Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley

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Aquifer overexploitation could significantly impact crop production in the United States because 60% of irrigation relies on groundwater. Groundwater depletion in the irrigated High Plains and California Central Valley accounts for ∼50% of groundwater depletion in the United States since 1900. A newly developed High Plains recharge map shows that high recharge in the northern High Plains results in sustainable pumpage, whereas lower recharge in the central and southern High Plains has resulted in focused depletion of 330 km^3 of fossil groundwater, mostly recharged during the past 13,000 y. Depletion is highly localized with about a third of depletion occurring in 4% of the High Plains land area. Extrapolation of the current depletion rate suggests that 35% of the southern High Plains will be unable to support irrigation within the next 30 y. Reducing irrigation withdrawals could extend the lifespan of the aquifer but would not result in sustainable management of this fossil groundwater. The Central Valley is a more dynamic, engineered system, with north/south diversions of surface water since the 1950s contributing to ∼7× higher recharge. However, these diversions are regulated because of impacts on endangered species. A newly developed Central Valley Hydrologic Model shows that groundwater depletion since the 1960s, totaling 80 km^3, occurs mostly in the south (Tulare Basin) and primarily during droughts. Increasing water storage through artificial recharge of excess surface water in aquifers by up to 3 km^3 shows promise for coping with droughts and improving sustainability of groundwater resources in the Central Valley.

Gravity Recovery and Climate Experiment satellite | irrigated agriculture | managed aquifer recharge

Irrigation resolves spatial and temporal disconnects between water supply and water demand and allows us to grow crops in semideserts. Irrigation consumed ∼90% of global freshwater resources during the past century (1, 2) and represents 20% of cropland and ∼40% of food production (2, 3). During the past couple of decades, groundwater has become an increasingly important source of irrigation and currently is used in ∼40% of the area equipped for irrigation globally and 60% within the United States (4). Expansion of groundwater-fed irrigation is attributed to the ubiquity of groundwater, ready access to this resource, minimal infrastructure requirements, and general continuity of supply providing a buffer against droughts (5). A recent analysis reports an approximate doubling of global groundwater depletion between 1960 and 2000 and identifies several hot spots of depletion, mostly in irrigated regions, including the High Plains (HP) and California Central Valley (CV) aquifers in the United States (6).

With growing dependence of agricultural production on unsustainable groundwater use threatening future crop production, the following basic questions arise: How much groundwater has been depleted? Are we running out? What is the spatiotemporal variability in depletion? Can groundwater-fed irrigation be managed sustainably? Ground-based monitoring, modeling, and satellites [Gravity Recovery and Climate Experiment (GRACE)] have been used to estimate groundwater depletion in different irrigated regions (6–8). Maximum available blue water resources (rivers and aquifers) have only been depleted by ∼10% globally, suggesting that we are not running out of water; however, we may be running out of water locally and during droughts because of spatiotemporal variability in depletion (9). Unlike oil production, where the objective is to produce all available oil in a reservoir, groundwater production is often restricted by its impacts on surface water through reductions in groundwater discharge to streams, and effects on groundwater-dependent ecosystems, land subsidence, and water quality. Thus, with the exception of mining fossil groundwater, the total amount of groundwater storage depletion is primarily constrained by the effects of depletion on water flows, water quality, and/or heads (in the case of subsidence) (9, 10).

The objective of this study was to quantify spatiotemporal variations in depletion at the aquifer scale, determine controls on depletion, and evaluate approaches to reduce groundwater depletion. The analysis was conducted for the HP and CV aquifers because they are hot spots for depletion and are among the most intensively monitored aquifers globally. Understanding water sustainability of the HP- and CV-irrigated regions is important for future crop production in the United States. Analysis of groundwater depletion is based on water level monitoring in ∼9,000 wells in the HP and ∼2,300 wells in the CV. A map of groundwater recharge was developed in this study for the HP that complements previous site-specific recharge estimates. Groundwater depletion in the CV was examined using the newly developed CV hydrologic model (11). The GRACE satellites have also been used to monitor groundwater depletion in both aquifers (12, 13, 14). The impact of climate variability on water resources is addressed; however, effects of climate change projections are outside the scope of the study. The wealth of data for these aquifers provides an opportunity to advance our understanding of groundwater depletion and examine approaches to manage groundwater resources more sustainably. Unique aspects of this work are the synthesis of a variety of data from satellite and ground-based observations and numerical modeling and comparisons between the HP and CV aquifers to develop an understanding of spatiotemporal variability in groundwater depletion that is used to assess more sustainable management approaches.

Comparison of General Attributes of the HP- and CV-Irrigated Regions

The HP aquifer (450,000 km^2) and CV aquifer (52,000 km^2) are ranked first and second, respectively, among aquifers in the United States for total groundwater withdrawals (15) (Fig. 1 and Figs. S1 and S2). The HP is less intensively cultivated (39%

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