good quality water through the municipal system. NRDs have been tasked by the Nebraska legislature to manage groundwater quality and quantity in order to preserve its usefulness into the future. Additionally, shallow groundwater may have different natural chemical characteristics than deep groundwater and is more easily and quickly affected by activities on the surface than deeper groundwater.

The Database makes accessing and reviewing data relatively simple. One must use caution, though, when utilizing the vast Database because differences in wells may result in incorrect assumptions. Data may be collected from:

- deep wells (bottom of the aquifer) vs. shallow wells (top of the aquifer) or
- irrigation wells (potentially screened across multiple aquifers) vs. dedicated monitoring wells (with perhaps only 10 feet of screen) or
- wells located near potential sources of contamination such as septic tanks or past chemical spills vs. wells located in pristine rangeland or
- wells used for measuring water levels (observation) vs. wells used for water quality.

Several different methods have been used to present and interpret the nitrate data collected since the early 70s. The median (center of the data set) of the data is presented in tables (Figures 9 and 10) for the entire data set (1974-2019) and for the years with consistent sample events and locations (2000-2019). Simple trends are also shown on Figures 9 and 10.


Pine Glen Wildlife Management Area, Brown County (Sam Williams, Middle Niobrara NRD)

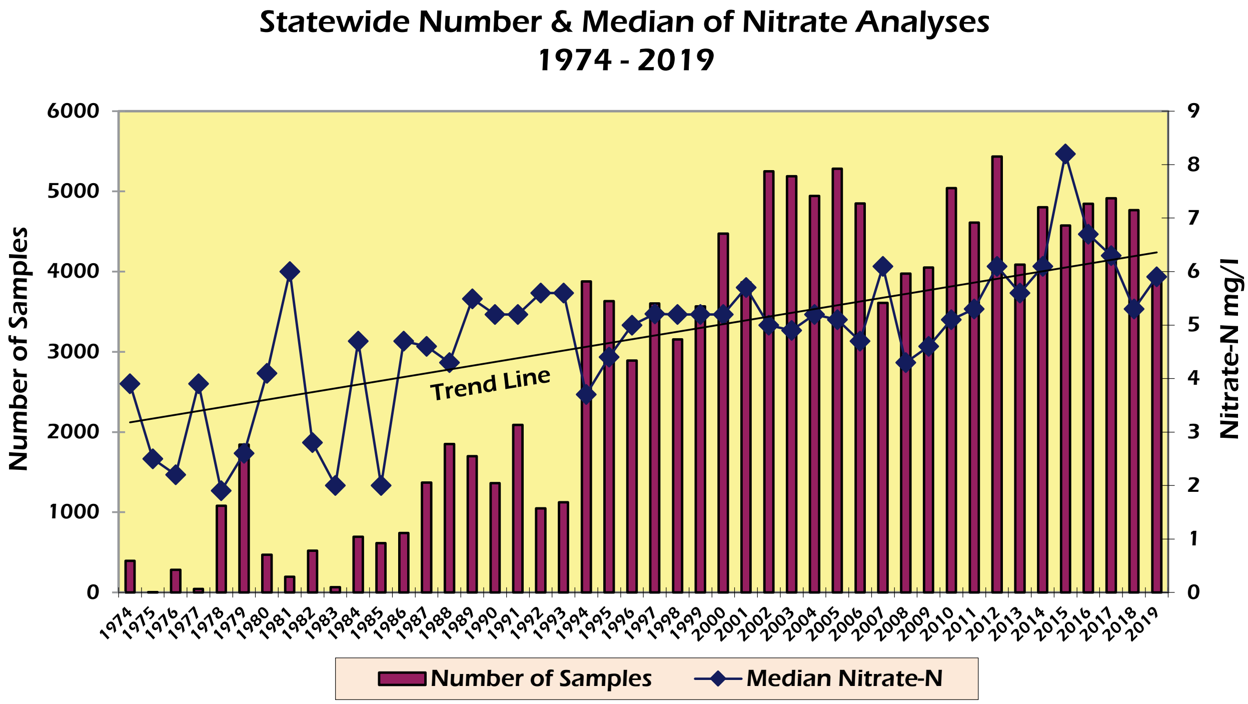


Figure 9. All 130,713 analyses and median nitrate-nitrogen levels for Nebraska, 1974-2019. (Source: Quality-Assessed Agrichemical Database for Nebraska Groundwater, 2020)

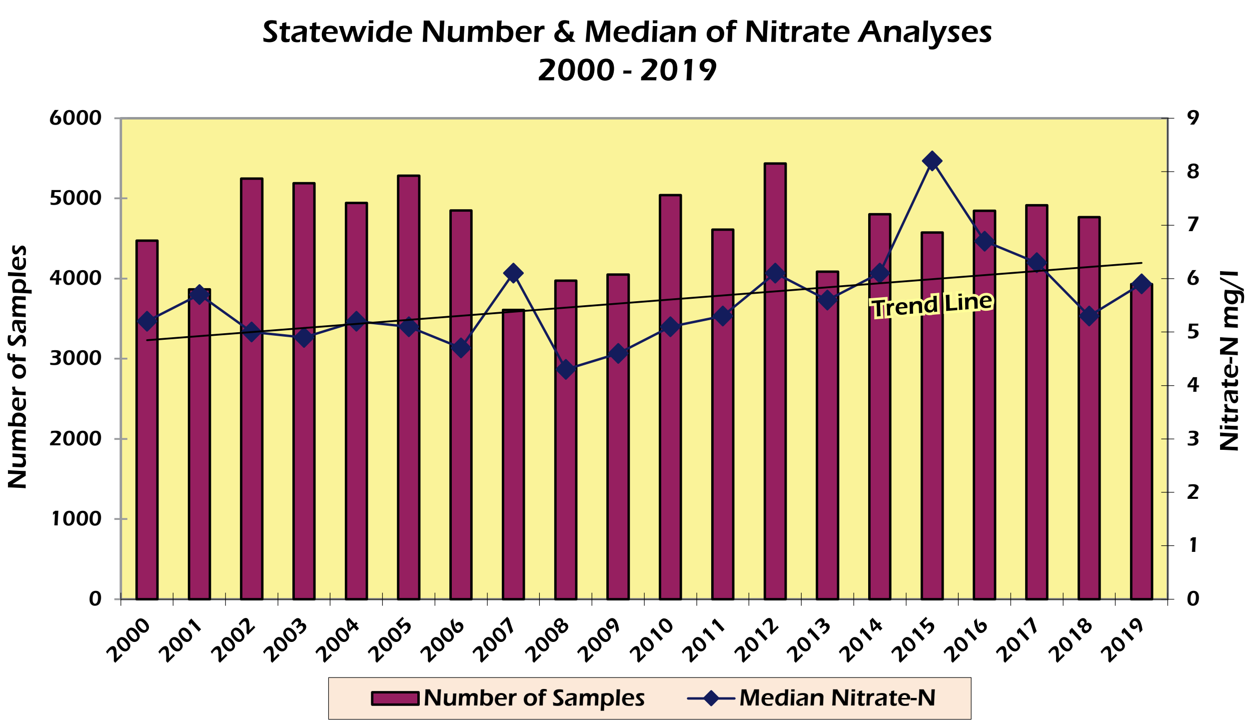


Figure 10. All 92,498 analyses and median nitrate-nitrogen levels for Nebraska, 2000-2019. (Source: Quality-Assessed Agrichemical Database for Nebraska Groundwater, 2020)

Most Recent Nitrate-N Concentrations

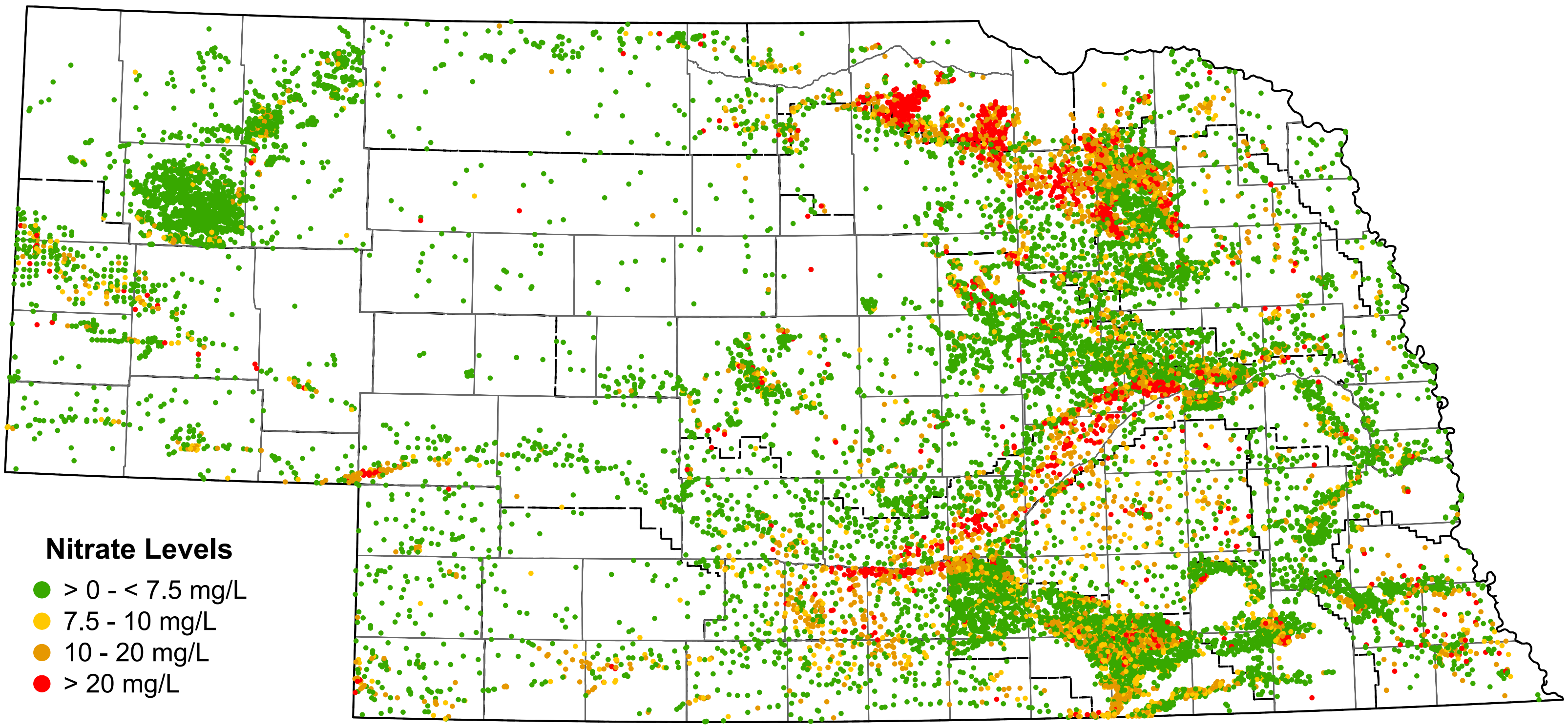


Figure 11. Most recent recorded Nitrate-N concentrations of 18,247 wells from 2000-2019. (Source: Quality-Assessed Agrichemical Database for Nebraska Groundwater, 2020) *Empty areas indicate no data reported, not the absence of nitrate in groundwater.*

Nitrate-N Concentrations of Wells Sampled in 2018

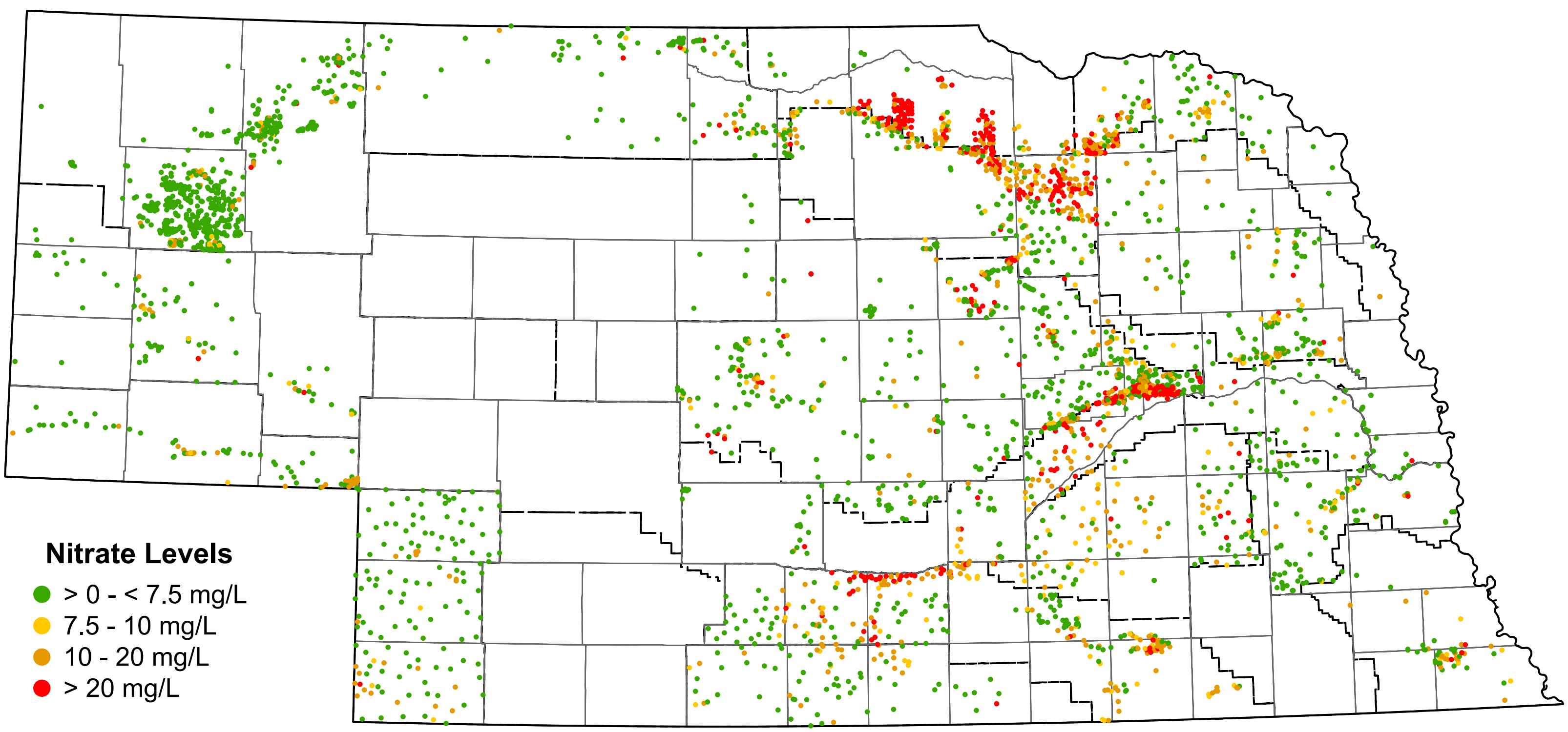


Figure 12. Most recent recorded Nitrate-N concentrations of 3,797 wells sampled in 2019. (Source: Quality-Assessed Agrichemical Database for Nebraska Groundwater, 2020)
Empty areas indicate no data reported, not the absence of nitrate in groundwater.

Most Recent Nitrate-N Concentration by Township

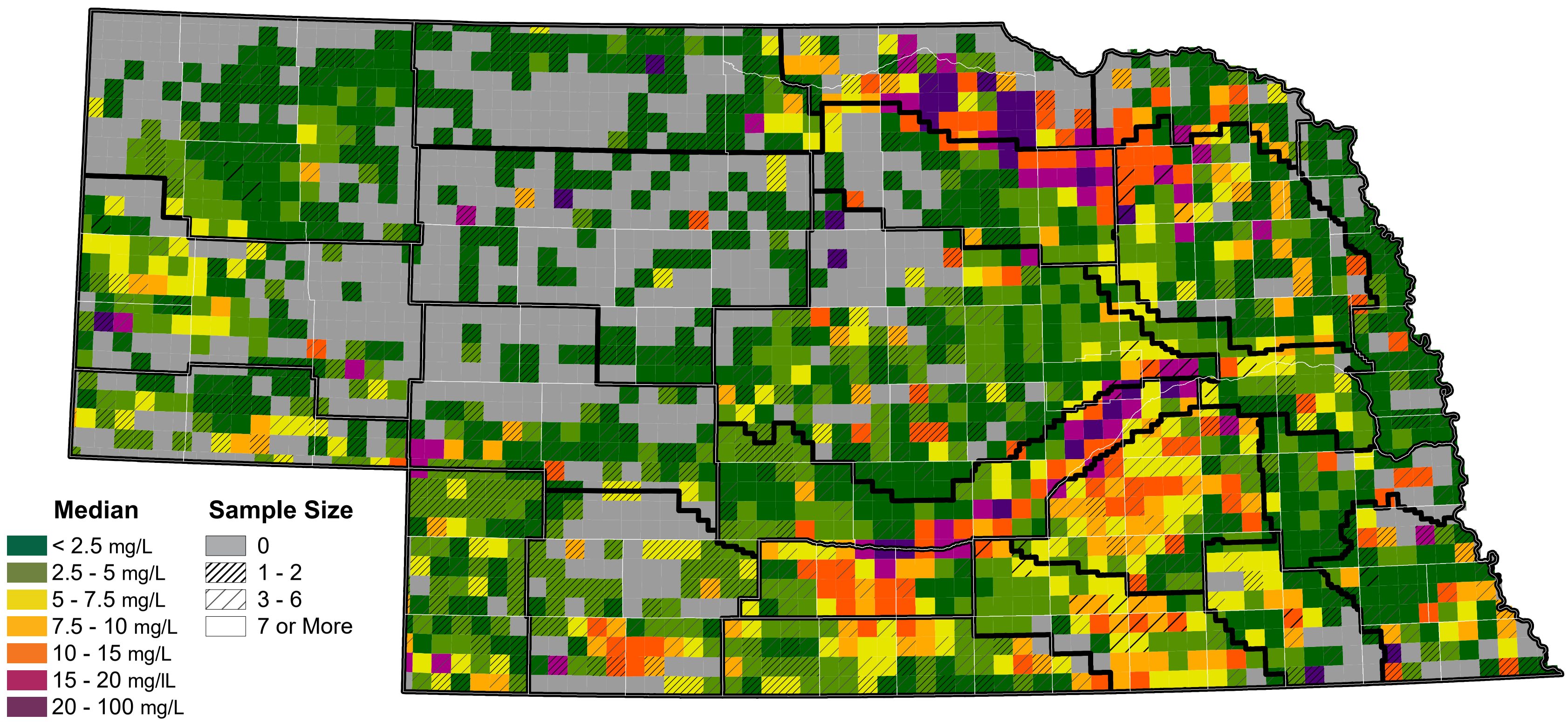


Figure 13. Median of the most recent Nitrate-N concentration by township of 18,247 wells from 2000-2019. (Source: Quality-Assessed Agrichemical Database for Nebraska Groundwater, 2012)
Gray areas indicate no data reported, not the absence of nitrate in groundwater.

Birchwood Creek, Lincoln County (Sidney Norris, Twin Platte NRD)

Maps are used to help "see" the data and were generated using the entire Database data set in an attempt to show "current" statewide groundwater quality (see Figure 11) from the most recent time the well had been sampled (aiming to show the most current water quality at that location). A township (36 square miles) map was also developed again in this report using the same data from Figure 12. The most recent sample for each well analyzed since 2000 was used to calculate the median value of nitrate for each township (Figure 13). One of the best ways to use the entire data set is to refer to the maps found in Appendix B, which show the results of sampling done each year, and compare the monitoring data over time. These maps give the reader an idea of where there are reoccurring "problem" areas. For example, the reader is directed to look at the samples collected over the years in parts of Phelps, Kearney, Merrick, Nance, Platte, Holt, and Antelope Counties as shown in Figures 11, 12, and 13. These are all locations with sandy soils, shallow groundwater, and high nitrate.

In 2002, the NRDs and NDEQ began discussing a Statewide Monitoring Network (a defined subset of wells from the Database identified as the Network) with regularly sampled wells to help better assess Nebraska's groundwater quality and better develop and analyze trends for this report. Unfortunately, over the last several years, resources were not always available to the NRDs or new problem areas were identified, and not all of the wells were sampled. Starting in 2016, the NDEQ and the NRDs began working on reviewing the Network based not only on location, but in which aquifer they are screened. Within the last year, the NDEE has been working with the USGS and their National Groundwater Monitoring Network. This network has over 500 wells that have known aquifer parameters and consistent sampling. The USGS network will take the place of the Statewide Monitoring Network.

Nitrate in Public Water Supplies

In an effort to protect the drinking water quality of America's public water systems, the federal Safe Drinking Water Act authorizes the EPA to set national drinking water standards. These standards include maximum contaminant levels based on health effects due to exposure of both naturally occurring and man-made contaminants. When a Public Water System (PWS) exceeds the Maximum Contaminant Level (MCL) for a regulated contaminant, Public Notification to the customers of the system is mandatory. If exceedances continue, an Administrative Order (AO) will be issued. This AO will mandate that the PWS make changes to their water system to bring the contaminant results consistently below the MCL for that contaminant.

Reverse Osmosis treatment plant to remove nitrate (Seward, NE).

The MCL for nitrate-nitrogen is 10 mg/L, but PWS systems with wells or intakes testing over 5 mg/L may be required to perform quarterly sampling. Of the nearly 550 groundwater based community PWS systems in Nebraska that supply their own water, 108 of those must perform quarterly sampling for nitrate. If a PWS exceeds the nitrate-nitrogen MCL two times in a rolling 9 month period, an AO will be issued. A nitrate AO will mandate that the PWS take steps to bring their nitrate results consistently below the MCL such as drilling a new or deeper well, hooking on to a neighboring water system, blending, or building a water treatment plant. Figure 14 shows the

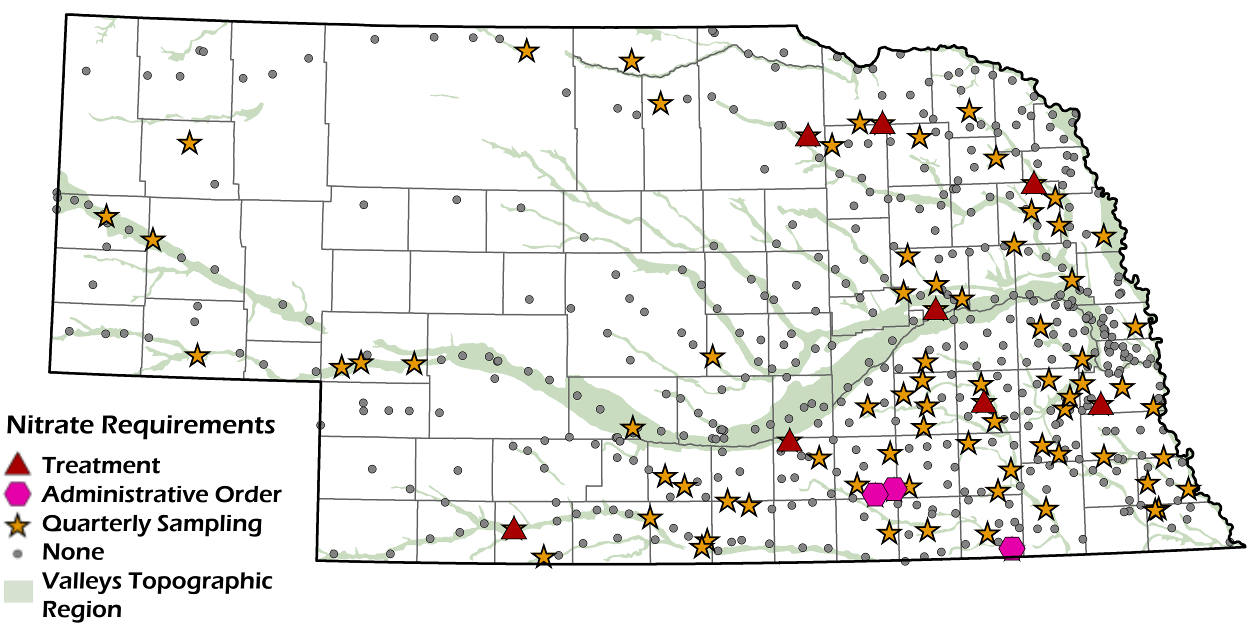


Figure 14. Community public water supply systems with requirements for nitrate. (Source: Nebraska Department of Health & Human Services, November 2020)

location of active community PWS systems that have their own source of water. Colors indicate if there is an administrative order for nitrate, systems required to perform quarterly sampling, and systems treating water because of high levels of nitrate. AOs due to high levels of nitrate do not necessarily fall in the areas of highest nitrate problems, as indicated in Figures 11 and 12 and the figures in Appendix B.

Several recent studies considered the relationship of nitrate leaching into the subsurface and uranium concentrations found in groundwater. Research indicates that natural uranium in the subsurface may be oxidized and mobilized as the nitrate (in many forms) moves through the root zone and eventually to groundwater. Uranium is found naturally in sediment deposited mainly by streams and rivers.

Some public water supply systems treat not only nitrate, but also uranium. The MCL for uranium is 0.030 mg/L. Figure 15 shows the location of active community public water systems with uranium requirements.

Ion Exchange plant to remove uranium (McCook, NE).

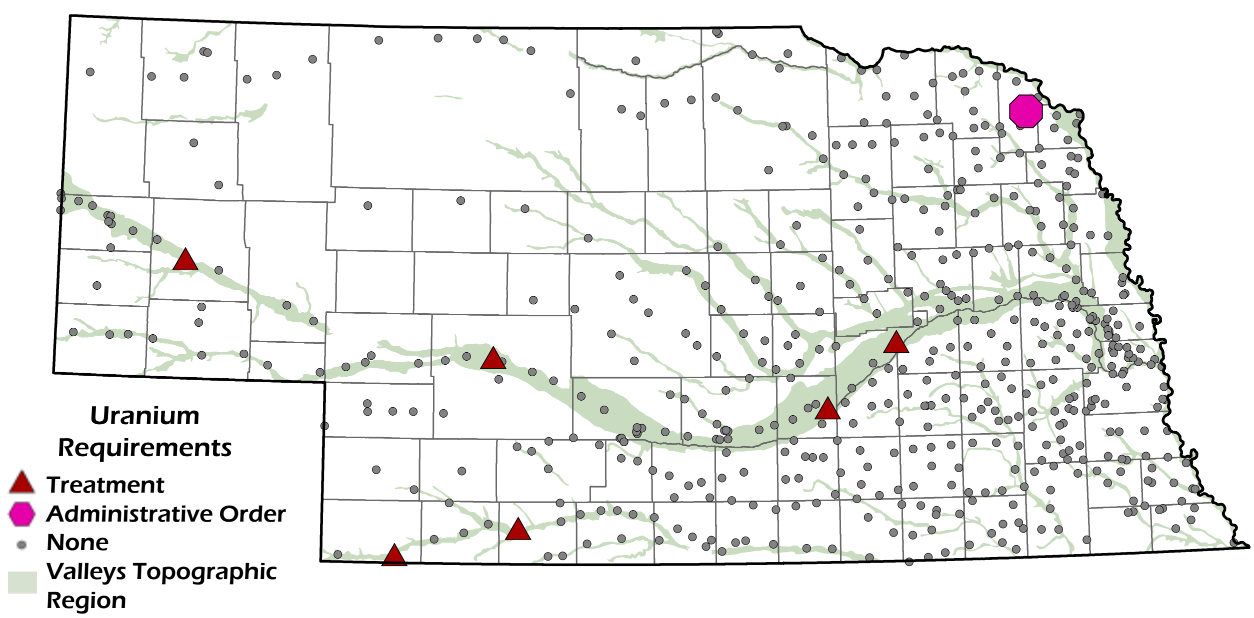


Figure 15. Community public water supply systems with requirements for uranium. (Source: Nebraska Department of Health & Human Services, November 2019)

2021 NCF-Envirothon Nebraska
Current Issue Study Resources

Key Topic #4: Environmental Impacts of Conservation Practices

12. Identify innovative approaches to agriculture conservation and natural resource management.
13. Identify various conservation practices that address natural resources concerns.
14. Apply innovative management techniques to address soil health, water quality and water quantity concerns.

Study Resources

Tri-Basin NRD Eligible Conservation Practices – *Tri-Basin NRD, 2019* (Page 80 - 81)

The Business Case for Conservation – *Illinois Corn Growers Association, 2019* (Page 82 - 89)

Groundwater Quality Management Program – *Central Platte Natural Resources District, 2021* (Page 90 - 95)

<u>Study Resources begin on the next page!</u> ➡

Tri-Basin NRD

The Nebraska Soil and Water Conservation (NSWCP) Act, established in 1977, is administered by the Nebraska Department of Natural Resources. The Act established the Nebraska Soil and Water Conservation Fund, providing state financial assistance to Nebraska landowners for the installation of approved soil and water conservation measures that improve water quality, conserve water, and help control erosion and sedimentation. This program is funded by the Nebraska Unicameral.

The Nebraska Department of Natural Resources (DNR) is responsible for determining eligible practices and establishing operating procedures for NSWCP. DNR allocates funds among the state's 23 Natural Resources Districts and approves payments to landowners. Natural resources districts are responsible for administering the NSWCP program at the local level according to state rules and regulations. The USDA/NRCS provides technical assistance in planning and developing the approved conservation measures. In order to be eligible for funding, cost-share applications must be approved by the NRD board before you start a project. Listed below are the cost-share practices available through Tri-Basin NRD:

Eligible Nebraska Conservation (NC) Practices

NC - 1 Constructing Terrace Systems

NC - 2 Constructing Terrace Underground Outlets

NC - 3 Constructing Water Impoundment Dames

NC - 4 Constructing Grade Stabilization Structures

NC - 5 Constructing Irrigation Tailwater Recovery Pits with or without Underground Return Pipe

NC - 6 Constructing Diversions

NC - 7 Constructing Grasses Waterways

NC - 8 Constructing Water-and-Sediment-Control Basins

NC - 9 Constructing Dugouts for Livestock Water (runoff collection only)

NC - 10 Pasture Planting or Range Seeding (land use conversions)

NC - 11 Critical Area Planting (grass)

NC - 12 Windbreaks

NC - 13 Constructing Underground Return Pipe from Irrigation Tailwater Recovery Pits

NC - 14 Planned Grazing Systems

NC - 16 Windbreak Renovation

NC - 17 Irrigation Water Management

NC - 18 Stream Bank Stabilization

NC - 19 Repair of Practices

NC - 20 Brush Management

Links to related sites:

Nebraska Department of Natural Resources

Nebraska Soil and Water Conservation Program

For more information about NSWCP, contact Carie Lynch at clynch@tribasinnrd.org.

A program of the

Illinois Corn Growers Association

2015–2019 Data Summary

The Business Case for Conservation

Cost-Benefit Analysis of Conservation Practices

P C M

Precision Conservation Management

P C M

Precision Conservation Management

Illinois Corn Growers Association

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Table of Contents

NOTE FOR THE READER: To truly utilize the economic benefit of conservation practices, you must suspend the belief that higher corn yields equal increased profitability. As a farm organization, we believe this quest for higher yields has been "baked" into farmers' psyche for generations. We'd like to challenge readers to consider that obtaining high yields, and the higher input costs that goal often requires, may not be the best economic or conservation model for Illinois farms and Illinois farm families.

What is Precision Conservation Management (PCM)?

PCM is a farmer service program designed to help farmers understand and manage risks associated with adopting new conservation practices with the objective of helping farmers make sound financial decisions.

The program evaluates conservation practices on both their impact to the environment and their impact to family farmer profitability.

Farmers in five key watersheds in Illinois and Kentucky voluntarily participate in the program. Participating farmers can utilize the one-on-one technical assistance to guide them through conservation decisions and to aid in the evaluation of their farm relative to others in the program.

To date, over 325 farmers have enrolled in PCM, representing more than 300,000 acres.

Farmers in the program also have access to Natural Resources Conservation Service (NRCS) Conservation Stewardship Program funds; Environmental Quality Incentive Program funds (CSP & EQIP); and special offers from industry partners only made available for participating PCM farmers.

Local Farms – Corporate Investment

Illinois farmers are partnering with PepsiCo and other large corporations across their supply chain. PCM and PepsiCo have spent two years in partnership, working with participating farmers to reduce CO2 emissions by 8,155 metric tons, equivalent to taking 1,762 cars off the road. The project is part of PepsiCo's efforts to help build a more sustainable food system.

As a global food and beverage company, agriculture makes up the largest portion of PepsiCo's footprint. The company's climate strategy related to agriculture goes hand in hand with their sustainable sourcing goals. Through PepsiCo's Sustainable Farming Program, they promote and support practices that lead to better yields, improved soil health, lower deforestation and higher productivity for farmers, which also leads to GHG emission reductions.

PepsiCo understands that investing in farmers and helping farmers understand the financial and environmental benefits to changing farm management practices is the best way to make positive water quality and climate impacts.

PCM has over 30 contributing partners, including projects with NASA Harvest, National Fish and Wildlife Foundation, Ecosystem Services Market Consortium (ESMC), Soil Health Partnership (SHP), Field to Market® and The Nature Conservancy (TNC).

ROI From Relationships

"I agree with the philosophy that sustainability is not a result. It is a continual process. I have learned so much over the years from other farmers who are farther ahead on the learning curve. My hope now is some people can learn something from our practices."
Marty Marr, New Berlin, IL

MARTY MARR reviews his Resource Analysis and Assessment Plan, which reviews Marty's input costs and return per acre per field, as well as aggregated data from his region, so he can see how he's doing compared to others in his area using different management practices.

"The primary goal of a PCM conservation specialist is to form a long-term, trusting relationship with each farmer they work with. Each specialist strives to attend multiple conferences, courses and demonstrations throughout the year to maintain a robust agronomic skill set to ensure we're relaying the most up-to-date and relevant information possible every time we walk into a cooperating farmer's shed."
Shane Sinclair, PCM Specialist

A Note On PCM Data

The PCM program now represents over 6,000 corn and soybean fields in Illinois from 2015-19; this is up from 3,600 fields last year. Providing the most valuable information to PCM farmers and to other farmers interested in conservation practices, we parse PCM data into higher (SPR>136) and lower (SPR<136) soil productivity levels. Detailed information on lower SPRs can be found at www.ilcorn.org/pcm.

Some profitability trends for tillage and nutrient management have changed since last year's summary. The long-term value of PCM data is to provide farmers with accurate, unbiased data that they can rely on to make good financial decisions for their farming operation. We pride ourselves on providing analysis that is transparent, objective and accurate. As we add more data every year, we expect to see new trends, and over time, we know PCM data will begin to more closely reflect the real farm financial impacts of the PCM standard practices (tillage, nutrient management and cover crops).

What Can We Learn From 2019?

Impacts of Unprecedented Spring Weather

Illinois farmers will never forget 2019 – and not in a good way. Significant flooding left farmland and newly planted crops underwater. Farmers waited: for signs of life from seeds in the ground, for farmland to dry enough to plant, for a signal to quit trying. Illinois saw the largest number of prevent plant acres in 2019 since the USDA began reporting such data in 2007.

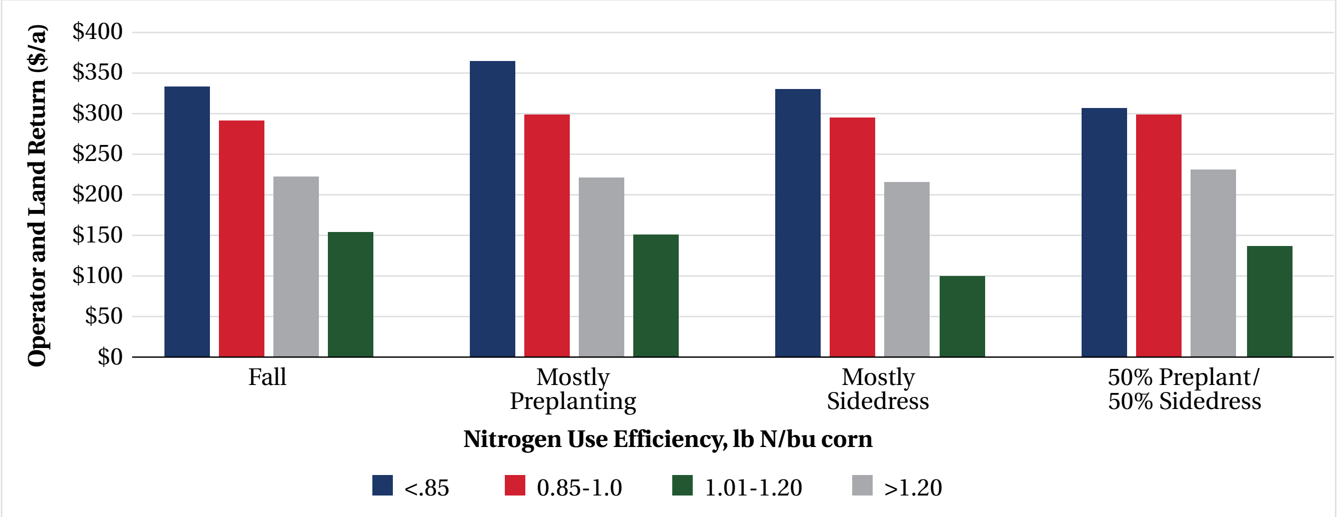
> *Illinois Prevent Plant Acres, reported by USDA Farm Service Agency*
> *Corn: 1,145,385 acres*
> *Soybeans: 331,247 acres*

Farmers enrolled in PCM experienced the same unprecedented struggles throughout the growing season, and the data reflects the struggle. However, the 300,000 acres of program data can teach us the factors that could make Illinois farmers most successful.

In assessing the 2019 PCM data, specifically the nutrient (nitrogen) management systems employed across our program, we noticed a trend – the highest rate of return for corn farmers on high SPR soils was realized when the Nitrogen Use Efficiency (NUE) was 1.0 lb N/bu or lower.

Nitrogen is the most limiting nutrient for corn production, and with the wet conditions, one might think this would be more evident where lower N rates were applied.

Figure 1 – Corn, High SPR, Profitability by N Management and NUE 2019



As you can see in the table, regardless of timing, farmers that applied 1 pound of N for every 1 bushel of corn produced (NUE) or less had the greatest return on investment.

Year to year, and field to field, the optimal N rate is going to vary. Rainfall, temperature, moisture and drainage are among a long list of factors that are going to affect your final yields and ROI. Tight profit margins are making decisions on inputs to crops difficult for farmers. Decisions on when and where to use fertilizers can be important to ensure maximum profitability.

AS YOU READ THE REST OF THIS REPORT:

*Remember that we've summarized data by high and low SPR soils. Most PCM data comes from high SPR soils, and this report details that data. For more information on both high and low SPR soils in Central Illinois, **visit www.ilcorn.org/pcm**.*

Tillage Data & Recommendations

In our last analysis, strip-till and 1-pass light tillage were the most profitable tillage systems among PCM farmers regardless of soil productivity range. The new 2018 and 2019 data changed these trends. High SPR corn fields that adopted a 2-pass light tillage system had the highest average net return; 1-pass light tillage systems were only a few dollars per acre behind 2-pass light tillage.

Big changes prompt PCM experts to review what could have caused the change, and the weather is certainly one explanation.

Farmers experienced the wettest spring on record in Illinois in 2019. It's possible that ONLY those fields that were the most well-drained and regionally lucky to miss a few rain events would have even allowed for a second tillage pass in 2019. Those same fields would have likely had the most suitable conditions for early planting and early season growth, all pointing toward higher yields that had very little to do with additional tillage passes.

In Illinois in 2018, we had cool early season conditions that could have encouraged farmers to make an extra tillage pass in the spring.

The analysis this year drops strip-till to fourth place in profitability. Our most profitable strip-till fields use the strip-till bar to apply less total N, eliminate one field pass and yield about 18 bushels/acre greater than farmers that do not use the bar to apply liquid fertilizer. The 2019 weather could have impacted the viability of this practice as well.

Figure 2 – Tillage application data and recommendation

CORN IL, HIGH SPR 2015-19 AVG VALUES	NO-TILL	STRIP-TILL	1-PASS LIGHT	2-PASS LIGHT	2-PASS MODERATE	2+ TILLAGE PASSES
No. Fields	310	296	710	139	302	46
Yield per acre	209	219	220	224	223	216
GROSS REVENUE	***$750***	***$787***	***$790***	***$804***	***$801***	***$773***
TOTAL DIRECT COSTS*	***$388***	***$395***	***$382***	***$384***	***$396***	***$422***
Field work	$0	$20	$10	$22	$26	$38
Other power costs**	$96	$93	$96	$93	$92	$97
TOTAL POWER COSTS	***$96***	***$113***	***$106***	***$115***	***$118***	***$135***
OVERHEAD COSTS	***$37***	***$37***	***$37***	***$37***	***$37***	***$37***
TOTAL NON-LAND COSTS	***$521***	***$544***	***$524***	***$536***	***$550***	***$594***
OPERATOR & LAND RETURN	$229	$243	$266	$269	$250	$180

**Direct costs = fertilizers, pesticides, seed, cover crop seed, drying, storage and crop insurance | **Other power costs = fall fertilizer application, spraying, planting, cover crop planting, spring/in-season fertilizer application, harvesting and grain hauling*

No-Till = No tillage; 1-Pass Light = 1 pass w/ low-disturbance tillage; 2-Pass Light = 2 passes w/ low-disturbance tillage; 2-Pass Medium = 2 passes (1 low-disturbance +1 high-disturbance); 2+ Pass = more than 2 tillage passes, any intensity level

Nitrogen Application Data & Recommendations

PCM nitrogen fertilizer management analysis on high SPR soils shows that corn fields receiving more than 40 percent of the total nitrogen application in the fall demonstrated a Nitrogen Use Efficiency (NUE) >1.0, higher nitrogen fertilizer application rates and higher total costs than most in-season nitrogen fertilizer application systems. This resulted in reduced operator net financial return. The most profitable nitrogen application systems applied less than 40 percent of the total nitrogen in the fall with the balance either in a preplant or sidedress application.

Figure 3 – Economic returns resulting from various nitrogen fertilizer management strategies for corn production in Central Illinois from 2015-19.

CORN IL, 2015-2019 HIGH SPR	>40% FALL	MOSTLY PREPLANT	MOSTLY SIDEDRESS	50% PRE/50 SIDEDRESS	3-WAY SPLIT
AVG NUE (lb N/bu grain)	1.01	0.93	0.92	0.91	0.94
Yield per acre	219	218	220	221	230
No. Fields	732	492	612	228	52
GROSS REVENUE	***$789***	***$785***	***$791***	***$793***	***$827***
N fertilizer	$84	$78	$76	$84	$95
Other direct costs*	$320	$286	$307	$311	$338
TOTAL DIRECT COSTS	***$404***	***$364***	***$383***	***$395***	***$433***
Field work	$16	$16	$16	$18	$19
Other power costs**	$97	$89	$94	$95	$93
TOTAL POWER COSTS	***$113***	***$105***	***$110***	***$113***	***$112***
OVERHEAD COSTS	***$37***	***$37***	***$37***	***$37***	***$37***
TOTAL NON-LAND COSTS	***$554***	***$506***	***$529***	***$545***	***$582***
OPERATOR & LAND RETURN	$235	$279	$261	$248	$246

**Direct costs = fertilizers, pesticides, seed, cover crop seed, drying, storage and crop insurance | **Other power costs = fall fertilizer application, spraying, planting, cover crop planting, spring/in-season fertilizer application, harvesting and grain hauling*

Mostly Fall = >40% of total N application rate applied in fall; Mostly Preplant = more than 50% of total N applied at or before planting in spring; Mostly Sidedress = more than 50% of total N applied after planting; 50% Pre/50% Sidedress = total N application is split roughly evenly between Preplant and sidedress; 3-Way Split = <40% total N is fall-applied and balance is roughly evenly applied between preplant/sidedress

Nitrogen Data & Recommendations

Figure 4 – Nitrogen Rates, Yields and Returns. This table demonstrates that the greatest net income is generated from the 151 to 175 lb of total nitrogen per acre rate range when averaged over all years and high SPR soils. For reference, corn following soybean rate recommended from the Maximum Return to Nitrogen rate calculator would be about 180 lb nitrogen per acre.

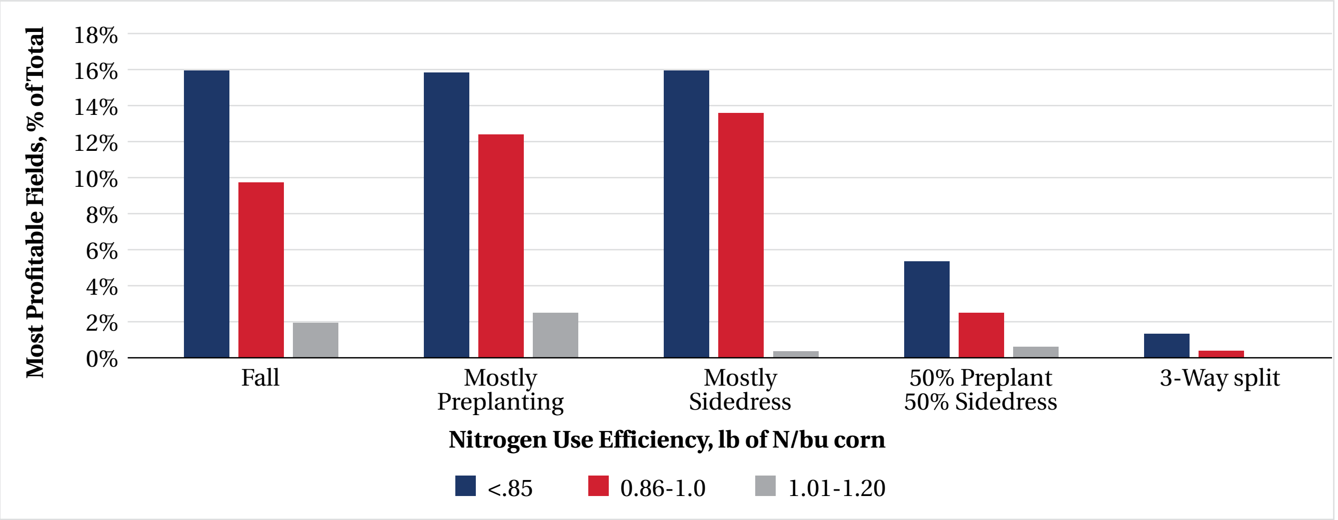
CORN, HIGH SPR, N RATE LBS PER ACRE	NO. OF FIELDS	SPR	2015	2016	2017	2018	2019	AVG 2015-19	OPERATOR AND LAND RETURN – 2015-19
			Bushels per acre						
Less than 150	41	139	154	222	212	216	198	**200**	**$221**
151 to 175	114	140	191	229	212	231	205	**213**	**$270**
176 to 200	382	140	205	226	220	232	207	**218**	**$264**
201 to 225	574	140	207	223	222	234	211	**219**	**$252**
Over 225	336	139	210	233	233	241	217	**227**	**$242**

For more information about the economic impacts of nitrogen timing and rates, tillage options, and low SPR soils, visit **www.ilcorn.org/PCM**.

Most Profitable Strategies

What did the most profitable fields in our dataset have in common?

Figure 5 – Most Profitable Corn, High SPR, N Management and NUE, 2015-19



The most profitable PCM corn fields shared a few common themes: 1-Pass Light tillage and low Nitrogen Use Efficiency values (NUE).

Although there were a range of N application rates among the most profitable high SPR corn fields, it appears that low NUEs are a common strategy among the most profitable fields.

This likely means that the most profitable farmers have a good idea of the yield potential for these fields and apply N fertilizer at moderate rates which, in our analysis, are within the same range as the University of Illinois' Maximum Return to Nitrogen (MRTN) recommendation system.

There was one obvious nitrogen strategy among the most profitable low SPR corn fields: mostly preplant with NUE in the range of 0.86-1.0 lb N/bu (data not shown).

In terms of N timing, Mostly Fall, Mostly Preplant and Mostly Sidedress were used in similar proportions among PCM high-profit, high SPR corn fields.

Most Profitable Strategies

What did the most profitable fields in our dataset have in common?

Figure 6 – Most Profitable Corn, High SPR, Tillage, 2015-19

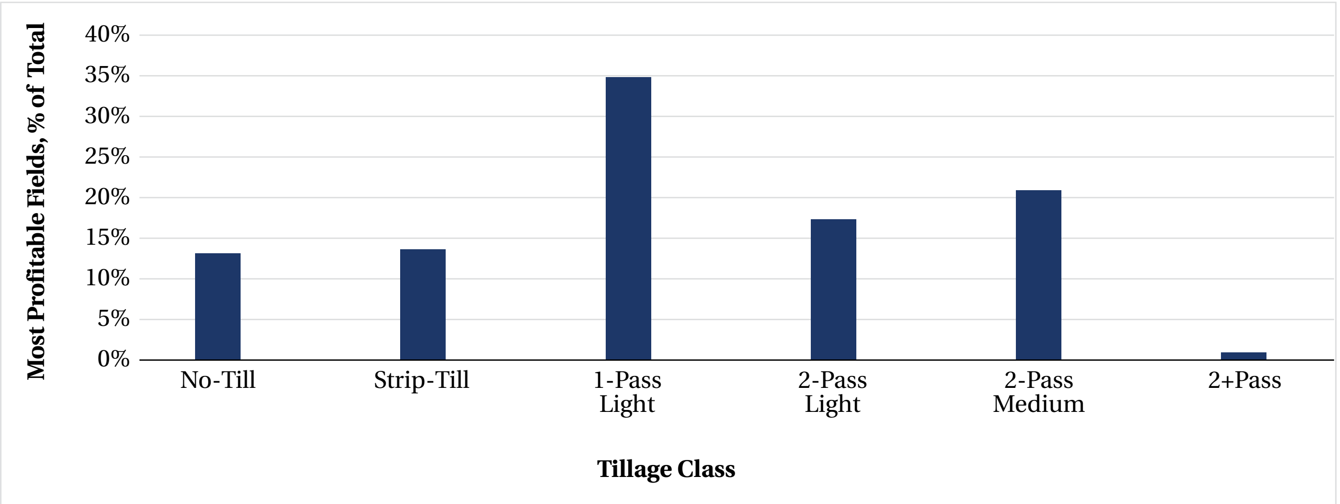
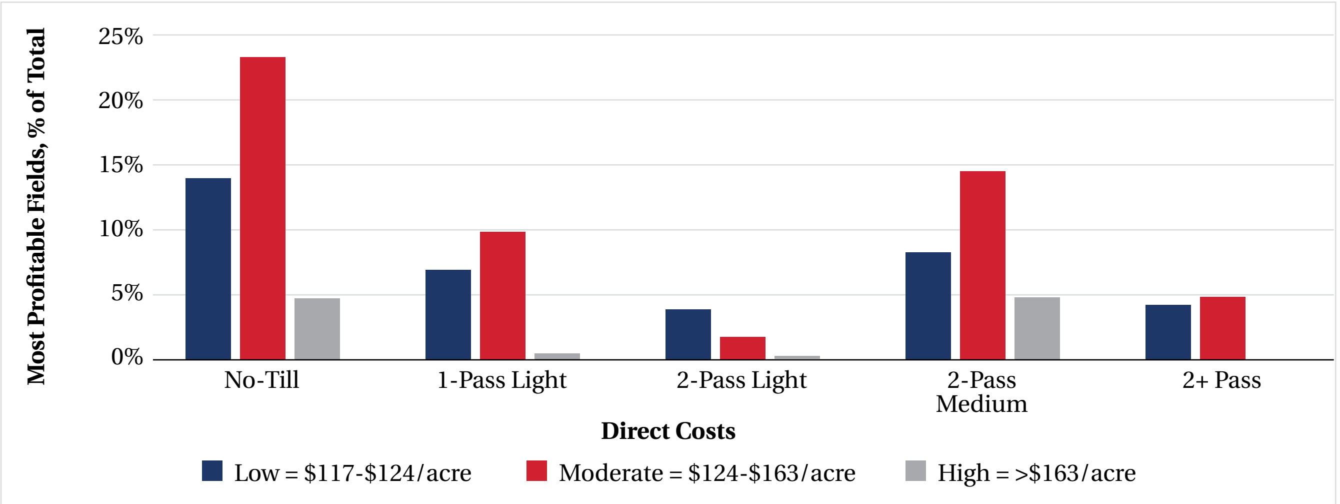


Figure 7 – Most Profitable Soybean, High SPR, Tillage and Direct Cost Classes, 2015-19



PCM data consistently shows that the most profitable fields focus on reducing total costs to make more money instead of just more bushels.

1-Pass Light tillage was the most common high-profit tillage system for high SPR corn fields, representing 35 percent of the most profitable fields. Continuing the theme, the most common tillage strategy among low SPR corn fields was also 1-Pass Light tillage, representing 36 percent of all fields.

The other low-SPR tillage strategies, in order of prevalence, were: 2-Pass Medium (17%), 2-Pass Light (15%), No-Till and Strip-Till (both at 12%), and 2+ Pass Tillage (8%).

Surprisingly, no-till was the most common tillage practice for our highest profit soybean fields, regardless of soil productivity range. No-till has never been one of the more profitable tillage systems for soybean production among our full pool of PCM fields but, considering only the most profitable fields, no-till was the clear tillage winner representing 41 percent and 47 percent of high and low SPR soybean fields, respectively.

It appears that no-till soybeans can be worth learning to do correctly!

Another interesting theme among the most profitable soybean fields is the importance of keeping direct costs in a moderate range. For high SPR soybean fields, "moderate" direct costs were in the range of $124-$163/a. For low SPR soybean fields, "moderate" direct costs were in the range of $117-$124/a. Over 50 percent of the most profitable soybean fields (for both high and low SPR soils) maintained expenses in this moderate direct cost range.

CONSIDER:

- *Will another tillage pass increase yield enough to pay for itself?*
- *Are more inputs an investment in your crop, or are you throwing money down the drain and nutrients down the river?*
- *Is your best strategy to apply nitrogen in the fall, hoping it will still be available to your crop in the spring?*

PCM Professionals

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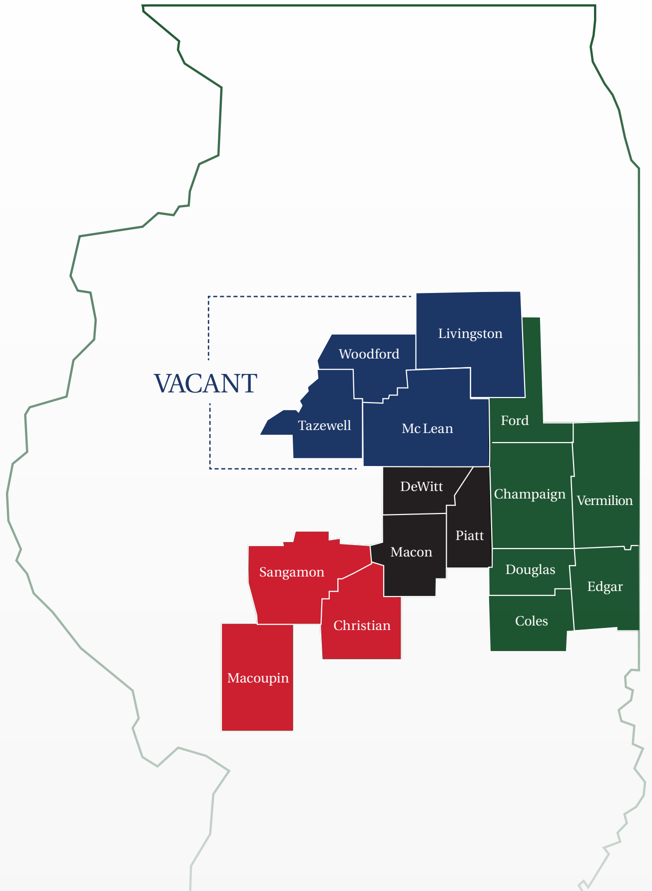

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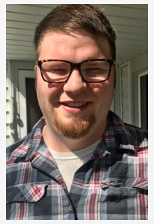

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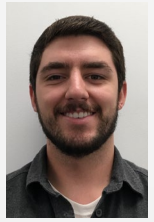

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The PCM program is also active in Kentucky.

PCM Recognized

The National Corn Growers Association and Environmental Defense Fund (EDF) launched the Success in Stewardship Network in 2020 to celebrate and accelerate the use of agricultural conservation practices on U.S. corn farms. IL Corn's Precision Conservation Management Program was recognized in the first year of this network's existence.

"The Success in Stewardship Network will break down the notion that conservation is only for an elite group of farmers," said Callie Eideberg, director of agricultural policy and special projects at EDF. "Practices that protect the land and water and increase climate resilience are more prevalent than many think, and this network will bring farmers and agricultural organizations together to continue making conservation commonplace."

In addition, PCM has been recognized by the following organizations for innovation, efficiency and impactful work since 2018:

- Field to Market
- USDA Natural Resources Conservation Service
- National Fish and Wildlife
- Walton Family Foundation
- Council for Best Management Practices
- The Nature Conservancy

In 2015, PCM was created through the Natural Resources Conservation Service (NRCS) Regional Conservation Partnership Program (RCPP). Later, PCM was the first NRCS RCPP Partner Spotlight recognized for its innovative service to farmers.

Groundwater Quantity Management Program

NRDs Protecting Water Quantity

Groundwater Management Rules & Regulations

Basin-Wide Plan & CPNRD Integrated Management Plan

Basin-Wide Plan **PDF**

The Board approved the proposed Second Increment Basin-Wide Plan for Joint Integrated Water Resources Management of Overappropriated Portions of the Platte River Basin, developed by the Platte Basin Natural Resources Districts (North Platte, South Platte, Central Platte, Twin Platte, Tri-Basin NRDs), and the Nebraska Department of Natural Resources. The geographic area of the Plan is the extent of the Nebraska portion of the Platte River surface water basin beginning at the Nebraska-Wyoming State line and ending at the Kearney Canal Diversion, at Elm Creek. The proposed plan includes: 1) introduction; 2) planning process; 3) activities of the first increment; 4) goals, objectives, and action items; 5) monitoring. The plan does not include controls.

The Districts and Department will make a joint decision within 60 days on whether to implement the proposed plan with or without modifications. Further information may be requested at (308) 385-6282, or the Department's website at dnr.nebraska.gov or by telephone at (402) 471-2363.

Integrated Management Plan **PDF**

The board approved the proposed Second Increment Joint Integrated Management Plan (IMP) cooperatively developed by Central Platte NRD and the Nebraska Department of Natural Resources. The geographic area subject to the proposed IMP is the entirety of the land area within the District boundary. A general description of the contents of the proposed IMP includes the following: Effective Date; Authority; Maps and Management Area Boundaries; Vision; Funding; Science and Methods; First Increment Accomplishments; Goals and Objectives; and Action Items, which include Controls and Triggers, and Monitoring and Evaluation. The District will continue existing groundwater controls which are: 1) groundwater moratorium, 2) certification of groundwater uses, 3) groundwater variances, 4) groundwater transfers, and 5) municipal and industrial accounting.

The Department will continue the existing surface water controls which are: 1) maintaining the moratorium on new surface water appropriations and on expanded surface water uses; 2) transfers of appropriations are subject to statutory criteria and Department rules; 3) continuation of surface water administration and monitoring of use of surface water; 4) no additional requirements of surface water appropriators to use additional conservation measures, and 5) no other reasonable restrictions on surface water use.

by the Central Nebraska Public Power District and the Nebraska Public Power District. After reviewing the testimony provided, CPNRD and NeDNR concluded that amendments to the proposed plans were not necessary.

————————————————————————————————

Groundwater Quantity Management

Central Platte NRD's Groundwater Management Quantity goal is to assure an adequate supply of water for feasible and beneficial uses through proper management, conservation, development and utilization of the District's water resources. CPNRD collects groundwater level observations and administers programs for irrigation runoff, groundwater quantity, groundwater quality, groundwater modeling, and is developing a surface water flow model for a comprehensive groundwater and surface water management program. **Annual Water Use Summary**

Management Plan Rewrite

07/25/19 Olsson was selected to rewrite the NRD's Groundwater Management Plan (GMP) in the amount of $102,000. Olsson will incorporate new data and insight acquired since the approval of the plan in 1985. As mandated by the legislature in the early 1980s, the Central Platte NRD prepared a comprehensive GMP based on the hydrogeologic, climate, and socioeconomic information available at the time. Since 1985, the NRD has acquired and developed significant data and information about the groundwater resources in its district. Over the last 35 years, the rules and regulations implemented by the NRD have changed significantly and groundwater management goals have evolved. For these reasons, the NRD requested proposals to ensure that the rules and regulations currently implemented by the district are in sync with what is written in the plan. The other proposal was submitted by JEO Consulting for $149,000.

Policy Changes to the Groundwater Management Plan *(as of November 2018)*
***Irrigation** New wells that irrigate new acres are not allowed. Supplemental & replacement wells are still allowed.
***Transfer Schedule** Transfer applications for irrigated acres will be accepted from September 1st – March 1st.
***Sub-Area Transfer** A sub-area is required to stay under the transfer limit rule for 5 consecutive years. Transfers & supplemental wells are not allowed until the sub-area groundwater level exceeds 25% of the maximum acceptable decline.

————————————————————————————————

Reoperation of Surface Water Canals: **Putting Water Back to the Platte River**

The NRD has been proactive in creating new ways to increase irrigation efficiency, protect water supplies, and increase flows to the river in Dawson County by working with the canal companies in the area. The Canal Rehab Project was initiated by former general manager Ron Bishop as the first conjunctive water management project in the District. 2015 marked the first year that all three of CPNRD's irrigation canal rehabilitations in Dawson County has been in full operation. The Cozad Ditch, Thirty Mile Irrigation District, and South Side Irrigation District produced needed returns back to the Platte River from both excess flows and natural flow diversions, as they were designed to do. **History/Details of the Canal Rehabs**

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CPNRD Integrated Management Plan

May 23, 2019 The Central Platte NRD board of directors took action to approve the Basin-Wide and Individual Integrated Management Plan drafts to hold public hearings on July 15, 2019, at 3:00 and 3:30 p.m. respectively. A public information meeting will be held at 2:30 p.m. just prior to the hearings. The original plans were approved in 2009 with a requirement that the same parties develop a second increment within 10 years after the adoption of the first increment plans. The Basin-Wide and CPNRD Integrated Management plans were implemented to ensure that Nebraska is following the Nebraska New Depletions Plan included within the Platte River Recovery Implementation Plan. Additional details are available on the Nebraska Department of Natural Resources website at **dnr.nebraska.gov/iwm**.

Basin-Wide IMP Goals

1. Incrementally achieve and sustain a fully appropriated condition, while maintaining economic viability, social and environmental health, safety, and welfare of the basin.
2. Prevent or mitigate human-induced reductions in the flow of a river or stream that would cause non-compliance with an interstate compact or decree or other formal state contract or agreement.
3. Partner with municipalities and industries to maximize conservation and water use efficiency.
4. Work cooperatively to identify and investigate disputes between groundwater users and surface water appropriators and, if determined appropriate, implement management solutions to address such issues.
5. Keep the Upper Platte River Basin-Wide Plan current and keep stakeholders informed.

2019 Spring Groundwater Level Report

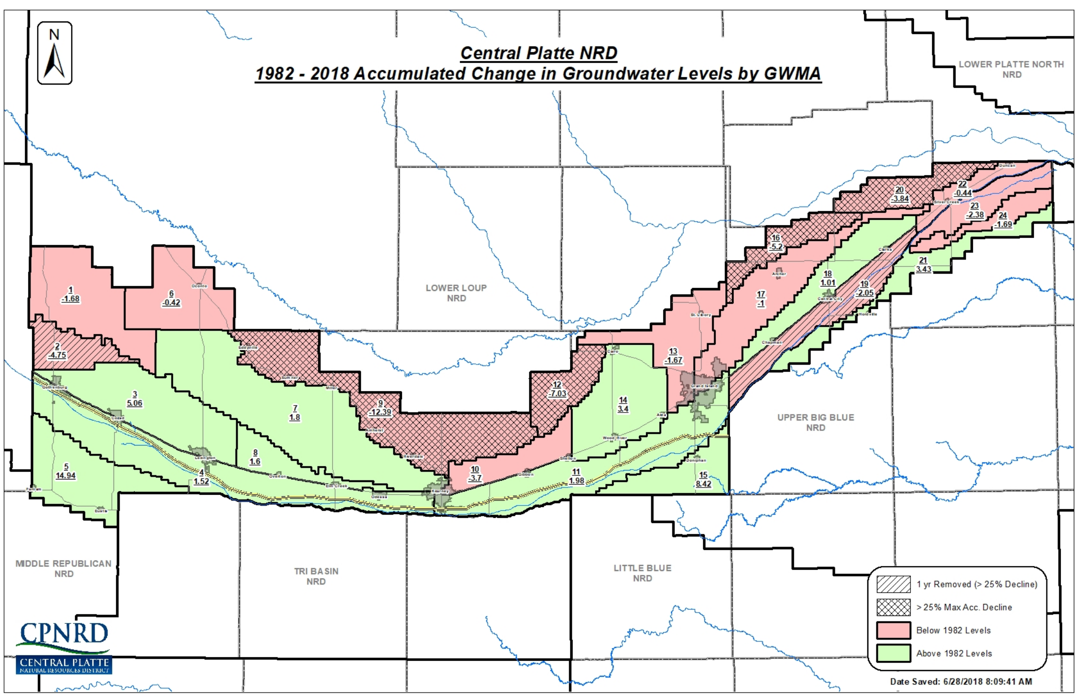
Spring Water Levels Increase Throughout Central Platte NRD

The average 2019 spring groundwater levels across the District increased 2.08 feet since 1982. These levels are averaged from the 437 wells that NRD staff read this year from mid-April to mid-June. Zakrzewski said all 24 GWMAs saw increases because of timely rains during the 2018 irrigation season that continued throughout the fall, and 200 to 300 percent above normal precipitation this spring.

The 1982 levels were established as the standard for the NRD's Groundwater Management Plan with maximum acceptable declines and a margin of safety calculated for each of the District's 24 Ground Water Management Areas (GWMA).

Four of the 24 GWMAs are currently in the 25 percent decline suspension that does not allow transfers of irrigated acres into the areas or supplemental wells. The NRD's rules and regulations require the areas to stay in suspension for five years. Two of the four areas in suspension are above the 25 percent decline for the second consecutive year, while the remaining two areas are showing an increase for their first year. If the water table would fall to 50 percent of the maximum decline, Phase II would go into effect requiring mandatory reductions in irrigated acres.

Central Platte NRD serves 11 counties including all of Dawson and parts of Frontier, Custer Buffalo, Hall, Howard, Nance, Merrick, Hamilton, Platte, and Polk. Interactive maps are available at *cpnrd.gisworkshop.com.*



Download this map.

Interactive maps are also available at ***http://cpnrd.gisworkshop.com****.* Your Contact: **Luke Zakrzewski**

Rural-Urban Partnership Helps Clean Water Supply

Development of Groundwater Quantity Management Program

Nebraska leads the nation in irrigation production with over 8 million irrigated acres. Being in the Platte River Watershed, the District's primary surface water feature is the Platte River. However, most farmers rely on groundwater for their irrigation needs since groundwater is abundantly available across the District. Water supply is under continuous monitoring throughout the District and a groundwater supply management plan to address potential shortages has been adopted by the NRD's board of directors and has been in effect since 1987. Groundwater aquifer declines have been documented where irrigation use is the heaviest. Groundwater is the District's chief source of drinking water and primary economic resource of the NRD since we depend on it for irrigation; which, in turn, enables us to have a strong economy rooted in agriculture.

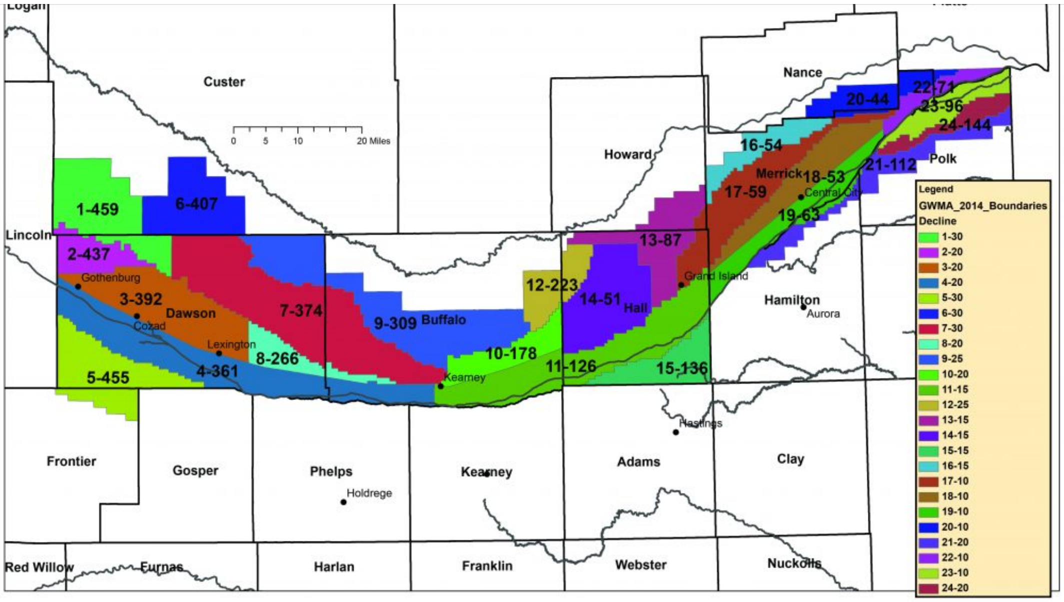
If there was any doubt that we need to take care of this resource, it should've been dispelled by declining water tables in the late 1970s and early 1980s. Rainfall increased in the mid-1980s/1990s, which caused water tables to rise, but the historical record suggests complete groundwater recovery from the dry periods during the wet periods does not always occur in all areas. Careful management of the resource is necessary. Aquifer thickness varies from 25-300+ feet across the district, so a drop of one foot has a more significant impact on some parts of the District than on others. Groundwater depths and thicknesses are charted and used to help establish 24 groundwater supply management areas. Besides the aquifer conditions, the soils and topographic characteristics are similar in each management area.

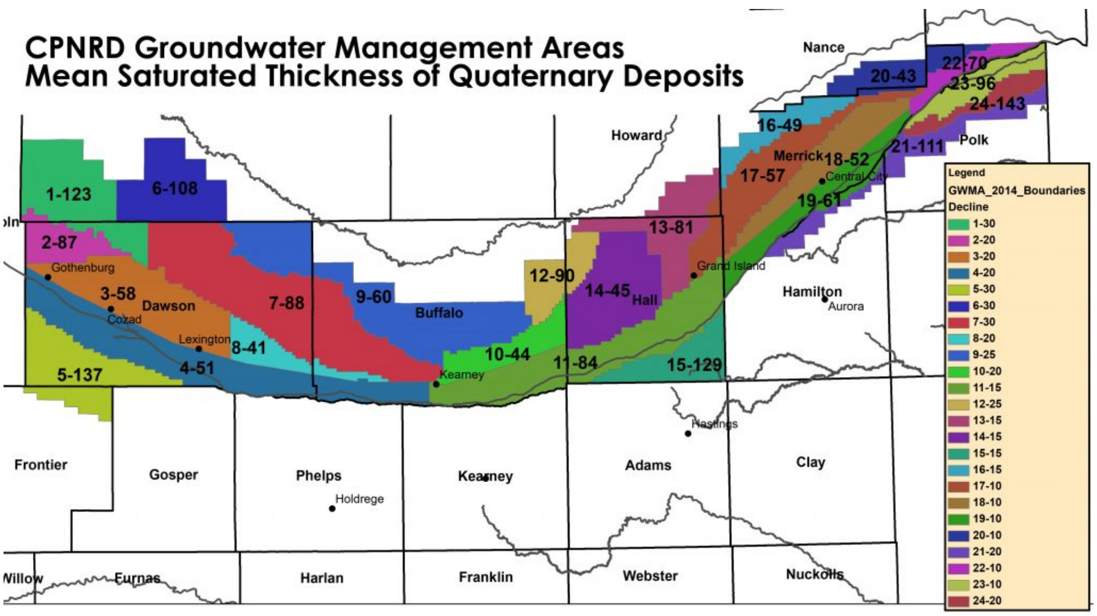
The 1982 groundwater levels were established as the standard for the management plan since rainfall and recharge were above average several years since 1982. The maximum acceptable decline for each of the management areas was calculated, establishing a margin of safety in each area. It was determined that as an area's average groundwater level declined through that margin of safety, certain controls ought to be mandated to slow the decline.

In 1987, the board established the Groundwater Management Plan with a phased program to implement controls when needed. The maximum acceptable decline ranges from 10' in the eastern end of the District to 30' in portions of the western end of the district. If the water table falls to 50% of that maximum decline (5 and 15 feet respectively for each of the range parameters), Phase II would go into effect for any area or areas affected, triggering mandatory reductions in irrigated acres and establishing spacing limits for new irrigation wells. Further declines to 70%, 90% & 100% of the maximum acceptable decline will trigger Phase III, IV and V controls respectively, mandating additional cutbacks in irrigated acreage and increased spacing limits for new wells.

Complete details of the controls are available in district publications. Because of the differences in the aquifer depth and conditions, it is conceivable that some areas could be in the higher phases while other areas may always be in Phase I.

Your CPNRD staff contacts: **Brandi Flyr** | **Luke Zakrzewski** | **Dan Clement** | **Angela Warner**





Statewide Groundwater Management

Map | Summary | Restrictions on Irrigation

Nebraska Groundwater Management & Protection Act

Erosion & Sediment Control Plan *(updated 2017)*

Platte River Recovery Implementation Program

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

framework for a long-term Program that will satisfy Endangered Species Act (ESA) requirements for water users in the basin. The first PRRIP increment, planned to last 13 years, includes completion of water projects expected to improve flows in the central Platte by an average of 130,000-150,000 ac/ft annually. A second Program element is the protection and maintenance of 10,000 acres of habitat during the first increment, ultimately working toward a 29,000-acre goal. The specifics of subsequent increments will be planned as more information is developed. Through an adaptive management process, the Program goals may be modified as appropriate. **PRRIP WEBSITE**

CPNRD has a big stake in the Program's goal to improve and conserve habitat for three threatened and endangered species on the central Platte (the whooping crane, piping plover, and least tern) and the endangered pallid sturgeon on the lower Platte. The Program was developed as the states and federal governments face stiff challenges to protect threatened and endangered species using the Platte River and their habitats. The signatories to the Program hope to equitably provide greater certainty for water users facing ESA requirements. The U.S. FWS plays a major role in enforcing the ESA. Authorization legislation for federal funding was passed by Congress in 2008 and associated appropriations will be addressed in an ongoing process. District board members, management, and staff are actively involved in Program Governance and Advisory Committees.

The Program is starting to develop a plan for the review of the U.S. FWS's target flows for the Platte River. Ongoing research and monitoring on the Platte are showing the Service's current target flows to be ineffective in accomplishing the objectives they have set out. The Program's Land Advisory Committee includes a member/alternate from CPNRD, member/alternate from Tri-Basin NRD, and a joint member/alternate. The Program's Water Action Committee is looking at intentional groundwater recharge through diversions through the canal systems. One of the projects that were done in fall and winter 2011, was to study recharge in the Phelps Canal, one of CNPPID canals just below the J-2 Return. In 2013, the Program's Governance Committee (GC) and CNPPID independently agreed to fund and develop the J2 Regulating Reservoirs at a cost of $13 million for five years.

In September 2015, CNPPID and its engineering contractor, RJH Consultants, Inc., provided the GC with a progress report on the development of the J2 Reservoirs Project which detailed significant increases in cost from the original estimate of $63 -$170 million, not including land acquisition. The GC authorized the Program's Executive Director to work with CNPPID and NDNR to evaluate J2 Project alternatives that can be accomplished within the available budget. Central Platte, Twin Platte, and Tri-Basin NRDs each purchased a percentage of the Nebraska share. CPNRD purchased 20% of the State's share (2,040 ac-ft annually) for just over $1.5 million. In July of 2016, the GC directed the project be put on hold until further notice while the PRRIP pursues other water project opportunities involving groundwater recharge, smaller scale storage projects, and water acquisition and transfer opportunities.

In 2016, a contract with CPNRD and Aqua Geo Frameworks LLC was approved by the board for aerial electro-magnetic survey work. The survey work includes additional coverage of flight lines to cover various project areas at a Program cost of $64,000.

Program Extension: The Governance Committee approved $27.9 million FY2019 Budget and Work Plan, including $18 million for Water Plan implementation. The Committee is working on a proposed Lakeside Slurry Wall Pit Project and discussing other options because of increasing project costs and the prospect for cheaper water options. One option includes the continuance of the Central Platte NRD/Central Nebraska Public Power & Irrigation District pilot program. More discussion is needed with the Nebraska Department of Natural Resources regarding project permitting and operation. In May 2019, the CPNRD board approved a water exchange MOU with the Central Nebraska Public Power & Irrigation District for the second year of the project.

The Program's continued funding of phragmites (and other noxious and invasive plant) control was also debated. Wyoming's opposition to their proportionate share has reduced phragmites control funding to $200,000 annually. Several representatives on the Committee are changing including Mike Thabault from the Denver office of the USFWS, Don Kraus with Central NPP&ID (being replaced with Devin Brundage), and pending retirements by Don Ament from Colorado and Harry LaBonde from Wyoming. The Downstream Water Users appointed Czaplewski as their representative on the Program's Finance Committee.

Also in May 2019, the NRD signed a one-year extension request with NRCS for the Regional Conservation Partnership Program (RCPP). In 2014, the NRD was awarded a five-year grant for the *Ogallala Aquifer & Platte River Recovery* project. The project addresses excess/insufficient water, inadequate habitat for fish and wildlife, soil erosion, water quality degradation, inefficient energy use, and air quality impacts. The resource concerns meet environmental habitat needs under the Platte River Recovery and Implementation Program.

In June 2019, the Program's Governance Committee was briefed on Congressional work to extend the first increment to 2032. Senate Bill 990 and House bill 3237 were introduced and a hearing was held on the Senate bill. There is broad regional support for the bills including co-sponsorship of the Senate bill by Nebraska Sen. Deb Fischer. All three Nebraska Representatives have signed on as co-sponsors and Central Platte NRD submitted a letter of support for the extension. Another item of interest was the approval of an NPPD surface water exchange agreement patterned after the agreement CPNRD worked out with Central NPP&ID.

2021 NCF-Envirothon Nebraska
Current Issue Study Resources

Key Topic #5: Nebraska's NRD System

15. Identify partnership opportunities with other state and federal agencies.
16. Explain the regulatory authority of the NRDs.
17. Describe the processes for creating rules and regulations.

Study Resources

Water Quality: Central Platte NRD – *Central Platte NRD, 2006* (Page 97 - 101)

Nebraska State Statute 46-707: Natural Resources District – *Nebraska State Legislature, 2021* (Page 102 - 107)

Study Resources begin on the next page! ➡

IV. Water Quality

GOAL: To protect and enhance the quality of surface and groundwater within the District.

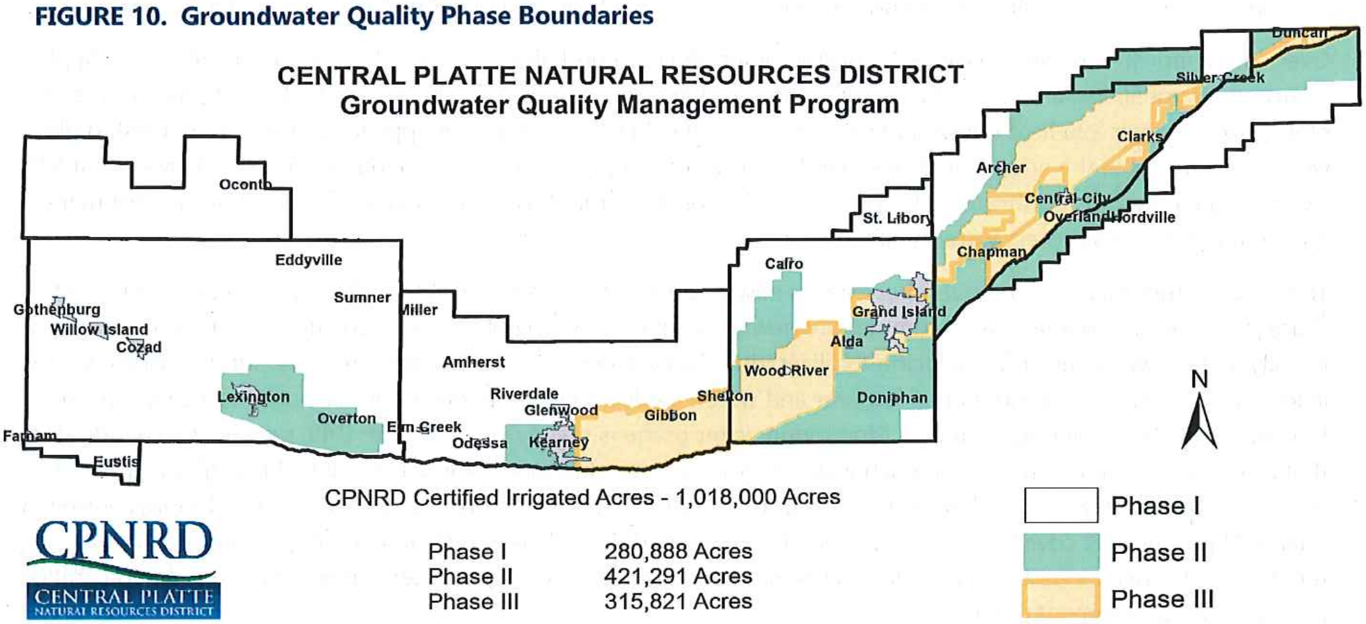
The main source of groundwater pollution in the District is nitrate-nitrogen in amounts greater than the maximum contaminant level of 10 ppm (parts per million) allowed by the state and federal government. High nitrates are a problem in varying degrees throughout the District. In the western portion of the NRD, concentrations of sulfate are not uncommon. High iron and magnesium levels, along with high total dissolved solids in many areas, have the potential for considerable problems in municipal supplies, particularly in areas where large quantities of water are used for industrial purposes.

Management Program The NRD's nitrogen management program was adopted in response to increasing high concentrations in large areas of nitrate-nitrogen in the groundwater and vadose zones (areas between root zone/ top of water table). High groundwater nitrates in some areas of the valley were first identified in 1961. Excessively high nitrates can lead to methemoglobinemia, known as "blue baby syndrome" and are also a potential hazard to livestock. Commercial nitrogen fertilizer is the primary cause for high nitrates in groundwater in the Central Platte Valley. Public hearings and numerous meetings with farmers, crop consultants, & fertilizer industry representatives were conducted to determine how best to implement solutions. As a result, CPNRD adopted necessary rules, regulations, boundaries, and controls for the first quality management program to be included in the Groundwater Management Plan that became effective in August 1987.

When the Program started, Nitrate levels had increased 0.5 ppm per year to 19.24 ppm. Nitrate levels have been lowered through long-term management efforts by the NRD and landowners implementing efficient practices. The plan uses a phased approach, with lesser restrictions in areas that are not high in nitrates and additional regulations applying to areas with higher nitrate concentrations in the groundwater. Because the phases are by area, individual wells in a Phase Area may be higher or lower than the designated range of nitrate concentrations. Other factors, including proximity to a municipal water supply and vadose zone nitrates are also used in determining the Phase Areas. ***See Figure 11. CPNRD Quality Management Rules and Regulations on Page 19*** CPNRD will continue to work with producers, ag business operators, and the public to further reduce high nitrates in the groundwater.

Changes to Rules & Regulations In 2017, changes combined and updated the Rules and Regulations for all of the District's groundwater management programs into the *Groundwater Management Plan Rules & Regulations-General Provisions & Procedures for Enforcement.* Two major changes included cease & desist enforcement procedures and removal of the 2-in-10 irrigation rule.

FIGURE 10. Groundwater Quality Phase Boundaries



Management Area Changes In 2016, parts of southern Hall and northern Hamilton counties, south of the Platte River, were transferred from a Phase I to a Phase II Groundwater Management Area due to increasing nitrate levels.

Additional Testing In 2016, an agreement with UNL was approved for $80,000 to revisit 27 vadose zone core sites originally collected in the 1990s. The agreement was also to determine where additional cores may best characterize nitrate storage & estimated transport rates to the water table. Core samples were collected for vadose zone nitrate including some areas previously sampled. The 2017 report showed locations of the first 8 core samples collected with comparison of nitrate profiles to previous time periods, and estimation of nitrate transport rates at each location. Approximately 27 sites collected between 1990-1996 were digitized and used to compare profiles to determine how fast nitrate is moving & whether changing land use management has resulted in reduced loading of nitrate in the vadose zone. The sites are all being used for ag production. 8 sample results indicate lowering N fertilizer applied, reducing irrigation water, & changing land use practices at the surface may be lowering the nitrate concentrations in the vadose zone. Annual reports are provided by UNL.

Online Reporting Form In 2015, GIS Workshop was hired for $64,500 to develop a new online system for producers to fill out their annual Groundwater Management forms. Upon logging in, producers use their User ID and may log in throughout the year to record their water and soil test results, and their actual yields prior to submitting the form. Producers benefit by having all past information in one location. The system significantly reduces administrative time for staff to manually enter the 6,000-7,000 forms submitted each year. Meetings were held across the District with producers to demonstrate how to use the new online form. The site was updated in 2018 to improve usability for staff and producers, and to provide a better format to inform producers on recommended nitrogen applications.

Violations Violation notices were sent out to **72** operators by certified mail for not submitting the required reports for the 2017 crop year in the Phase II and III areas of the Water Quality Management Program. Operators worked with staff to be brought into compliance with no legal action.

PROJECTS AND RESEARCH

Central Platte Demonstration Projects The Nitrogen & Irrigation Management Demonstration Project is one of the longest-existing demonstration projects in Nebraska and possibly the nation. Other state and national demonstration projects have been modeled after this educational effort. The Project was initiated in 1984 following the Hall County Water Quality Special Project to show that new practices that impede nitrogen fertilizer from leaching into the aquifer are successful. Farmers with varying soils/conditions are recruited to work with UNL/CPNRD to use best management practices to demonstrate that nitrates can be managed efficiently and effectively while maintaining crop yields. The Platte Valley Project included areas where nitrate-N concentrations were in excess of 40 ppm; due to a combination of coarse-textured soil, shallow groundwater, intense irrigation & over-application of Nitrogen fertilizer.

Over 400 demonstration sites have been located on producers' cornfields where randomized levels of N were applied in increments of 50 lbs. above & 50 lbs. below the calculated recommendation based on the UNL algorithm. These plots provided over 290 field days/meetings. Research on field length, producer applied, & producer harvested plots were instrumental in the adoption of practices by producers. A producer survey conducted in 1997 showed that 54% tested irrigation water for nitrates, 34% used a nitrification inhibitor, & 70% attended a tour/meeting on best management practices to protect water quality.

The project emphasis changed over the years as new technology become available to the ag sector. CPNRD's cost-share programs are modified to accommodate new techniques/tools to help farmers practice better management. Initially, emphasis was given to reducing fertilizer input by counting contribution from residual sources. However, the leaching problem has 2 components: fertilizer and water. Reducing water applied normally produces less leaching than just reduction of fertilizer inputs. Monitoring water usage is mandatory in Phases II/III, since research indicated that most farmers didn't know how much water they were using during irrigation. Newest technologies include ET gages, watermark sensors to schedule irrigation, soil moisture capacitance probes, polymer material, slow/controlled release N products, & cover crops in seed corn. Extension and demonstration efforts in areas of irrigation management have also been a part of the project. Field days and articles educate producers on results of the demonstrations and on best management practices.

Crop Irrigation & Demand Network Started in 2013, this program receives data collected by McCrometer Connect Telemetry which provides a vast amount of real-time data. The Program allows CPNRD to view information such as water usage and soil moisture from fields where producers have installed telemetry equipment. Participatns may check their readings such as GPM used, inches applied/day & throughout the season, & soil moisture readings through a website at McCrometer.net. The amount of water pumped and precipitation are measured to provide data to develop irrigation efficiencies by equipment type, soil water holding capacities, & crop type. This advanced program was initiated through CPNRD in 2013 with $60,000 budgeted for the project and expanded by a $750,000 NeDNR grant in 2014. There are 77 sites across the District-11 sites in 2013, 30 sites in 2014; & 36 sites in 2015. The project's goal was to monitor different types of irrigation systems. Currently, there are 52 pivots, 18 gravity and 7 sites. Water pumped, system pressure, and rainfall are monitored at all locations, with soil moisture monitored at 30 locations. Partners include DNR, UNL Extension, Seim Ag Technology, CPNRD, and McCrometer.

Project SENSE UNL's Project SENSE (Sensors for Efficient Nitrogen Use & Stewardship of the Environment) pilot program promotes in-season nitrogen fertilization for corn to improve efficiency of N fertilizer applications with canopy sensors. Other participants in the UBBNRD, LPSNRD, LPNNRD, LLNRD, NRCS, & Nebraska Corn Board. The Project SENSE sites show the use of crop canopy sensors for in-season N application from 2015-2017 resulted in average profit increase of $13.21/acre. N rates were 20% less than comparable grower practices with average yield reduction of 2.6 bu/ac (1% less than grower yield).

Cover Crops Producers are working with UNL Extension/CPNRD to research effects of cover crops on soil health. Field days are held annually to show crop mixes planted on different dates and to compare aboveground biomass with below ground; as well as best mixes for grazing. Research includes whether compaction and infiltration are impacted, how biological activity and organic matter are affected, which mixes provide the highest quality forage for grazing, and how much crop usable nitrogen can be expected. Partners include UNL, NRCS, CPNRD, Arrow Seed, Green Cover Seed & O'Hanlon Seed Inc. In 2017, LLNRD/CPNRD hired EA Engineering, Science, & Technology, Inc. of Lincoln, NE, in the amount of $320,000 to conduct a 4-year study (if a grant is secured) to determine the impacts on groundwater due to cover crop management. The NRDs will split the cost of the project and are seeking assistance to identify and develop grant applications to aid in funding the study. The Lower Loup Basin and Central Platte River Basin have diverse soil type and cropping practices that can affect both water quantity and water quality. The study will determine the general influence of cover crops on soil moisture, groundwater recharge, & N movement in the soil in the area between South Loup River & Wood River with groundwater declines. It will include both irrigated and dryland cropped fields and span multiple years. Landowner ID, mobilization, & installation of field equipment was completed 2017, with the final report available in 2021.

Support Requests In 2017, letters of support were submitted to the Nebraska Environmental Trust for 2 research proposals to examine the efficacy of injecting sawdust slurry to soil below the root zone of corn to capture leached nitrogen; utilize eastern redcedar mulch on cropland to reduce erosion potential, improve soil structure, and to improve soil moisture retention. The research will be conducted by the UNL, Nebraska Extension, and USDA.

ADDITIONAL WATER QUALITY PROGRAMS

Decommissioned Well Program The potential danger and damage abandoned wells may cause to groundwater supply is a concern. CPNRD informs landowners to locate, fill & seal wells, cisterns, cesspools, and similar cavities on their property. The most dramatic danger caused by improper well abandonment is a hole into which children, animals, or equipment might fall. A more likely danger, though, is the creation of a path through which contamination of the groundwater might occur. Abandoned wells that have not been properly filled and sealed can act as a direct conduit for pollutants to the water supply beneath the earth's surface. State law requires abandoned wells be properly sealed. NRDs, the State of Nebraska and NRCS provide well owners with financial and technical assistance to get the job done right through well decommissioning programs. In 2013, CPNRD stopped providing cost share for replacement wells. Cost share is available for any old irrigation well (60%), up to $500 on any well that pumps 50 gpm or less, $750 for any well pumping over 50 gpm, and for any hand-dug well up to a $1,500. Licensed water well contractors/licensed pump installation contractors are required to abandon the well and verify that the water well was decommissioned in accordance with state law, standards, rules and regulations.

Irrigation Run-Off The District has adopted rules and regulations designed to control groundwater irrigation run-off that have been in effect since 1977.

Erosion Changes were made to the NRD's Erosion & Sediment Control Plan in 2017. The following changes made to the Erosion & Sediment Control Act in 2015 were updated: add sheet & rill erosion, ephemeral gully erosion, soils updates, & changed governing authority. The plan allows NRDs to petition the District Court for a Cease & Desist Order and removes 90% cost share previously required for NRDs to provide for erosion control practices. NRCS's new requirements for control of ephemeral gully (concentrated flow) erosion were added. If erosion is found on a producer's property, they will be required to develop a plan to use conservation practices to help treat this type of erosion, by December 31, 2019, for conservation compliance and to remain eligible for USDA program benefits. Those practices include no-till, cover crops, terraces and waterways.

Buffer Strips In 1998, the Nebraska Legislature established the Nebraska Buffer Strip Program to use filter strips to reduce the amount of chemicals that run off farm fields into the streams around the state. Cost-share is available to landowners who replace cropland with grass buffer strips along banks of perennial or intermittent streams or permanent bodies of water.

Chemigation Program Irrigators that chemigate must comply with Nebraska's Chemigation Act & Regulations adopted by NDEQ & CPNRD. The Act requires any operator applying chemicals through a closed irrigation system to have specific safety equipment, to be properly trained & certified, and obtain a permit from the appropriate NRD before chemigating. Certification is for 4 years, after which renewals are required. In 2014, LB272 changed the provisions relating to chemigation permits and fees. The bill gave NRDs authority to set fees for new, special, re-newal, and emergency permits. The bill also clarified that emergency permits must be approved within two working days and can't be issued on Saturdays, Sundays, or federal/state holidays. The permit holder & certified applicator are required to sign all applications. Application fee-$60. Special per-mits-$60. Annual renewal- $20. Emergency permit- $500. If staff is required to make a second trip to complete a chemigation inspection, a $50 fee is charged to the permit holder/applicator. The fee is increased to $100 on the third trip.

Violations The board issued one cease & desist order in 2017 for chemigating without permits.

Fertilizer/Pesticide Used Crop Season 2018	Total Applied (Gallons)
Fertilizer	9,871,523
Alpine	11
Afrome	68
Azoxy	22
Bifenture	12
Brigade 2EC	43.75
Dimelholute	8.9
Fanfare	1
Frenzy	12
Delox	28.49
Gold Rush	73
Headline	271.25/43.5 lbs
Hero	29.34
Lamda	6.38
N-Phuric	480
On Ground	82.66
Propic Zone	23
Quilt	13.5
Satori	74.7 oz
Seize	30
Sniper	90 oz
Thio	362
Tundra	8
Warrior	1
Total Acres Treated	118,359

FIGURE 11. 2018 Annual Chemigation Report

	New	Renewal	Emergency	Total
Apps Received	276	1,460	12	1,748
Apps Approved	272	1,460	12	1,744
Fees Collected	$16,560	$29,200	$6,000	$51,760

Inspections	Initial	Routine	Follow Up	Total
	283	**327**	**38**	**648**

Water Quality Objectives

1. *Reduce groundwater nitrate levels in areas that exceed 10 ppm, the amount allowed by the state & federal governments.*
2. *Maintain groundwater nitrate levels at or below permitted levels in areas that are less than10 ppm.*
3. *Monitor groundwater quality for other contaminates with nitrates.*
4. *Develop necessary groundwater quality management program(s) if other non-point source contaminants show signs of approaching or exceeding maximum safe levels.*

FIGURE 12.

Rules & Regulations

Rev.01-2016

Commodity Crop Growers in the Central Platte NRD must adhere to the following regulations

Phase I - between 0 & 7.5 ppm; Phase II - between 7.6 & 15 ppm; Phase III - 15.1 ppm or higher
Phase IV - Areas where nitrate levels are not declining at an acceptable rate

Because NRDs do not have the authority to regulate surface water, surface water irrigators are not required to take water samples or monitor water applications

	Phase I	Phase II	Phase III	Phase IV
Fall applications of N fertilizer **on sandy soils** are prohibited.	X	X	X	X
Fall N applications **on heavy soils** are permitted after November 1.	X			
Application of commercial nitrogen fertilizer is prohibited on all soils until after March 1st.		X	X	X
Commercial nitrogen fertilizer can be applied on sandy soils **after March 1.**	X	X		
Farm operators using nitrogen fertilizer **must be certified**. Certification good for 4 years.		X	X	X
Spring application of commercial nitrogen fertilizer will **require** split application [pre-plant/pre-emergent and sidedress (post-emergent)] or the use of an approved inhibitor on corn and sorghum. Up to 80 pounds of pre-plant/pre-emergent nitrogen can be applied without an inhibitor. **Operators who pre-plant/pre-emergent apply are required** to furnish **certification** from dealer than **inhibitor** was used at the recommended rate.			X	X
All crops must be reported (including corn, sorghum, potatoes, beans, alfalfa, small grains and any other commodity crop), on District approved report forms. **Reports will be due each crop year by March 31st and include** the legal description of well(s) irrigating the crop, acres of each crop and the crop planted. Crops other than corn, sorghum and potatoes do not have to take soil and water tests.		X	X	X
In addition to the above, the report for corn, sorghum, and potatoes must list the following for the **upcoming crop year**: expected yields, water and soil test results, credits for past legume crop and manure or sludge, and the UNL's recommended nitrogen application rate. The report will also include the following for the **previous crop year:** actual yields, fertilizer applied as pre-emergent or sidedress, and irrigation water applied. **Laboratory reports for soil, water and manure analysis, and an inhibitor receipt if used, must be submitted with the annual report.**		X	X	X
An annual **deep soils analysis** for residual nitrogen (NO3-N) on each field or 80 acre tract growing corn, sorghum or potatoes, whichever is smaller, with the analysis to be conducted by a laboratory participating in the Unversity of Nebraska Soil Testing Program. A composite sample tested must consist of a mixture from no less than one three-foot probe every five acres. **The report from the lab must be attached to the annual report.**		X	X	X
A **groundwater analysis** for nitrogen (NO3-N) content on each field growing corn, grain sorghum or potatoes must be made **annually. The report from the lab must be attached to the annual report.**		X	X	X
If **manure or sludge** is used, a **credit** for the nitrogen in the manure or sludge must be **used in the calculation** for the nitrogen recommendation. A laboratory analysis must be conducted for each source of manure or sludge and attached to the report form.		X	X	X
A **credit for previous year's crop** if the previous year was in beans, alfalfa, etc., must be used in the calculation for the nitrogen recommendation on corn and sorghum.		X	X	X
The **expected yield to be set by the District** (last 5 year average of regulated crop + 5%)				X
Nitrogen applications must not exceed District Recommendations with a copy of a fertilizer receipt attached to the annual report.				X
NRD Staff work with individuals on best management practices				X
Operators must **monitor groundwater applications** to allow for the better management of fertilizer applications and control leaching of nitrates.		X	X	X
Phase II, III and IV areas can be established in the future based on N levels in **Vadose Zone** or based upon **nitrate levels not declining** at an acceptable rate as determined by the Board of Directors.		X	X	X

46-707.

Natural resources district; powers; enumerated; fee.

(1) Regardless of whether or not any portion of a district has been designated as a management area, in order to administer and enforce the Nebraska Ground Water Management and Protection Act and to effectuate the policy of the state to conserve ground water resources, a district may:

(a) Adopt and promulgate rules and regulations necessary to discharge the administrative duties assigned in the act;

(b) Require such reports from ground water users as may be necessary;

(c) Require the reporting of water uses and irrigated acres by landowners and others with control over the water uses and irrigated acres for the purpose of certification by the district;

(d) Require meters to be placed on any water wells for the purpose of acquiring water use data;

(e) Require decommissioning of water wells that are not properly classified as active status water wells as defined in section 46-1204.02 or inactive status water wells as defined in section 46-1207.02;

(f) Conduct investigations and cooperate or contract with agencies of the United States, agencies or political subdivisions of this state, public or private corporations, or any association or individual on any matter relevant to the administration of the act;

(g) Report to and consult with the Department of Environment and Energy on all matters concerning the entry of contamination or contaminating materials into ground water supplies; and

(h) Issue cease and desist orders, following three days' notice to the person affected stating the contemplated action and in general the grounds for the action and following reasonable opportunity to be heard, to enforce any of the provisions of the act or of orders or permits issued pursuant to the act, to initiate suits to enforce the provisions of orders issued pursuant to the act, and to restrain the construction of illegal water wells or the withdrawal or use of water from illegal water wells.

Before any rule or regulation is adopted pursuant to this subsection, a public hearing shall be held within the district. Notice of the hearing shall be given as provided in section 46-743.

(2) In addition to the powers enumerated in subsection (1) of this section, a district may impose an immediate temporary stay for a period of one hundred eighty days on the construction of any new water well and on any increase in the number of acres historically irrigated, without prior notice or hearing, upon adoption of a resolution by the board finding that such temporary immediate stay is necessary. The district shall hold at least one public hearing on the matter within the district during

such one hundred eighty days, with the notice of the hearing given as provided in section 46-743, prior to making a determination as to imposing a permanent stay or conditions in accordance with subsections (1) and (6) of section 46-739. Within forty-five days after a hearing pursuant to this subsection, the district shall decide whether to exempt from the immediate temporary stay the construction of water wells for which permits were issued prior to the date of the resolution commencing the stay but for which construction had not begun prior to such date. If construction of such water wells is allowed, all permits that were valid when the stay went into effect shall be extended by a time period equal to the length of the stay and such water wells shall otherwise be completed in accordance with section 46-738. Water wells listed in subsection (3) of section 46-714 and water wells of public water suppliers are exempt from this subsection.

(3) In addition to the powers enumerated in subsections (1) and (2) of this section, a district may assess a fee against a person requesting a variance to cover the administrative cost of consideration of the variance, including, but not limited to, costs of copying records and the cost of publishing a notice in a legal newspaper of general circulation in the county or counties of the district, radio announcements, or other means of communication deemed necessary in the area where the property is located.

46-708.

Action to control or prevent runoff of water; natural resources district; rules and regulations; power to issue cease and desist orders; notice; hearing.

(1) In order to conserve ground water supplies and to prevent the inefficient or improper runoff of such ground water, each person who uses ground water irrigation in the state shall take action to control or prevent the runoff of water used in such irrigation.

(2) Each district shall adopt, following public hearing, notice of which shall be given in the manner provided in section 46-743, rules and regulations necessary to control or prohibit surface runoff of water derived from ground water irrigation. Such rules and regulations shall prescribe (a) standards and criteria delineating what constitutes the inefficient or improper runoff of ground water used in irrigation, (b) procedures to prevent, control, and abate such runoff, (c) measures for the construction, modification, extension, or operation of remedial measures to prevent, control, or abate runoff of ground water used in irrigation, and (d) procedures for the enforcement of this section.

(3) Each district may, upon three days' notice to the person affected, stating the contemplated action and in general the grounds therefor, and upon reasonable opportunity to be heard, issue cease and desist orders to enforce any of the provisions of this section or rules and regulations issued pursuant to this section.

46-709.

Ground water management plan; required; contents.

Each district shall maintain a ground water management plan based upon the best available information and shall submit amendments to such plan to the Director of Natural Resources for review and approval.

The plan shall include, but not be limited to, the identification to the extent possible of:

(1) Ground water supplies within the district including transmissivity, saturated thickness maps, and other ground water reservoir information, if available;

(2) Local recharge characteristics and rates from any sources, if available;

(3) Average annual precipitation and the variations within the district;

(4) Crop water needs within the district;

(5) Current ground water data-collection programs;

(6) Past, present, and potential ground water use within the district;

(7) Ground water quality concerns within the district;

(8) Proposed water conservation and supply augmentation programs for the district;

(9) The availability of supplemental water supplies, including the opportunity for ground water recharge;

(10) The opportunity to integrate and coordinate the use of water from different sources of supply;

(11) Ground water management objectives, including a proposed ground water reservoir life goal for the district. For management plans adopted or revised after July 19, 1996, the ground water management objectives may include any proposed integrated management objectives for hydrologically connected ground water and surface water supplies but a management plan does not have to be revised prior to the adoption or implementation of an integrated management plan pursuant to section 46-718 or 46-719;

(12) Existing subirrigation uses within the district;

(13) The relative economic value of different uses of ground water proposed or existing within the district; and

(14) The geographic and stratigraphic boundaries of any proposed management area.

If the expenses incurred by a district preparing or amending a ground water management plan exceed twenty-five percent of the district's current budget, the district may make application to the Nebraska Resources Development Fund for assistance.

Each district's ground water management plan shall also identify, to the extent possible, the levels and sources of ground water contamination within the district, ground water quality goals, long-term solutions necessary to prevent the levels of ground water contaminants from becoming too high and to reduce high levels sufficiently to eliminate health hazards, and practices recommended to stabilize, reduce, and prevent the occurrence, increase, or spread of ground water contamination.

46-710.

Ground water management plan preparation or modification; district; solicit and utilize information.

During preparation or modification of a ground water management plan, the district shall actively solicit public comments and opinions and shall utilize and draw upon existing research, data, studies, or any other information which has been compiled by or is in the possession of state or federal agencies, natural resources districts, or any other subdivision of the state. State agencies, districts, and other subdivisions shall furnish information or data upon the request of any district preparing or modifying such a plan. A district shall not be required to initiate new studies or data-collection efforts or to develop computer models in order to prepare or modify a plan.

46-711.

Ground water management plan; director; review; duties.

(1) The Director of Natural Resources shall review any ground water management plan or plan modification submitted by a district to ensure that the best available studies, data, and information, whether previously existing or newly initiated, were utilized and considered and that such plan is supported by and is a reasonable application of such information. If a management area is proposed and the primary purpose of the proposed management area is protection of water quality, the director shall consult with the Department of Environment and Energy regarding approval or denial of the management plan. The director shall consult with the Conservation and Survey Division of the University of Nebraska and such other state or federal agencies the director shall deem necessary when reviewing plans. Within ninety days after receipt of a plan, the director shall transmit his or her specific findings, conclusions, and reasons for approval or disapproval to the district submitting the plan.

(2) If the Director of Natural Resources disapproves a ground water management plan, the district which submitted the plan shall, in order to establish a management area, submit to the director either the original or a revised plan with an explanation of how the original or revised plan addresses the issues raised by the director in his or her reasons for disapproval. Once a district has submitted an explanation pursuant to this section, such district may proceed to schedule a hearing pursuant to section 46-712.

46-712.

Management area; establishment; when; hearing; notice; procedure; district; powers and duties.

(1) A natural resources district may establish a ground water management area in accordance with this section to accomplish any one or more of the following objectives: (a) Protection of ground water quantity; (b) protection of ground water quality; or (c) prevention or resolution of conflicts between users of ground water and appropriators of surface water, which ground water and surface water are hydrologically connected.

(2) Prior to establishment by a district of a management area other than a management area being established in accordance with section 46-718, the district's management plan shall have been approved by the Director of Natural Resources or the district shall have completed the requirements of subsection (2) of section 46-711. If necessary to determine whether a management area should be designated, the district may initiate new studies and data-collection efforts and develop computer models. In order to establish a management area, the district shall fix a time and place for a public hearing to consider the management plan information supplied by the director and to hear any other evidence. The hearing shall be located within or in reasonable proximity to the area proposed for designation as a management area. Notice of the hearing shall be published as provided in section 46-743, and the hearing shall be conducted in accordance with such section.

(3)(a) Within ninety days after the hearing, the district shall determine whether a management area shall be designated. If the district determines that no management area shall be established, the district shall issue an order to that effect.

(b) If the district determines that a management area shall be established, the district shall by order designate the area as a management area and shall adopt one or more controls authorized by section 46-739 to be utilized within the area in order to achieve the ground water management objectives specified in the plan. Such an order shall include a geographic and stratigraphic definition of the area. The boundaries and controls shall take into account any considerations brought forth at the hearing and administrative factors directly affecting the ability of the district to implement and carry out local ground water management.

(c) The controls adopted shall not include controls substantially different from those set forth in the notice of the hearing. The area designated by the order shall not include any area not included in the notice of the hearing.

(4) Modification of the boundaries of a district-designated management area or dissolution of such an area shall be in accordance with the procedures established in this section. Hearings for such modifications or for dissolution may not be initiated more often than once a year. Hearings for modification of controls may be initiated as often as deemed necessary by the district, and such modifications may be accomplished using the procedure in this section.

(5) A district shall, prior to adopting or amending any rules or regulations for a management area, consult with any holders of permits for intentional or incidental underground water storage and recovery issued pursuant to section 46-226.02, 46-233, 46-240, 46-241, 46-242, or 46-297.

(6) If a ground water management area has been adopted by a district under this section that includes one or more controls authorized by subdivision (1)(f) or (1)(m) of section 46-739, the district may request the Department of Natural Resources to conduct an evaluation to determine if an

immediate stay should be placed on the issuance of new surface water natural-flow appropriations in the area, river basin, subbasin, or reach of the management area, and the department may determine that the stay is in the public interest. The stay may include provisions for exceptions to be granted for beneficial uses as described in subsection (3) of section 46-714 or for a project that provides hydrological benefit to the area of the stay and may include provisions that the stay may be rescinded based on new or additional information that may become available.