



Groundwater and Agriculture

I. Introduction

Agriculture requires a steady supply of water to meet crop and livestock requirements, linking food security directly to water security. Agriculture is the largest consumer of freshwater resources in the world and in the United States. Some countries do not have sufficient supplies of surface water to meet their agricultural demands, so groundwater is extracted to compensate for the difference. In the United States, about 65% of groundwater withdrawals are for agricultural irrigation which averages an estimated 50 billion gallons of water per day (1). The groundwater pumped from the country's largest aquifer, the High Plains aquifer in the central U.S., represents one-third of all U.S. irrigated agriculture and helps create an estimated \$20 billion annually in food and fiber (2), some of which may be for biofuels.

As the global human population is expected to reach 8 billion before 2036, food production will likely have to be doubled, despite limited freshwater supplies. Excessive groundwater withdrawals deplete aquifers and limit their future utility for water supply and food production. Agricultural fertilizers and pesticides used to increase crop production also can impact groundwater quality, as can animal waste. It is essential to implement management practices which maximize food production, minimize agricultural impact on groundwater quantity and quality, and minimize non-recoverable land subsidence.

II. Groundwater and Food Production

Nearly 90% of groundwater for U.S. irrigation is withdrawn by 13 western states, where, on average, the annual precipitation is less than 20 inches per year (3). The lack of precipitation, therefore, causes agriculture to extract groundwater to acquire enough water to maintain crop and livestock production.

Corn accounts for 25% of 56 million acres of irrigated cropland in the United States, followed by forage products such as hay (18%), soybeans (14%), vegetables and orchard crops (8%), cotton (7%), wheat (7%), and rice (5%) (4). Corn and soybeans are the highest revenue-producing crops in the country, accounting for \$81.8 billion in sales in 2015 (5). Nearly 19 million acres of corn and soybeans are irrigated by groundwater, equating to an estimated economic value of \$12.3 million (6). Groundwater extraction for food crops will face competing demand from water necessary for meat production and biofuels (7).

III. Agriculture and Groundwater Quality

Although 73% of the total amount of water used for mining geological deposits from the subsurface, such as coal, natural gas, and oil comes from groundwater, most of the groundwater withdrawn is saline (2).

Available evidence indicates that significant amounts of brackish groundwater exist around the country. For instance, Texas has an estimated 2.7 billion acre-feet of brackish groundwater. In New Mexico, 75% of groundwater is too saline for most uses without treatment.

Fertilizer and pesticides

Increased crop production has been aided by the application of fertilizer and pesticides. These chemicals may leach, or percolate, through soils to contaminate groundwater.

Croplands are estimated to be responsible for 96% of nitrates leached into groundwater (8). Although nitrogen runoff from fertilizer is more of a concern to surface water due to eutrophication hazards, excess nitrogen ingestion from drinkable groundwater can cause low oxygen levels in human infants and livestock disease (9).

A study of 51 hydrologic systems across the country found one or more pesticides present in groundwater near agricultural areas about 61% of the time (and 97% of the time in surface water) (10). Contact with pesticides may compromise human immune and hormonal systems, and cause cellular damage and other chronic health concerns. Proper application training is essential to limit pesticide application in accordance with accepted health protection standards.

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Animal waste

Livestock operations may contain thousands of animals in a concentrated area and may produce as much excrement as a small city (11). A single dairy cow produces about 120 pounds of manure per day which equates to the waste produced by 20-40 people (11). Animal fecal matter can enter groundwater, allowing for viruses and pathogens, such as *Salmonella* and *E. coli*, to contaminate groundwater.

Agriculture and salinization

Soil salinization is the process by which naturally occurring salts present in soil and water accumulate near the surface of the soil. Areas with low precipitation and high evaporation rates, such as in the western United States, are especially prone to salt accumulation in soils, which can reduce land productivity and leach into groundwater. U.S. agriculture overall experiences an annual estimated revenue loss of \$2.8 billion to soil salinization, with a 60-fold higher loss of revenue per acre in the western states than in the eastern states (12). High quantities of salt in groundwater can degrade the taste of drinking water, induce a laxative effect, damage ecosystems where groundwater discharges into surface water, and corrode subsurface infrastructure (13).

Biofuels

Ethanol is primarily developed from plants such as corn, sugar cane, or sorghum (14). Roughly 40% of corn grown in the United States is used for biofuels (15). Corn ethanol currently accounts for 90% of U.S. ethanol production (16). An estimated 15 gallons of water are required to produce 1 gallon of ethanol derived from corn (17). The amount of water used for bioethanol production depends on the type and location of crop used. Nearly all gasoline consumed in the United States, an estimated 140 billion gallons annually (18), is 10% ethanol by volume. Bioethanol production competes with food production for land, water, and human resources. Similar to crop production for food, growing crops for biofuel production has the potential to contaminate groundwater with fertilizer and pesticides.

IV. Agriculture and Groundwater Quantity

A growing demand for food production requires increased arable land, that is often achieved by clear-cutting of forests and the draining of wetlands and coastal areas. Such practices may contribute to groundwater depletion, that in turn may impact agricultural productivity.

Aquaculture

Aquaculture, or the cultivation of aquatic organisms such as plants, fish, and other aquatic animals, uses an estimated 1.82 billion gallons of groundwater per day in the United States (19). Aquaculture can damage freshwater and saltwater ecosystems by degrading habitats and reducing oceanic and wetland biodiversity. Wetlands and coastal areas, in particular, are of great value to local ecosystems, as they are essential not only for breeding commercial fish, but are also native habitats to one-third of the U.S.'s endangered and threatened species (20).

In order to lessen the exploitation of fresh groundwater, researchers are investigating the possibility of saline groundwater to cultivate marine species (21).

Land subsidence

Land subsidence is the gradual or sudden sinking of land, often as a result of groundwater pumping for agriculture and other purposes. More than 17,000 square miles in the United States have been, and continue to be, affected by land subsidence. Excessive subsidence has the potential to cause severe flooding and cause cracking, tilting, and other infrastructure damage. In 1991, the estimated damage caused by land subsidence exceeded \$125 million (22).

Irrigation technologies

Of the 56 million acres of irrigated land in the United States (23), 43% are irrigated by groundwater (1). The amount of U.S. land irrigated by groundwater has been increasing, with sprinkler and micro-irrigation systems accounting for half of the irrigated land in the United States (10). Flood irrigation is associated with high water consumption rates, while sprinkler and micro-irrigation technologies are much more water-efficient. Up to one-fourth of the water used in flood irrigation is saved with micro-irrigation techniques (24).

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V. Agriculture and Groundwater Sustainability

Virtual groundwater

Virtual water, or embedded water, is the volume of water required to produce a good or service at the place where the product was produced (25). In 2007, an estimated 9 trillion gallons of groundwater from the High Plains, Mississippi Embayment, and Central Valley aquifers was transferred as water embedded in food and other products. Between 45% to 58% of this virtual groundwater was transferred to states not overlying the aquifers and 9% of the virtual groundwater was transferred outside the United States (26). Virtual water demonstrates the value aquifers have in meeting nationwide food demand and underscores the potential vulnerability of food production.

Sustainable agriculture

About 30% to 40% of the world's food (27) comes from 973,000 square miles of irrigated land, of which 38% is irrigated by groundwater (28). Water conservation can be achieved by improving irrigation efficiency, which may be promoted by providing subsidies to decrease water use, or increasing the cost of water. According to the

U.S. Department of Agriculture, increasing irrigation efficiency by just 10% could potentially save agricultural production almost \$192 million per year due to reduced fuel consumption (29). Efficient irrigation, however, can result in increased water use because farmers may shift toward more water-intensive crops or to expanding irrigated acreage (30).

Precision farming, a concept made possible by satellite remote sensing, targets farm efficiency by using location and plant characteristics to optimize crop yield while preserving soil, water, and energy (31). Precision agriculture is predicted to reduce nitrate leaching by 47% and save up to 50% in applied water, depending on the geographic region (32). Education initiatives for farmers on water management and proper fertilizer application would further reduce nitrate leaching and reduce the cost of food production.

Whether it is through irrigation or strategic management, implementing sustainable food production practices is necessary for conserving groundwater and maintaining its availability for future use.

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