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Investigating the Environmental Effects of Agriculture Practices on Natural Resources

Scientific Contributions of the U.S. Geological Survey to Enhance the Management of Agricultural Landscapes

The U.S. Geological Survey (USGS) enhances and protects the quality of life in the United States by advancing scientific knowledge to facilitate effective management of hydrologic, biologic, and geologic resources (http://www.usgs.gov). Results of selected USGS research and monitoring projects in agricultural landscapes are presented in this Fact Sheet. Significant environmental and social issues associated with agricultural production include changes in the hydrologic cycle; introduction of toxic chemicals, nutrients, and pathogens; reduction and alteration of wildlife habitats; and invasive species. Understanding environmental consequences of agricultural production is critical to minimize unintended environmental consequences. The preservation and enhancement of our natural resources can be achieved by measuring the success of improved management practices and by adjusting conservation policies as needed to ensure long-term protection.

Interdisciplinary USGS research and monitoring plays a key role in providing independent scientific information needed for the understanding, management, and mitigation of short- and long-term effects of agricultural practices on natural and human resources. USGS scientific information is used by a variety of stakeholders that include public, private, and special-interest groups, agricultural producers, and State, Tribal, and Federal governments that manage the Nation's natural resources.

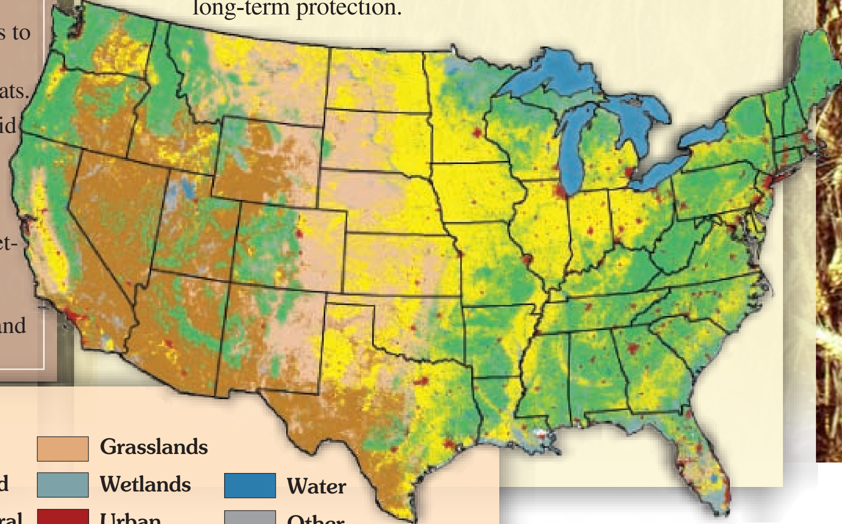
Science Issues and Needs Identified by the USGS, as Related to Environmental Impacts of Agricultural Practices

- Effects of land use change and habitat fragmentation on wildlife.
- Balancing conflicting urban and agricultural water demands.
- Influence of air and ground-water and surface-water interactions on water quality.
- Effects of agricultural drainage, irrigation, and return flow on water quality.
- Development and implementation of innovative farming techniques to conserve soil and water and to improve water quality.
- Effects of genetically modified organisms on native species and habitats.
- Tools for identifying sources of agricultural contamination and rapid assessment techniques.
- Effects of pesticides, nutrients, and sediments on fish and wildlife health and habitat quality.
- Effects of watershed characteristics—soils, riparian forests, and wetlands—effects on nutrient uptake, retention, and cycling.
- Transport and fate of endocrine disrupting compounds, veterinary antibiotics, feed additives, hormones, and pathogens in terrestrial and aquatic ecosystems.

Over half of the land in the Nation's lower 48 States is in crops, pasture, and range (Lubowski and others, 2006). By 2004, half of the original wetlands in the lower 48 states was converted to mostly agricultural uses (Claassen, 2004). From the start of European settlement until 1954, about 42 percent of original wetlands were drained and filled and used for settlement and agriculture. From 1954 to 1974, wetland loss was reduced by half (Wiebe and Golleron, 2006). Nearly all of the pre-settlement forest, prairie, and wetland areas in the Midwestern and Great Plains States have been converted to or affected by agricultural production.

Technological advances in agricultural production methods over the past 60 years have dramatically changed the character of agriculture. The number of farms declined from 6.8 million in 1935 to 2.1 million in 2002. Whereas small family-owned farms once produced the majority of the Nation's agricultural products, in 2003 small farms accounted for 91 percent of farms, but only 27 percent of total agricultural production. By 2002, half of the farm sales came from 2 percent of farms and 11 percent of the land in farms (Wiebe and Golleron, 2006). Support of this intensified agriculture requires larger fields, reduction in the types and rotations of crops, and greater reliance on agrichemicals (nitrogen, phosphorus, pesticides) to maintain high productivity.

Significant environmental and social issues associated with agricultural production include changes in the hydrologic cycle; introduction of toxic chemicals, nutrients, and pathogens; reduction and alteration of wildlife habitats; and invasive species. Understanding environmental consequences of agricultural production is critical to minimize unintended environmental consequences. The preservation and enhancement of our natural resources can be achieved by measuring the success of improved management practices and by adjusting conservation policies as needed to ensure long-term protection.

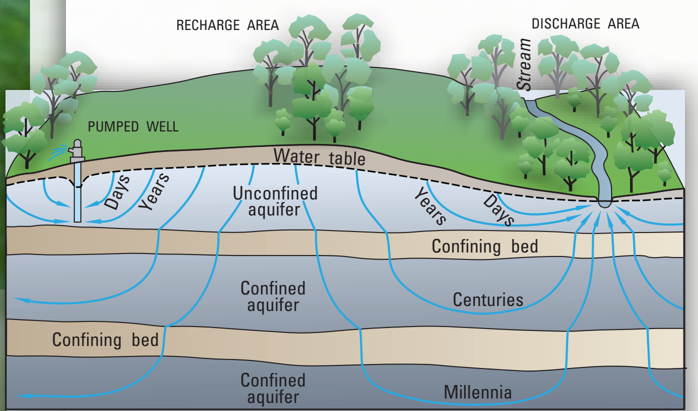


Land cover map of the conterminous United States from early 1990s data (Vogelmann and others, 2001; Nakagaki and Wolock, 2005).

Movement of Agricultural Chemicals Through the Hydrologic System

The key to understanding and managing effects of agriculture-associated chemicals, bacteria, and pathogens involves tracing the movement of compounds from where they are applied, knowing their persistence in the environment, measuring their transport and fate, and measuring their bioavailability and potential effects on humans and wildlife. Transport by air and water-soil mixtures are the two primary ways for compounds to travel from agricultural lands into surrounding environments. Effects of agricultural chemicals can vary widely depending on local topography, hydrology, soils, geology, and the rate and timing of applications relative to precipitation.

The USGS studies the movement of agricultural chemicals in the entire hydrologic cycle. Many studies of the behavior of chemicals applied to crops and soils have focused on crop uptake, soil quality, and surface runoff, and do not include the movement of these chemicals in the atmosphere, below the root zone, through the unsaturated zone, into ground water, and eventually into streams. USGS studies have shown that watersheds with large ground-water inflows generally respond more slowly to changes in chemical application rates than watersheds dominated by surface-water inflows (Bohlke, 2002). Tile drainage intercepts downward flow, or recharge, and delivers it quickly to streams, reducing the potential for nutrient reduction. Understanding the interaction of these processes is key to understanding associated movement of natural and agricultural chemicals. The amounts of chemicals transported can vary by several orders of magnitude due to fluctuations in precipitation, streamflow, and ground-water movement. It can be difficult to predict or measure the response of a watershed to changes in management if the watershed response to those changes is equal to or less than changes caused by natural variability. Understanding the hydrologic setting and its controlling variables can improve the design and efficiency of monitoring programs and models that measure or estimate watershed response to changes in management practices.



Ground-water flow paths vary greatly in length, depth, and travel time from points of recharge to points of discharge in the ground-water system. From Winter and others (1998).

Nutrients

Nutrient concentrations in streams and shallow ground water within agricultural areas are often elevated due to multi-year inputs of nutrients from fertilizers and manure (U.S. Geological Survey, 1999). Stream and shallow ground-water nitrate concentrations are especially elevated in the Midwest, where soils are often artificially drained to improve crop production.

The U.S. Department of Agriculture (USDA) estimates that 50 percent of cropland in Indiana has been artificially drained, and Indiana ranks second in total area artificially drained (U.S. Department of Agriculture, 1987). Most nitrogen transport through tile drains corresponds to the flow of water through the drains (Brouder and others, 2005). Thus, control of tile drainage is important in reducing stream and ground-water nitrate concentrations.

In addition, tile drainage changes soil chemistry, which can have long-term effects. Cropland that is removed from production and restored to wetland habitat may not fully recover to native vegetation because of soil chemistry changes from tile drainage.

The USGS is also examining impacts of agricultural practices on streams and reservoir quality in the Fort Cobb watershed, Oklahoma. Agriculture is the primary land use, with row crops, pasture grazing of cattle, and several large concentrated animal feeding operations (CAFOs) for hog production present within the watershed. Ground water is highly contaminated with nitrate, and Fort Cobb reservoir is highly eutrophic, meaning that it has high concentrations of nutrients that promote excessive plant growth and low oxygen levels (Fairchild and others, 2004). USGS research to determine the sources of nutrients to the reservoir will guide State land management agencies in the development and application of best management practices to reduce the levels of nutrients in the reservoir.

The University of Wisconsin Discovery Farm and Pioneer Farm Programs are designed to gather on-farm and water quantity and quality information from a variety of farming systems within different environmental settings to better understand the effects of agriculture on water resources. Here, USGS personnel participate in an educational program to explain findings to agricultural producers.

Pesticides and Emerging Chemicals

Pesticides and their degradates can be found almost any time of the year in streams draining extensive agricultural or urban areas. They are also often found in shallow ground water (Gilliom and others, 2006). Samples collected from 1992 to 2001 showed that at least one pesticide compound was detected 97 percent of the time in streams and 61 percent of the time in shallow ground water.

Atrazine is a commonly used herbicide that controls broadleaf weeds for a wide variety of crops. It has an estimated annual application of 76 million pounds. Atrazine is also an endocrine disrupting chemical that can cause reproductive problems in mammals, amphibians, and fish. It has a high potential for entering surface and ground waters because it is relatively persistent in soils and is moderately soluble in water. Gilliom and others (2006) documented that atrazine was the most commonly detected pesticide in both streams and ground water. Rates of atrazine occurrence were found to be similar in both agricultural and urban areas.

> Pesticide concentrations exceeded human-health benchmarks in about 10 percent of stream samples and about 1 percent of shallow ground-water samples. Aquatic-life benchmarks were exceeded in 57 percent of stream samples and 31 percent of bed-sediment samples. Wildlife benchmarks were exceeded in 87 percent of whole fish collected. Urban areas had similar concentrations due to domestic use of pesticides for lawn care, gardening, and household uses (Gilliom and others, 2006).

Well-drained soils that do not have artificial drainage are estimated to have the most number of atrazine detections in shallow ground water (for example, western Iowa and eastern Nebraska). Gilliom and others (2006) identified the major factors controlling the presence of atrazine in shallow ground water to be soil-infiltration rates, presence and extent of artificial drainage, water-holding capacity of soils, soil permeability, quantity of ground-water irrigation, the proportion of the landscape in agricultural land, and the quantity of atrazine applied (Stackelberg and others, 2005). These factors were used to predict frequency of atrazine occurrence across the U.S.

The USGS conducted a multi-year study to determine population-level implications of atrazine on metabolic pathways related to endocrine regulation (Tillitt and others, 2006). The study developed, characterized, and validated biomarkers that identify atrazine occurrence in liver and gonad tissues. These biomarkers are used in environmental assessments of the effects of atrazine in mammals, amphibians, and fish.

The USGS also has developed innovative passive sampling techniques for detecting persistent organic contaminants (organochlorine pesticides), current use pesticides, and emerging contaminants (pharmaceuticals, hormones, and wastewater chemicals). Passive samplers are deployed in surface water and provide information on the time-weighted average concentration of the bioavailable fraction of these organic chemicals. These techniques can be used in combination with bioindicator tests to provide a toxicological assessment of compounds present in a watershed. A USGS study (Petty and others, 2004) utilized these passive samplers for tracking chemicals from treated wastewater into and out of a wetland. This study helped State and Federal agencies determine the effectiveness of these wetlands in removing contaminants.

Apprehension about the effects of emerging contaminants, such as antibiotics and hormones, entering the environment from animal and human waste has raised questions about the likely occurrence of these chemicals in streams and ground water. The USGS began studies to examine the occurrence of many emerging contaminants used in veterinary medicine based on research of emerging contaminants in the United Kingdom and the Netherlands (Boxall and others, 2003). Common veterinary medicines include anti-microbials, anti-parasitic and anti-fungal medicines, hormones, growth promoters, anti-inflammatory medicines, anesthetics, and tranquilizers.

The persistence and toxicity of these medications are affected by environmental conditions such as temperature, pH, and soil type; consequently, these chemicals may degrade quickly or persist longer than expected (Boxall and others, 2003). Compounds may be transported quickly to surface waters via runoff or they may be transported slowly and persist months after use. Environmental concentrations of emerging compounds generally occur in amounts that are an order of magnitude lower than acute toxicity levels.

The USGS is conducting interdisciplinary research in the watershed of Fort Cobb Reservoir, Oklahoma, to better understand relations between land use and water quality.

Management controls required to minimize these compounds in the environment will depend on a greater understanding of the toxic effects of these chemicals on wildlife and humans.

Veterinary antibiotics and hormones have been found at low levels in streams in agricultural areas, but the effect of mixtures of many compounds and degradates, which may also be toxic, is not well understood. It is important to assess the presence and movement of these chemicals, as well as the short- and long-term risk to wildlife and humans.

Bacterial Indicators and Pathogens

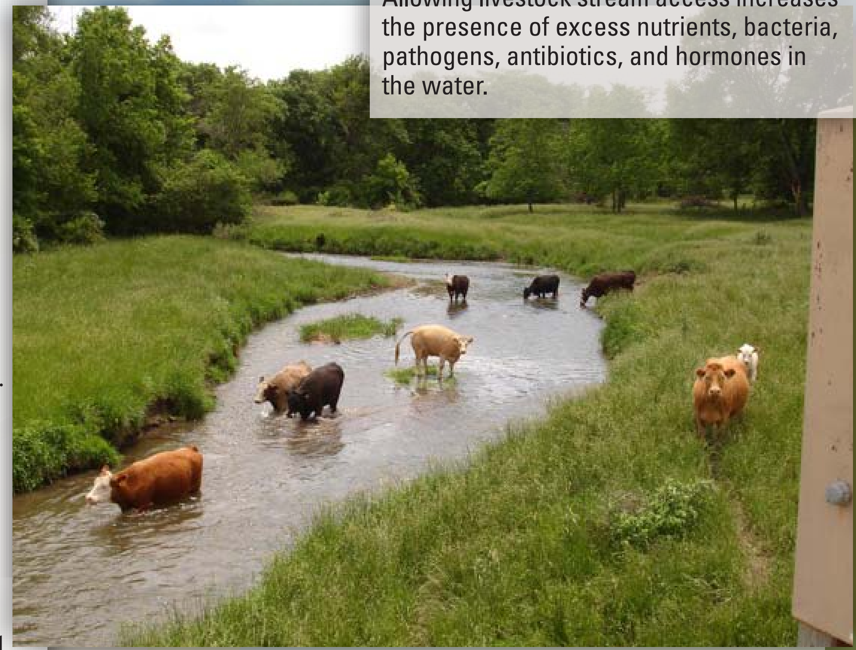
Animal agriculture can contribute excess bacteria and pathogens to streams and ground water if not properly managed. Practices such as grazing, storing manure in lagoons, and applying manure to fields must be properly sited and conducted under conditions that minimize the potential for microbial movement to streams and ground water. Fecal coliform bacteria in poultry litter survived for as long as 8 weeks in a Missouri stream that drained fields where litter was applied (Schumacher, 2003). CAFOs require particular attention because they house large numbers of animals in a small area. High numbers of bacteria and pathogens also can be introduced by other animals, such as large populations of wildlife or domestic pets in urban areas. A description of pathogens that relate to animal agriculture is available at http://lpe.unl.edu/pathogen.html

Development of techniques for determining the sources of bacteria and for analyzing pathogens directly helps to identify agricultural activities or areas that need better control. These techniques also are used to differentiate bacteria sources contributed by municipal and domestic sewage from those contributed by animal agriculture. Although many agencies and researchers are using source tracking of fecal contamination, the techniques can produce false identifications, and better tools need to be developed. The use of multiple lines of evidence, such as chemical and hydrologic evidence to identify transport pathways in addition to source-tracking techniques, provides the most reliable information on bacterial sources (Stoeckel and others, 2004).

Wetlands Ecosystem Services

Research began in 1967 at Cottonwood Lake, North Dakota, to understand the dynamic processes that support waterfowl and prairie wetlands in the prairie pothole region of the northern Great Plains (Swanson, 1987). Studies of soils, hydrology, water chemistry, and biotic communities (aquatic invertebrates and plants, amphibians, and birds) have demonstrated that hydrologic function and climate, in concert with the geochemical characteristics of prairie soils, are primary drivers of ecosystem function (Winter, 2003; Euliss and others, 2004).

Composition of wetland biological communities can shift drastically in response to climatic variations, which underscores the need to separate natural ecosystem drivers from agricultural influences (Euliss and Laubhan, 2005). Prairie wetlands cycle between climatic extremes of droughts and floods, which causes variability in wildlife habitat, flood-water storage, water-quality improvement, carbon sequestration, and ground-water recharge over time. The understanding gained through long-term study at Cottonwood Lake has implications for evaluating the effectiveness of USDA land conservation programs as well as providing guidelines for reestablishing, restoring, and preserving wetland functions that meet Farm Service Agency (FSA), Natural Resources Conservation Service (NRCS), and Department of Interior (DOI) objectives for wetland conservation.



Allowing livestock stream access increases the presence of excess nutrients, bacteria, pathogens, antibiotics, and hormones in the water.

Effects of Crops and Harvesting Practices on Waterfowl and Migratory Birds

Changes in agricultural practices and harvesting methods can have important effects on food sources of migratory birds and other wildlife dependent on agricultural lands. A USGS study (Krapu and others, 2004) in the Central Platte River Valley and Rainwater Basin area of Nebraska, important staging areas for bird migration, found that increased efficiency of corn harvest (up 47 percent over 25 years) and greater acreage devoted to soybeans has reduced availability of waste grains as a food source. The increased harvest efficiency resulted in decreased storage of fat by sandhill cranes and waterfowl on migration staging areas enroute to breeding grounds. Ongoing management discussions are evaluating how to provide adequate waste corn and high-energy foods to meet crane and waterfowl needs. Where possible, a wide distribution of roosting habitat is maintained in the Central Platte River Valley to disperse cranes and make food available near the river, shortening the distance that cranes fly to forage. Another strategy being considered is to establish scattered fields of corn grown specifically for crane needs; these fields would not be harvested until March to prevent waterfowl from consuming the corn before cranes arrive. These strategies are critical for determining the best ways to maintain agricultural production while providing for the migratory and reproductive needs of bird species.

Another USGS study in the lower Mississippi River alluvial valley investigated the effects of changes in rice production practices on the availability of waste rice seed for wintering waterfowl. Stafford and others (2006) sampled 150 rice fields over 3 years to determine the amount of seed remaining seasonally. This study has led to experiments comparing post-harvest management practices (such as disking and burning) that conserve waste rice following harvest with practices that would allow a second rice crop to be left in the field as waterfowl food. Regional managers have used these types of data to meet objectives for conserving foraging habitat as established by the Lower Mississippi Valley Joint Venture (LMVJV Migratory Bird Science Team, 2002).

Integrating Conservation into Agricultural Landscapes

In recent decades there has been a growing need for attention by the USDA for integration of effective conservation practices into agriculturally dominated landscapes (U.S. Department of Agriculture, 2001; Allen and Vandever, 2005). To be acceptable and more widely adopted by landowners, conservation programs must not present economic burdens in their application, and positive results must be observable to those participating. Since 1997, the USGS and the FSA have collaborated on research for maximizing management of over 34 million acres of land enrolled in the Conservation Reserve Program (CRP) to meet multiple environmental and landowner objectives. These studies focus on effects of grassland and conservation management practices (such as grazing, haying, buffers, and farmed wetlands) that address long-term quality of wildlife habitats associated with agricultural land use while meeting the expectations and limitations of operators enrolled in the program. Results from these CRP-focused studies have implications for management of lands enrolled in other USDA conservation programs such as the Environmental Quality Incentives Program (EQIP) and the Conservation Security Program (CSP). USGS studies have documented improvements that these conservation programs have made to increase wildlife populations, reduce soil erosion, and provide economic stability and social benefits to agricultural producers and the public (Allen and Vandever, 2003).

Science Understanding Enhances Protection of Natural Resources

The USGS relies on the complementary disciplines of biology, chemistry, geology, and hydrology to provide a multidisciplinary understanding of agricultural watershed processes. Monitoring the environmental consequences of agricultural land use and conservation effectiveness leads to improved scientific understanding of environmental conditions in both monitored and unmonitored areas. Identifying and understanding watershed processes is critical in identifying areas of the landscape that are most sensitive to contamination and in improving management practices.

Scientific results from USGS monitoring and research are freely available to the public and private sectors through published reports and Web-based sources. Landowners, scientists, and local, State, and Federal agencies with responsibilities for land, water resources, and wildlife can use this information to improve management of the Nation's natural resources.

Science-based management practices, refined through continued research and monitoring by the USGS and its partners, will lead to enhanced protection of the Nation's natural resources while maintaining an economically viable agricultural industry.

Sandhill cranes feeding in harvested cornfield in Central Platte Valley.

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