The influence of US water law on irrigation expansion

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Background

For decades, agricultural production in the US has largely been divided into two regions. West of the 100th meridian where annual precipitation is insufficient to support rainfed agriculture and East of the 100th meridian, where annual precipitation at least exceeds annual crop water needs making rainfed agriculture possible. In this region, the adoption of irrigation is optional, and is often considered in terms of the gross margin per rotated acre. However, expansion of irrigated land is also dependent on the availability of water and whether or not producers have the right to develop new water sources. Increased climate variability is making the decision to invest in irrigation increasingly attractive in the Corn Belt. Water withdrawals for irrigated agriculture were 129 million acre feet/year (maf) in 2010, which is 32% of the Nation's total water withdrawals. Although the trend of water withdraws declined 10% from 2005 and about 25% from 1990 (from 160 to 129 maf) due to increased efficiencies, the irrigated area has increased in the east (Fig 1b) over the last 20 years (2010-1990); in the west the expansion was very minimal (Maupin et al. 2014).

Figure 1 represents the amount of irrigated area in the US, which are mostly on the Western side and Figure 1b represents the patterns of change in irrigation. There is clear positive shift of irrigation from Western to Eastern US.

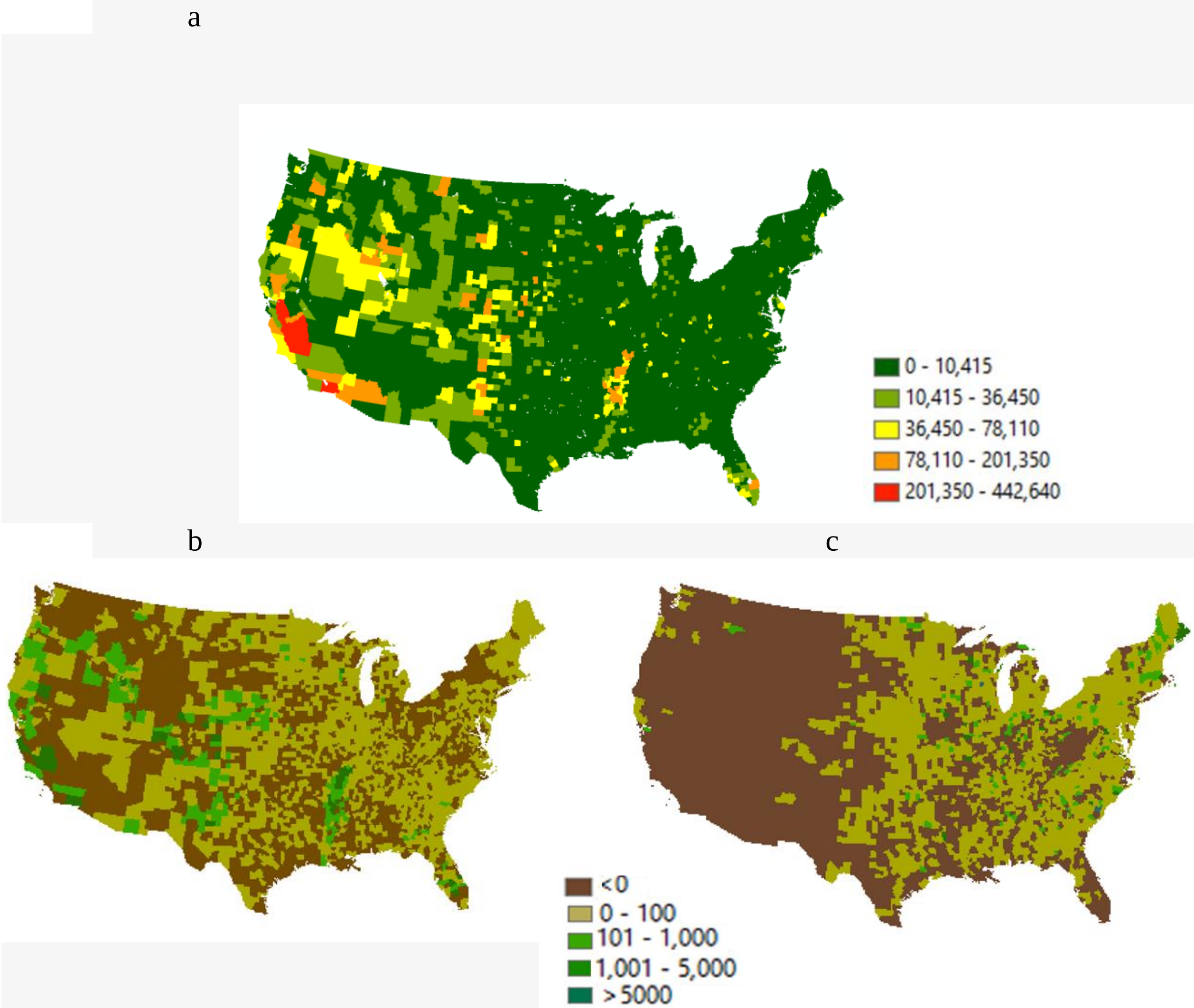

Figure 1: Total irrigated area (a) and change in irrigated area between (b)2000-1990 and (c)2010-2000.

Allocation of surface water and use of ground aquifers water vary from state to state and it is difficult to establish a unique rule for all. The role of water governance is to regulate water allocation, water withdrawals based on availability, and manage water stress situation of a region. In this work, a simple partial equilibrium model will be used to evaluate if the current structure of US water law has restricted the expansion of irrigated area over the last two decades.

Methods

Description of Simple model:

A multi-region multi-sector global partial equilibrium model, SIMPLE-on-a-grid is used to describe consumption and bilateral trade at the regional-level. Crop output and the demand for land are determined at the grid-cell level (5 arc-min) to better reflect the heterogeneous production response to commodity price change that takes place at the larger geographical scale. This model is modified from the peer-reviewed validated SIMPLE model (Baldos and Hertel 2014 Modifications highlight the split of irrigated and rainfed production, and a method to weight the rate of conversion to irrigated production by the dominant water governance structure in the state(sigma). Based on water availability, a parameter alpha is also introduced which controls the fraction of potential rainfed cropland to be irrigated. In this work, the SIMPLE-on-a-grid model will be used to evaluate if the current structure of US water law has influenced on the expansion of irrigated area over the last two decades. The model will be applied to current cropland areas in the US.

Sources of Data:

Cropland, Irrigated land and available data were composed from US geological survey and National land cover database as these data sources provide real-time digital information that were easy to analyze and process.

Cropland Data: National Land Cover Database 2011 (NLCD 2011) is the most current national land cover product by the Multi-Resolution Land Characteristics (MRLC) Consortium. NLCD (2011) is primarily based on circa 2011 Landsat satellite data. It provides 16 land classification for the whole US and in this project, only cropland data was used. Cell size of original data was 30 meter. Data was reprojected into 1 arc second. Cropland data was then aggregated by summing all cropland pixels to get 5 arc minutes from 1 arc second. According to National Land Cover Data the cropland area in the U.S. in 2011 was around 125 million hectares (Homer et al 2015).

Irrigated Area (A_i): The U.S. Geological Survey collects and compiles national water use data by county every five years (USGS). These water use reports all include estimates of irrigated land area. The fraction of irrigated cropland for each county was calculated and disaggregated to 5-arc minute resolution. The next step was to multiply this disaggregated irrigated fraction with 5-arc minute cropland area to get total irrigated area (A_i). Total Rainfed area (A_r) was obtained by subtracting the irrigated area from cropland area. The unit of cropland, irrigated area and rainfed land area is in hectares.

The volume of irrigation per hectare was calculated by dividing the total amount of fresh water withdrawals for irrigation by irrigated land area for each county level. The county average irrigation rate was then disaggregated to 5-arc minute resolution.

Water availability (WA): Water availability for irrigation is dependent on surface water runoff and groundwater recharge. For surface runoff, the USGS Water Watch Total Runoff product was used. USGS Waterwatch runoff is based on observed streamflow at gauging stations normalized by watershed area. For groundwater recharge, Wolock (2003) data has been used. The groundwater recharge rate is estimated based on observations of stream baseflow, so it represents the groundwater recharge that eventually emerges to surface water bodies. Restricting water availability to groundwater recharge means that groundwater mining is not considered in this model application. Geological Survey's (USGS) water watch provides a comprehensive and long-term storage of annual runoff data since back to 1910. For total runoff, the average runoff from 2006-2010 and 1986-1990 has been used to match the time period in the USGS water use reports for irrigation.

Land expansion coefficient, alpha (α): Alpha is an input parameter to the SIMPLE model that constrains the fraction of rainfed cropland that could be converted to irrigation. By calculating alpha, the availability of future irrigation area expansion is known. Alpha is dependent on the availability of water, irrigated area and rain fed land, and it was calculated by the equation below:

$$\alpha = (WA - I*A_i)/(I*A_r) \qquad (1)$$

Where A_r is the Rainfed area (ha), A_i is Irrigated area (ha), I is irrigation rate (m3/ha/yr). WA is the amount of Water Available (m3/yr) and it is equal to available surface water plus groundwater.

Irrigable area: Irrigable area is the product of rainfed area and alpha. Where surface water is limited, groundwater withdrawals are most prevalent for irrigation. In most areas, groundwater and surface water system are interlinked, excessive water withdrawals can alter the water movements from aquifers to stream, and lakes which effects the flow of groundwater that release into surface water. Excessive water withdrawals result in a reduction of ground water and surface water availability. Irrigation expansion is not possible where the amount of water withdrawal is higher than available water. It is possible to expand irrigation in those areas where water availability exceeds maximum irrigation water demand (USGS 2003).

Water Rights: A common set rules for ground and surface water is very challenging to establish due to the availability of water and site specific geology. Overall the six primary water doctrines shown in Figure 2, are based on only two conceptual pathways: law based on property rules and appropriation law. The first permits unlimited withdrawals of water by riparian property owners. In the second system rights to withdrawal water are separated from property ownership, and instead the first party to access the water has the right. Over time, different components have been added into these two basic laws, such as: water users have a time limited permit and they cannot extract water more than their proportion of property ownership (Figure 2).

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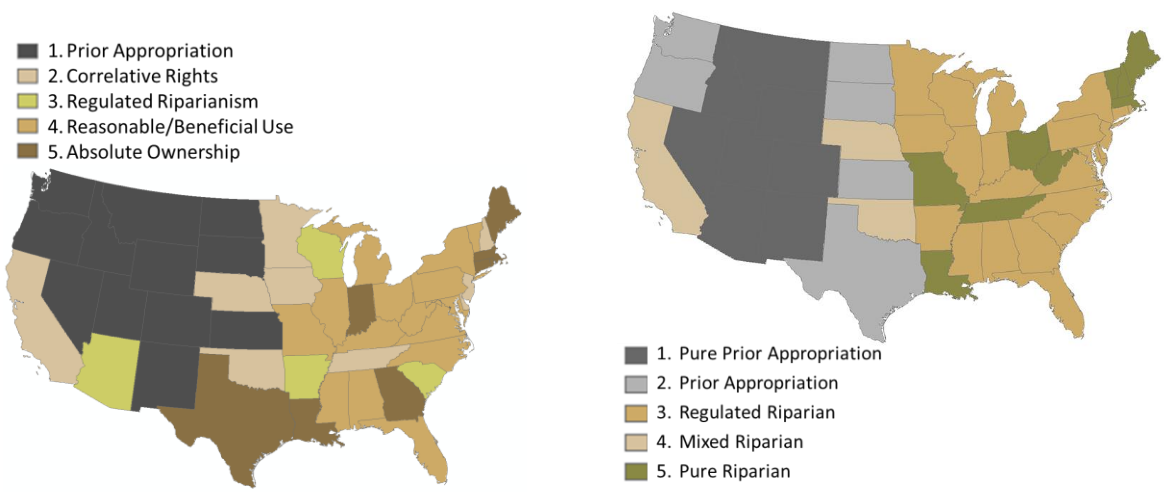

Figure 2: a) Ground water and b) Surface water doctrines in the U.S

In order to represent the complexity of water governance structure in the SIMPLE-on-a-grid model, all of the states are classified into six groups (from 1-6, one is the most restrictive and six is least restrictive) based on restriction for water uses/withdrawals. These will be used as an exogenous variable in SIMPLE-on-a-Grid model. By aggregating water restriction rules across grid cells for the entire U.S., the limitations of irrigated area expansion or contraction at a state level are determined. Simulated results for change in irrigated land from1990-2010 will be compared with the observed change to evaluate the model.

Weighted average of water rights sigma (σ) controls the rate of transfer between irrigated and rainfed agriculture in the SIMPLE model. We calculated sigma (σ) by following equation:

$$\sigma = (SW*SW\sigma + GW*GW\sigma)\ /SW+GW \tag{2}$$

Where, SWσ is the ranking of restriction for surface water rights and GWσ is the ranking of restriction for ground water rights.

Analysis

Irrigated area in the US has changed over the years due to economic demand and supply response and variable weather condition which is reflected in Figure 3 (1990 to 2010).

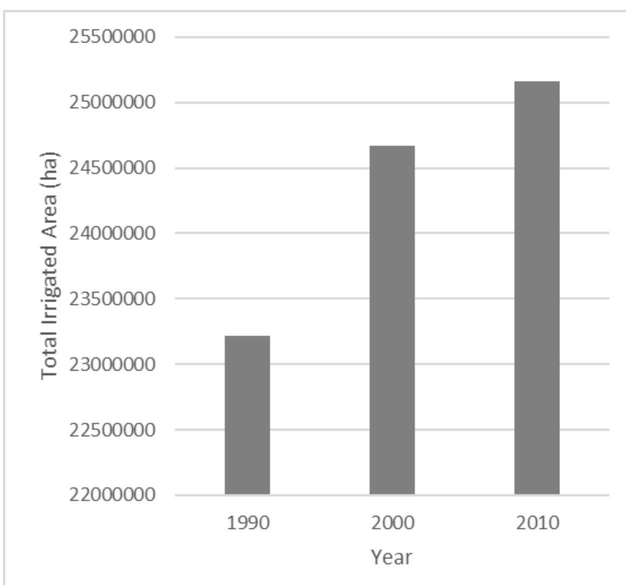

Figure 3: Total irrigated area increased over 20 years over the contiguous US (1990-2010).

Irrigated area expansion has been occurred across the US in 2000-1990 region. On the other hand, in Figure 1c, areas in brown color experienced a decrease or no change in irrigated area (mostly western states) whereas other colors indicate positive change in irrigated area (i.e. eastern and southern states-except parts of Florida and Texas) between 2010 and 2000. In 2000-1990. Change in irrigated area is high in Eastern region due to its humid weather and water availability. Rainfed agriculture mainly dominates in the eastern half of the US where precipitation is greater than 500 mm/year (Dellapenna 2005). Total rainfed area in the US can be classified into two types: irrigable and non-irrigable area (Figure 5). Comparing Figures 5 and 6 it is clear that the spatial pattern of currently irrigable land is very similar to the pattern of decreases/increases in irrigated land area over the last couple of decades.

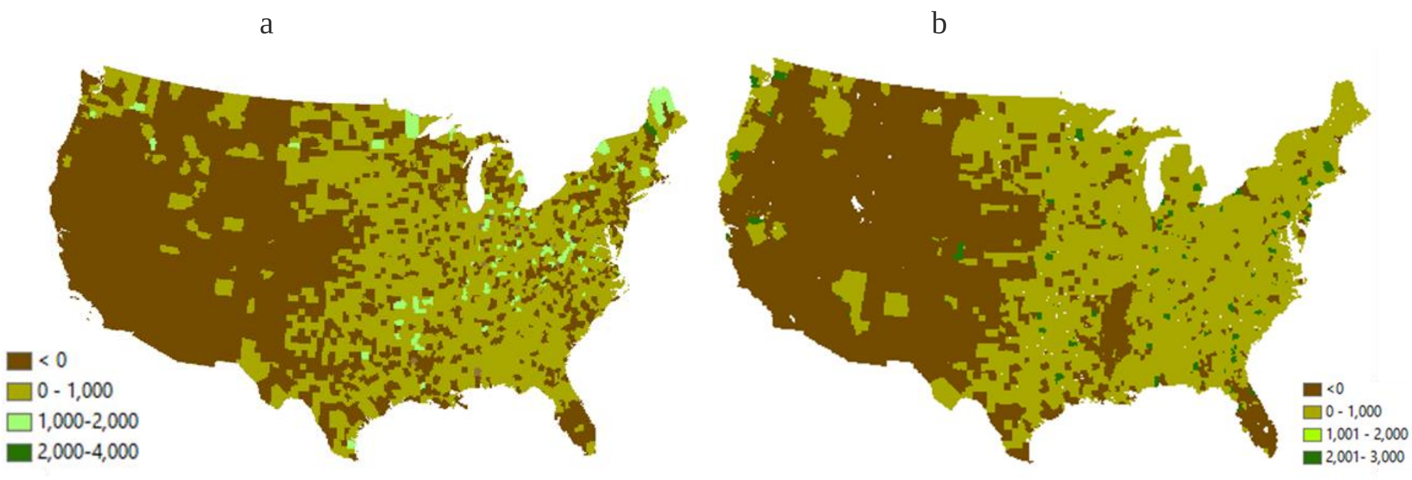

Figure 5: Irrigable area of US a) 2000-1990 and b) 2010-2000

Figure 6 indicates that the observed change in irrigated area relates with alpha. When alpha is negative, irrigated area decreased in the western side of US and irrigated area increased with increasing alpha. In some cases, higher value of alpha showed negative relationship which can possible if the cropland areas of specific states are small, such as: Alabama, Arkansas, Connecticut, Pennsylvania etc.

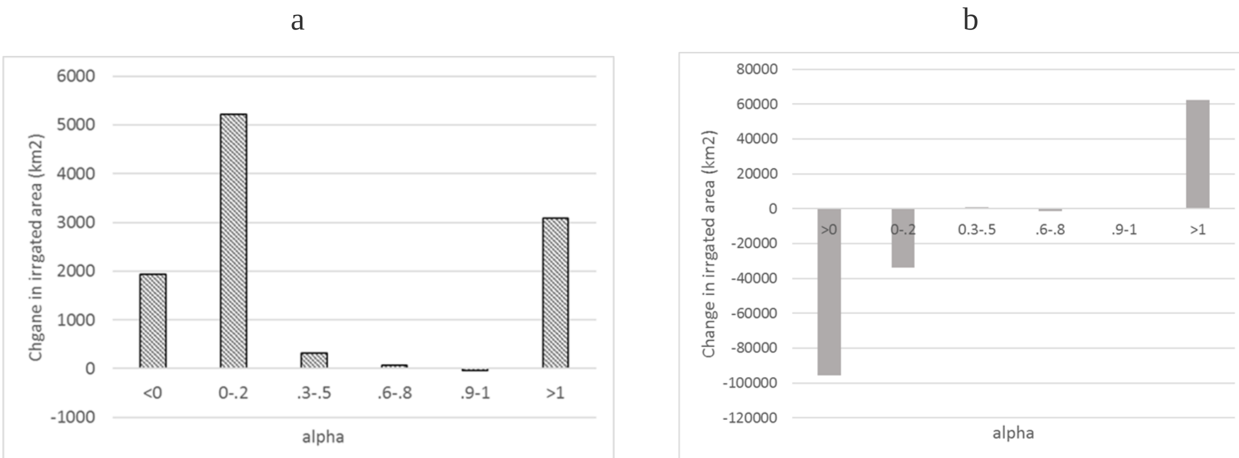

Figure 6: Change in irrigated area vs alpha a) 2000-1990 and b) 2010-2000

The weighted average water rights classification calculated using equation 2 is shown in Figure 7. The western and eastern US differ in their water rights and developed different approaches related to water. In general, water is being treated as common property in the East whereas in Western states water is being treated as private property (Franzluebbers 2011). This east/west difference is also reflected in our calculation of weighted average of water rights, (sigma) Figure 8. A lower value of sigma indicates that development of new water resources is more restricted by water rights and higher ones are more lenient for water use and consumption.

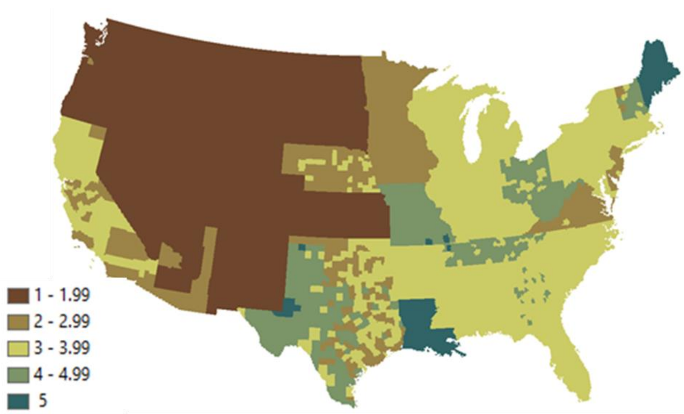

Figure 7: Weighted average of water rights

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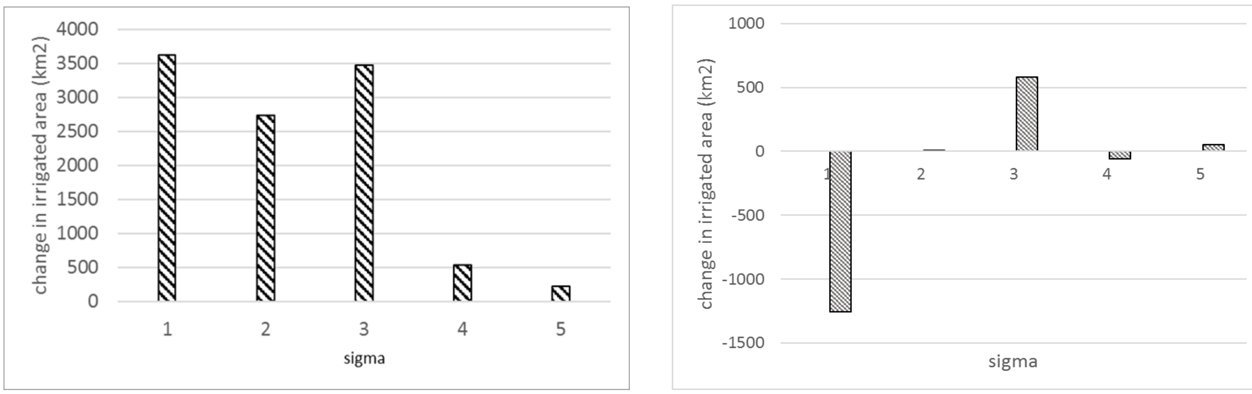

Figure 8: Change in irrigated area reflects by sigma a) 2000-1990 and b) 2010-2000

Conclusions

A clear trend of irrigation expansion has observed in Eastern region regardless of water rights. However, some of the places where irrigation expansion is possible, average change in irrigation decreased which required further analysis.

After analyzing alpha, sigma and their influence on change in irrigated area, it can be summarized:

- Over the last couple of decades irrigated land area has increased in the US by 8.35%, however most of this expansion occurred in the Western and Eastern US in 2000-1990, while irrigated area in the western US largely decreased in 2010-2000 period.
- The regions of decreased irrigated area largely correspond to areas with zero irrigable land, either because there is no non-irrigated land left or because of lack of water availability.
- Areas of increase in irrigated land are not linearly related to either water availability or the perceived leniency of water rights. The largest increases in irrigated area occurred in states that follow reasonable use or correlative rights doctrines.

References:

1. Baldos, U.L.C., Hertel, T.W.,2014. Global food security in 2050: the role of agricultural productivity and climate change. Aust. J. Agric. Resour. Econ. doi:10.1111/1467-8489.12048.

2. Dellapenna W. J., 2005. Water law in the Eastern United States: No longer a Hypothetical Issue.26 Energy & Min.L.Inst. chapter 11Franzluebbers, A., 2011. Rainfed farming system in the USA. USDA Agricultural Research Service -Lincoln,Nebraska.

3. Ground-Water Depletion Across the Nation. U.S Geological Survey Fact Sheet 103-03 November 2003.

4. Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015. Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing 81(5):345-354.

5. US Geological Survey: water use in the United States (https://water.usgs.gov/watuse/data/).

6. Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S.2014. Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405:56.