Image caption: On-farm water storage ponds can be used for irrigation. Photo from Open Rivers.

Tracking the Growth of On-Site Irrigation Infrastructure in the Arkansas Delta with Remote Sensing Analysis

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Abstract: Surface water impoundments built on farms to store water in the wet season for irrigation later in the year are one approach to reduce groundwater pumping and to sustain aquifers. However, there is limited information on where and how many of these reservoirs are present in Eastern Arkansas. This information would be useful to formulate effective policies to encourage the construction of more surface water systems. Analysis of Landsat imagery from 1995 to 2015 provides evidence for where and when reservoirs and tail-water recovery systems are present, doing so with annual resolution. Comparing our analysis – which extends the Dynamic Surface Water Extent (DSWE) algorithm for Landsat to identify irrigation storage reservoirs in Arkansas County – to the verified locations of these surface water impoundments, the analysis identifies 98% of all reservoirs in the verified study area.

Key Points:

- Publicly available imagery can identify on-farm surface water storage in Eastern Arkansas.
- The algorithm developed to identify the facilities for surface water storage identifies more than 98% of verified reservoirs.

Introduction

The sustainability of the Mississippi River Valley Alluvial Aquifer (MRVAA) is vital to maintaining long-term agricultural profitability in Arkansas (Maupin and Barber, 2005; Konikow, 2013). The extent of the aquifer includes seven states, and Arkansas is the largest consumer of water from the aquifer (Maupin and Barber, 2005). Although Arkansas has often been considered an area rich in water resources with annual precipitation amounts ranging from approximately 50 to 57 inches (NOAA, 2014), there are several key constraints to maintaining agricultural profitability in the region. The first is lack of timely rainfall, and the second is the increasing need for irrigation. The number of irrigated acres continues to increase in Arkansas in order to maintain and increase yields and mitigate risk as a result of recurring drought conditions (Vories and Evett, 2010). Moreover, most irrigated acres result from producers privately funding the installation of irrigation wells that draw groundwater from the MRVAA. It is known that the current rate of withdrawals from the aquifer is not sustainable, especially as the number of irrigated acres continues to increase each year (Barlow and Clark, 2011; ANRC, 2012; Evett et al., 2003).

The Agricultural Act of 2014 (or 2014 U.S. Farm Bill) introduced the Regional Conservation Partnership Program (RCPP) which consolidated several programs including the Mississippi River Basin Healthy Watersheds Initiative, Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP), in order to promote coordination between Natural Resources Conservation Service (NRCS) and its partners and provide technical and financial assistance to producers and landowners. These federal and state programs encourage more efficient and effective irrigation and have contributed to the voluntary implementation of water conservation practices such as tail-water recovery ditches, on-farm storage reservoirs, and use of sensor technologies, to name a few. Despite the prevalence of programs that are targeted to help farmers sustainably manage agro-ecosystems in Arkansas, the level of information about the use of these management practices and technologies is less than ideal and can be improved significantly. We do not yet know how much adoption of water conservation measures has already occurred and to what extent these various water conservation measures reduce pumping pressure on the MRVAA. This lack of knowledge is a pressing problem, especially as federal incentive programs face increased public scrutiny. We need to determine if conservation practices are effective at reducing groundwater declines in the MRVAA and also which practices are most frequently adopted and retained by farmers.

While the National Agricultural Statistic Service (NASS) does collect some data on water conservation practices, they depend on problematic sampling techniques when only a small proportion of producers use a practice, which is the case for on-site water storage and tail-water recovery. Further, NASS data do not disclose the location of the producer adopting a practice, and this prevents a full assessment of available surface water and what spatial features of the landscape might have caused the producer to adopt the practice. The objective of this research is to understand the construction of on-site water storage and tail-water recovery systems over time in the critical groundwater area of Arkansas County. Using various sources of multispectral imagery and aerial photography, we aim to identify and map the spatial extents of on-site water storage in the area and to attribute construction dates in a GIS database layer.

Methods

Data

Because of its continuous operation over the last several decades and its frequent return times, Landsat satellite imagery was used to track the construction of on-site irrigation storage reservoirs. Using the United States Geological Survey (USGS) EarthExplorer tool, we acquired all Landsat scenes overlying a study area of Arkansas County, Arkansas between January 1995 and December 2015. Landsat data are multispectral images with a spatial resolution of 30 meters and a return time of 16 days. Landsat-based methods for identifying on-site water storage are cost-effective, time-efficient, reliable, and easily repeatable.

Water Identification

In order to make the initial classification of all surface water we use the Provisional Dynamic Surface Water Extent (DSWE) algorithm developed by USGS (Jones and Starbuck, 2015; Jones, 2015). The identified scenes were pre-processed using the provisional DSWE algorithm which classifies water and non-water pixels in the Landsat imagery according to their surface reflectance and slope characteristics. Primary inputs to the algorithm are a Digital Elevation Model (DEM) and the Landsat reflectance bands for Blue, Green, Red, NIR, SWIR1, and SWIR2, along with the CFMASK band used to filter cloud and cloud shadow (Jones and Starbuck, 2015).

Extending the Algorithm for Reservoir Identification

Using Python and the arcpy library, all non-water pixels, including cloud and shadow, were reclassified to a value of “0” while all pixels identified as water were assigned a value of “1”. This was done for each scene between 1995 and 2015. With only surface water pixels containing values, we use TerrSet Geospatial Monitoring and Modeling software in combination with Python to apply filters based upon size and shape characteristics. Using TerrSet’s Group function, clusters of water pixels were identified as bodies of water and all pixels in a water body were assigned an ID value for that body of water. The Area and Perim functions calculated the area and perimeter of each grouped and identified water body, assigning these values to each pixel in a group. We characterize shape using a measure for compactness ratio and TerrSet's cratio function. Using the area and perimeter layers as inputs, the cratio function calculates the square root of the ratio of the area of the polygon to the area of a circle having the same perimeter as that of the polygon. This value is assigned to each pixel in a group.

We use Python and the arcpy library to filter out bodies of water with size and shape traits that are uncharacteristic of on-site irrigation storage reservoirs. Data on the characteristic size of reservoirs were obtained from both a 2016 survey (Edwards, 2016) and communication with Charolette Bowie of the USDA Natural Resources Conservation Service (NRCS) in Lonoke, Arkansas. The USDA-NRCS administers the EQIP program and maintains records on the construction of irrigation reservoirs under the cost-share program. Based on the information obtained from these sources, bodies of water smaller than 2.5 acres and larger than 600 acres were removed from all scenes.

Features with a high compactness ratio have a high likelihood of being man-made (McKeown and Denlinger, 1984). Because some of the constructed reservoirs do have organic, natural, shape qualities, we apply a minimal level of filtering based upon compactness. We do this primarily to eliminate streams and rivers with the lowest compactness ratios. Bodies of water with a compactness ratio less than .005 were removed from all scenes. For each scene, we executed a BooleanAnd operation, keeping surface-water pixels that satisfied both the area and compactness criteria. The results of this operation represent potential reservoirs in each individual scene.

The three-month period of March, April, and May is the wettest period of the year, and being prior to the growing season, irrigation storage reservoirs are likely to be most full. Interpreting Landsat scenes in these months is complicated by the presence of cloud cover (Kaufman, 1987; Ju and Roy, 2008). Due to this, we created a composite of probable reservoirs for the period (March – May) by taking the union of all algorithm-processed scenes within the calendar period, doing this for each year (1995 – 2015). Compositing of Landsat images provides a method for addressing data gaps resulting from cloud cover (Roy et al., 2010; Wulder et al., 2011). Probable reservoirs missing in one scene due to cloud cover are likely to be captured in the composite by another scene. Figure 1 summarizes the extended algorithm, while supplemental material reports the Landsat scenes used in constructing each of the annual composites.

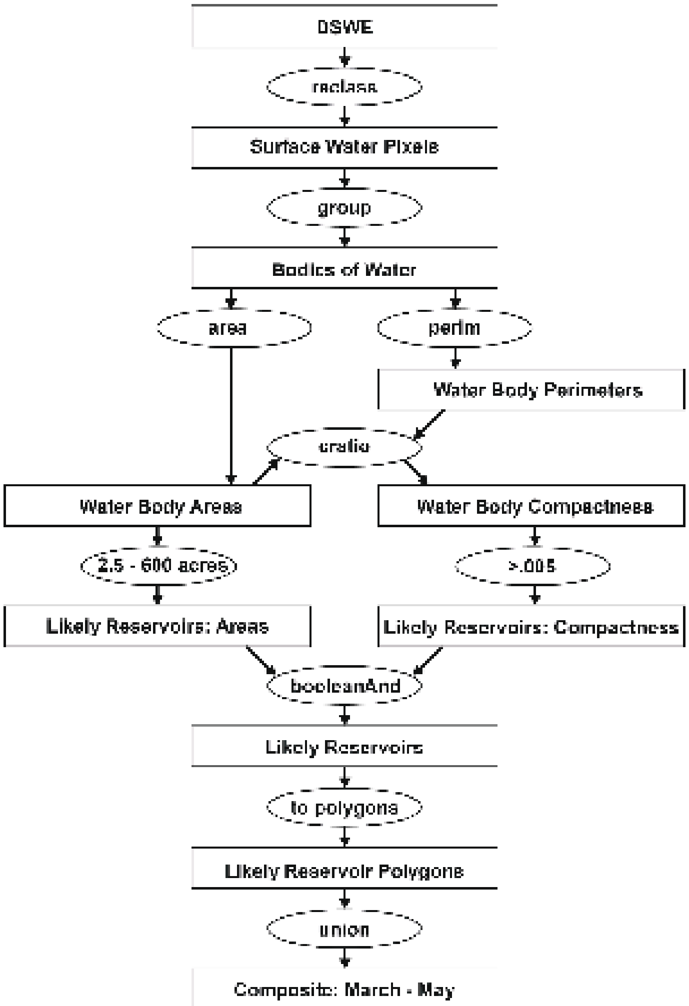

Figure 1. This summarizes the algorithm used to process Landsat scenes for identifying irrigation storage reservoirs. It takes scenes processed using the U.S. Geological Survey's Provisional Dynamic Surface Water Extent (DSWE) algorithm and extends that using spatial and temporal constraints (Jones and Starbuck, 2015; Jones, 2015). Rectangles in the figure represent data layers used or created in the algorithm, while ovals represent operations applied using Python and GIS.

Verification and Construction of Annualized Reservoir Data Layer

High-resolution imagery from the National Agriculture Imagery Program (NAIP) and Google Earth were necessary to identify tail-water recovery ditches and verify the presence of irrigation storage reservoirs. Mary Yeager and Michele Reba with USDA Agricultural Research Service (USDA-ARS) recently used these imagery sources and manual methods to identify and map irrigation storage reservoirs with tail-water recovery ditches for 2015 in the Cache and Grand Prairie areas, including Arkansas County. Though Yeager and Reba were not able to produce an annualized data layer, they do use NAIP imagery and historical imagery from Google Earth to verify reservoirs for each of the years 1996, 2000, 2006, 2009, 2010, and 2013, in addition to 2015.

We use this layer to assess the accuracy of reservoir identification for our extension of the DSWE algorithm and to aid in verifying annual reservoir locations. For each year verified manually, reservoir extents were compared to annual composites from the matching year. We also construct an annualized reservoir data layer using the annual composites, verified years, and some cases of deductive reasoning. We create Boolean identifiers in a GIS data layer to indicate the presence of a reservoir in a given year from 1995 to 2015.

Results

We compare probable reservoirs from the conceptual model (annual composites) to available years of verified reservoir locations. Table 1 reports the results of the algorithm accuracy assessment using manually verified years. The percentage of the manually verified reservoirs that were identified by matching annual composites ranged from 95.7% to 99.1% for the seven years included in the assessment. The most accurate composite was 2013 where 221 of 223 reservoirs were identified by the algorithm. The composite for 1996 failed to identify the largest number of reservoirs, missing seven, and was the least accurate by percentage identified. Between 2000 and 2006, the number of reservoirs increased by 30 which is the largest increase between verified years. It is also the longest period without available high-resolution imagery.

Table 2 reports the percentage of water bodies from the outputs of the conceptual model that positively identify verified reservoirs. On average, approximately 10% of probable reservoirs detected by the model proved to be actual reservoirs in the verified layer. The least accurate model year was 2006 (5.1% positive identification), while 2015 was more than twice as accurate as the average (20.3% positive identification). We construct an annualized GIS reservoir data layer for Arkansas County (Figure 2) using annual composites and verified years. Between 2000 and 2001 and between 2002 and 2003 there were 10 new reservoirs constructed, making these the most significant single years for growth in on-site irrigation storage infrastructure. In total, 69 storage reservoirs were constructed in Arkansas County from 1995 to 2015, with a majority built during the first 10 years of that period.

Conclusions, Recommendations and Benefits

We develop an algorithm using Landsat imagery that is more than 98% accurate at identifying verified surface water reservoirs. This algorithm is useful for application to future imagery without undertaking expensive travel to verify the presence of the reservoirs or to identify the presence of a reservoir not readily visible from public roadways. The ability to employ an accurate algorithm with Landsat imagery enables manual verification using high-resolution imagery to be much more feasible. In addition, the algorithm works with public Landsat imagery that is available at high frequencies. This could allow a temporally more granular investigation of the water levels at these storage systems to help irrigation specialists understand how these systems are in use throughout the year. The information gathered about the storage systems is useful for tailoring programs and policies to encourage more surface water use for irrigation and to help stabilize the aquifer levels in Eastern Arkansas.

We note that feedback obtained about the characteristic size of reservoirs indicated substantial variability in the depth and constructed dimensions of reservoirs. This fact, along with the prevalence of organically shaped reservoirs, meant that Landsat-based methods were inadequate for estimating reservoir storage volumes. Furthermore, the algorithm is only roughly accurate at the reservoir scale for identifying the presence of reservoirs. This fact decreases confidence that estimated reservoir areas are accurate enough to report. Future research to complement the imagery information is to collect data on the groundwater levels, weather patterns, and producer characteristics near the farms where the storage systems are present. This should help us to identify which of the factors that potentially drives the adoption of these systems plays the greatest role. A pilot survey or a series of focus groups might provide this information for the areas where clusters of the storage systems are present and built with greater frequency over the past few years.

Table 1. Accuracy Assessment, Percentage of Verified Reservoirs Identified. This summarizes the results of the accuracy assessment comparing annual composites to years with verified reservoir layers (Type II error).

NAIP-verified years	Number of verified reservoirs	Number identified by matching composite	Percentage Identified by composite
1996	164	157	95.70%
2000	176	171	97.20%
2006	206	204	99.00%
2009	215	212	98.60%
2010	219	215	98.20%
2013	223	221	99.10%
2015	229	225	98.30%

Table 2. Accuracy Assessment, Percentage of Model Water Bodies Identifying Verified Reservoirs. This summarizes the results of the accuracy assessment comparing annual composites to years with verified reservoir layers (Type I error).

NAIP-verified years	Total water bodies identified by model	Number positively identifying verified reservoirs	Percentage identifying verified reservoirs
1996	2476	150	6.10%
2000	1862	152	8.20%
2006	3763	193	5.10%
2009	2031	207	10.20%
2010	2597	201	7.70%
2013	2358	208	8.80%
2015	1115	226	20.30%

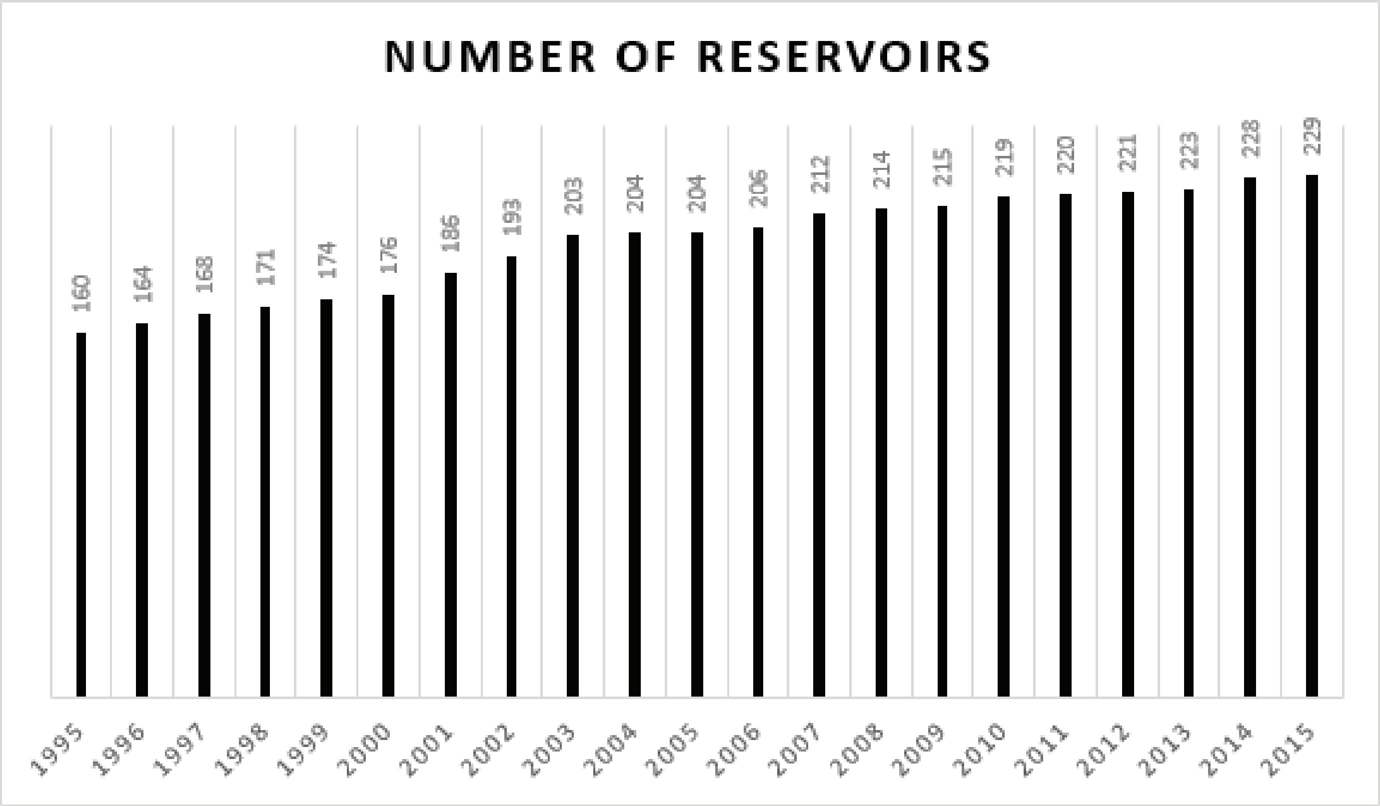

Figure 2. Reservoirs in Annualized GIS Data Layer.

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Supplement: Annual Composite Scene Lists

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2011
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2012
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2013
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2014
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2015
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