

Groundwater Management Policy Strategies for Effective Conservation of the Ogallala Aquifer

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Introduction

Background

The project seeks to maximize the net benefits from limited groundwater in the high priority areas (HPA) of irrigation overlying the Ogallala aquifer in Oklahoma. The goal of the project is achieved by determining the optimal location and size of the cooperative irrigation district (CID) in the HPA of irrigation that will give the maximum benefit of conserving the groundwater for future use. The major irrigated area in the High Plains of Oklahoma is the Oklahoma Panhandle (OP), which consists of Beaver, Cimarron, and Texas counties.

The primary irrigation source for the OP is limited groundwater from the Ogallala aquifer. For many decades, crop producers in the High Plains of Oklahoma are suffering from a continuous decline in the groundwater levels. Farm and Ranch Irrigation Survey, 2013 report shows that 99% of irrigation water pumped in the OP is from the Ogallala aquifer. The rainfall in the OP is far below the average rainfall received in the state of Oklahoma. Average annual rainfall in the OP from 2003 to 2017 ranges between 41 and 55 cm (MESONET 2018). The average annual groundwater recharge in the OP is almost less than 0.65 cm/year (Ochsner et al., 2014). Thus, crop producers in the OP face steady groundwater decline because the annual groundwater extraction exceeds the recharge rate. Due to low rainfall and little recharge, growing crops using irrigation water has caused groundwater levels to decline at the rate of 30 to 90 cm/year (McGuire, 2017). The continuous decline in groundwater has caused severe concerns about the life of the Ogallala aquifer in the High Plains of Oklahoma. Crop producers in the OP are interested in water conservation and improving irrigation technologies to reduce groundwater use as well as gain benefit from irrigated crop production.

Economic studies (Bosch et al., 1992; O'Brien, et al., 1998, Lamm et al., 2015; and Ramaswamy et al., 2017) conducted in southern High Plains to extend the life of the aquifer have suggested to replace the center pivot (CP) with more efficient subsurface drip irrigation (SDI). Irrigation studies (Klocke et al., 2014 and Warren et al., 2016) have indicated that replacing corn with more drought-tolerant grain sorghum. However, past efforts to conserve groundwater in the OP have been considerably unsuccessful; thus, mandated policy intervention may be considered to extend the life of the aquifer. Recent studies on forming groundwater management district in northwestern Kansas show that annual water use reduced by 20 percent (Golden, 2017). In 2017, the Oklahoma Water Resource Center project (USGS 104b) conducted by the current authors focused on constructing CID in the various hydrological setting with homogenous aquifer depth. In this present study, we focus on establishing the optimal size of CID in the HPA of irrigation in the OP, given the information of aquifer depth and hydrological properties of the aquifer basin underlying the HPA.

Objectives

The principal objective of this study is to identify the size of the CID and allocate irrigated corn or grain sorghum, and irrigated winter wheat considering the hydraulic properties of the aquifer basin connected to the CP fields. The OWRB monitoring groundwater well information represents the available groundwater for the CP fields within the aquifer basin. The specific objectives are,

- to identify the hydrological parameters and well depth for each CP fields in the HPA of irrigation using CropScape and geographic information system (GIS)
- to evaluate optimal irrigation amounts for the CP fields in the CID who maximize the benefit of the remaining groundwater for 15 years using mathematical programming model for conserving producers
- to evaluate the irrigation amounts for the CP fields for the short-term maximizing producers who are not in the CID using a recursive programming model
- to determine the seasonal groundwater levels under the CP fields using MODFLOW simulation model
- to identify the optimal size and location of CID in each HPA that will retain at least 95% of the saved groundwater within CID as well as increase the benefit of saving the groundwater

Methods

This study integrates the framework of GIS, crop management, and economic modeling to maximize the net benefit from declining groundwater in the HPA of irrigation in the OP. Extensive application of GIS has facilitated the representation of crop fields in more detail for optimal long-term planning (Boulaxis, 2002). However, most of the studies conducted on irrigation planning at a regional level using integrated GIS-economic modeling are with watershed networks (McKinney and Cai, 2002; Guvele and Featherstone, 2001; and Yang et al., 2003).

In this study, the methodology has three general procedures. The first step was to determine the HPA of irrigation in the OP according to the hydrological properties. The second procedure was to determine the head values (groundwater levels) for each CP fields in the HPA. The third and final step was to determine the optimal size and location of CID that will give the maximum benefit for the conserving producers.

Cropland satellite images in the form of raster files from CropScape (developed by National Agricultural Statistics Service) were obtained for the entire OP. The raster files transformed into polygons representing CP fields irrigating corn, grain sorghum, and winter wheat. The auto stratification process used to remove non-irrigated lands (polygons) from the shapefile. The irrigated cropland area were validated with the ground truth data of NASS. Once the irrigated land is validated, the CP fields merged with the aquifer properties of hydraulic conductivity and specific yield of the aquifer basin in the HPA of irrigation. The depth of the nearest OWRB monitoring well for the CP field was assumed as the saturated thickness for each CP field. In this study, CID was tested in at least two HPA of irrigation in all three counties. CID producers conserve the groundwater by following a long-term profit maximization, and producers not in CID maximize annual profits without considering the future "User's Cost."

The CP field locations, depth of the saturated thickness and irrigation amounts are entered into the MODFLOW simulated model to determine the annual groundwater levels for each CP field. The overall net benefit is determined using a mathematical programming model using General Algebraic Modeling Systems (GAMS) solved in a desktop computer. Finally, the rate of groundwater decline for short-term producers (not in CID) and long-term producers (in CID) are entered into GIS to display thematic maps for 15 years.

Preliminary Results

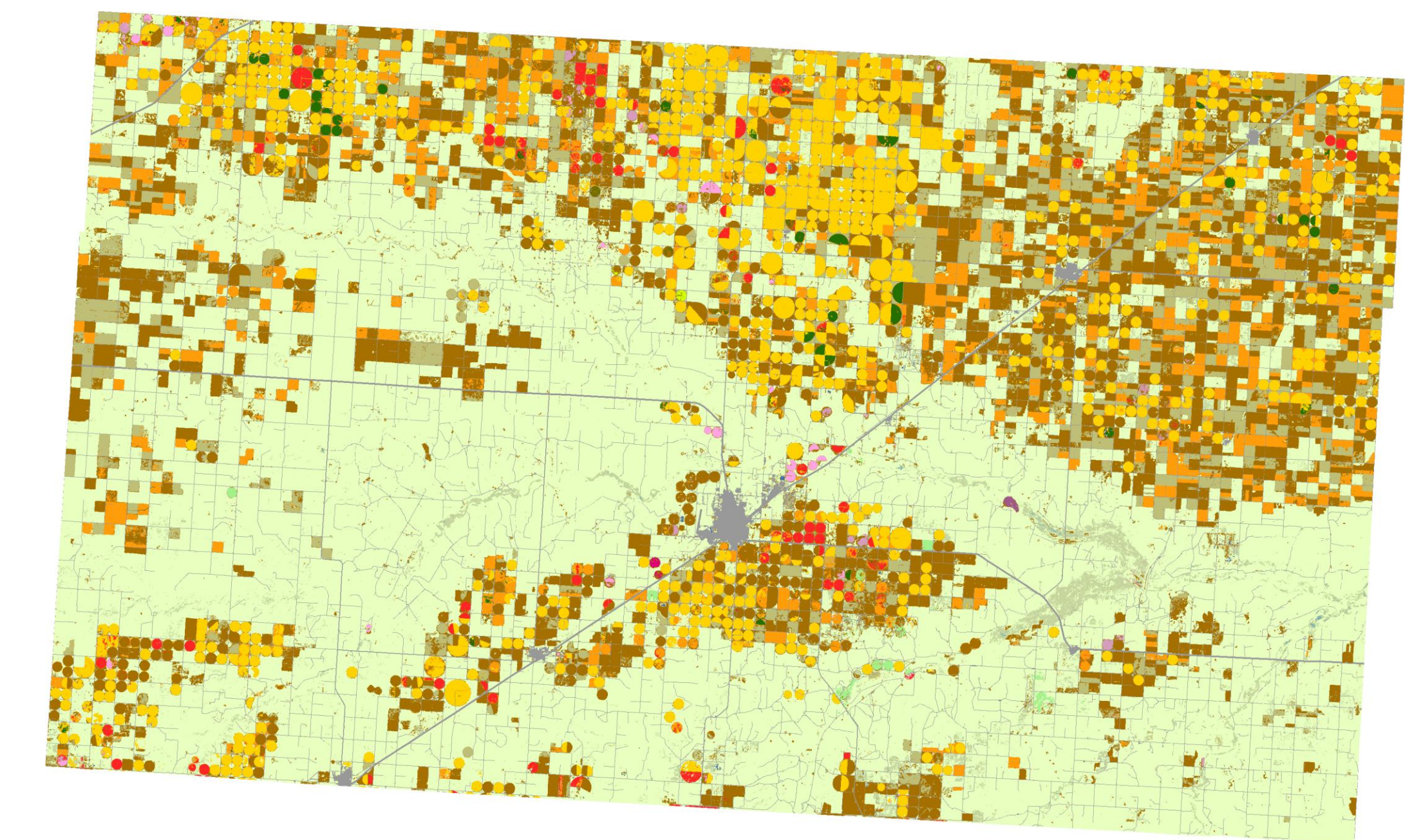


Figure 1. Image downloaded from CropScape as Crop Data Layer (CDL) of crops grown in Texas County, Oklahoma in 2017

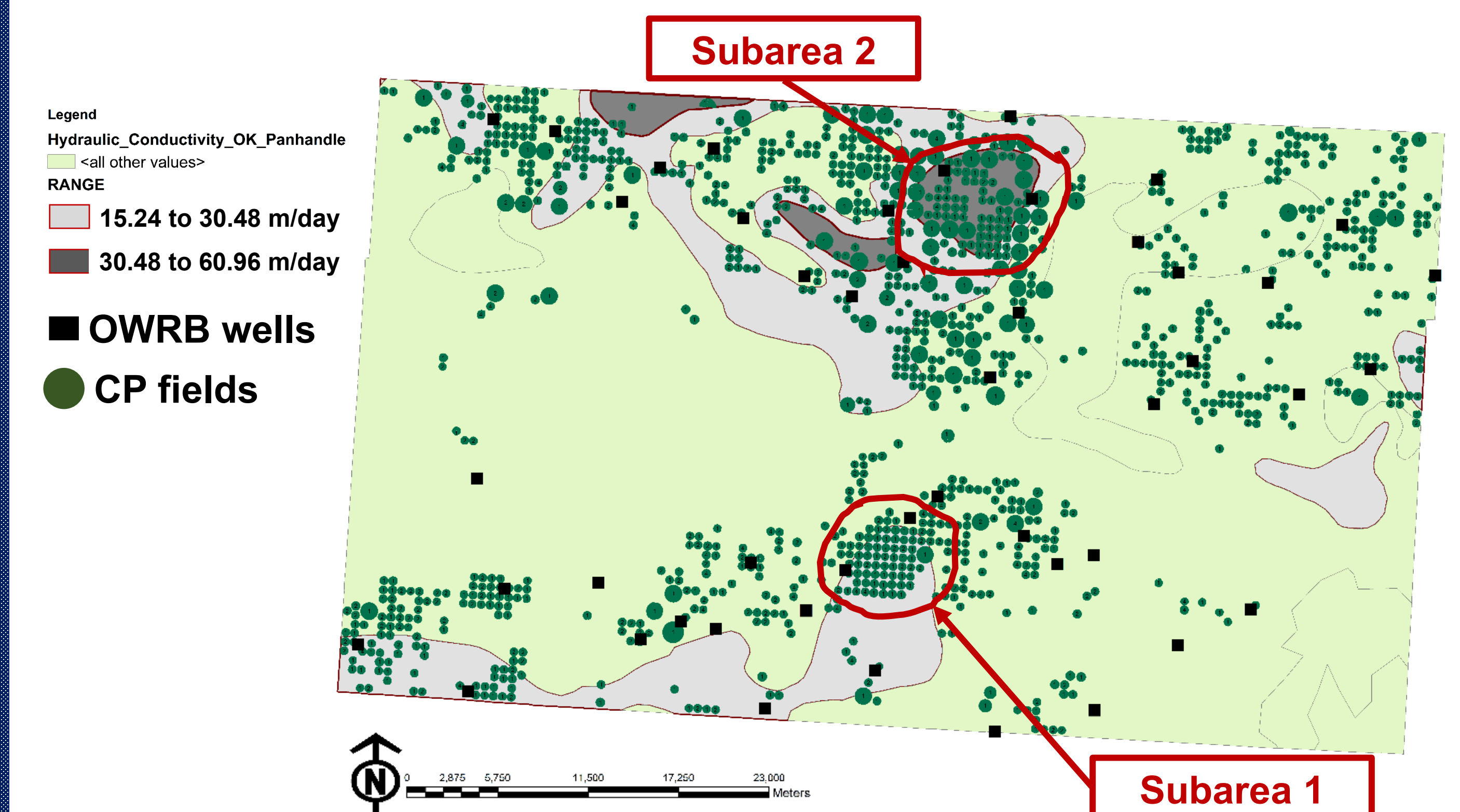


Figure 2. Image showing the CP fields (corn, sorghum, and wheat), OWRB monitoring wells, and hydraulic conductivity of aquifer basin in Texas County, Oklahoma

Table 1. Hydrological parameters of HPA of Irrigation (Subarea 1 & Subarea 2) in Texas County, Oklahoma

Item	Subarea 1	Subarea 2
Total Depth (m)	98.15	125.58
Static water level (m)	65.23	79.25
Saturated Thickness (m)	32.92	46.33
Available Saturated Thickness (m)	22.25	35.66
Hydraulic Conductivity (m/day)	15.24	30.48
Specific Yield	0.175	0.175
Total Water Supply/CP (ha-cm)	25,212	40,409

Acknowledgment

Oklahoma Water Resources Center (OKWRC)
United States Geological Survey (USGS)
Oklahoma Water Resource Board (OWRB)