

Multivariate spatio-temporal visualization of over-pumping the  
High Plains aquifer and impacts on the Arkansas River in western  
Kansas

By

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## **ABSTRACT**

Environmental assets like arable land and water have been developed extensively with consequences such as large-scale groundwater depletion caused by agricultural irrigation. Yet even in such a dramatically affected area, many people are still unaware of the consequences of large-scale groundwater pumping. Combining open data with modern computer technology enables a visual representation of data that will aid to understand the impacts of historical, current, and future decisions of pumping. In this project, we explore the landscape that develops as irrigation increases and then is no longer supported after groundwater storage has diminished. A time-evolving participative map showing the decline in water levels in the High Plains aquifer makes this evolution more visceral to people than has previously been possible. The map will correlate pumping and drought indices with new metrics of when perennial streams convert to ephemeral using field measurements from open databases. Online, interactive aspects include control of the spatial and temporal display, along with selection of point-specific series plots and data. The dynamic interface developed using GIS, JavaScript APIs, and other visualization tools improves community education and assists in policy making as stakeholders are enabled to clearly envision the relations between management decisions and landscape changes.

## **ACKNOWLEDGMENTS**

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## **CHAPTER 1: PREFACE**

### **Societal significance**

Groundwater decline, predominantly driven by overexploiting major aquifers, fuels concerns about the global water budget and longevity of freshwater to support irrigated agriculture, surface water dynamics, and the natural environment (Gleeson et al., 2012b). Excessive pumping of large agriculture-dependent aquifers occurs in many places worldwide. Groundwater systems in the Indus Basin Irrigations Scheme in Pakistan (Usman et al., 2015), the Krishna and Gadavari Basins in India (Sishodia et al., 2016), the North China Plain (Changming et al., 2001), the Uley South Basin in South Australia (Knowling et al., 2015) and the High Plains Aquifer in North America (Buchanan et al., 2015; Butler et al., 2013; Haacker et al., 2016; Scanlon et al., 2012) are being depleted at alarming rates—the High Plains Aquifer will become insufficient within 25 years as water levels will be too low to maintain current agricultural practices (Haacker et al., 2016). These examples epitomize the need to implement groundwater management practices that further agricultural production and environmental stewardship as many people remain/are unaware of the role played by large-scale groundwater depletion. This work features the High Plains Aquifer (HPA) of Kansas to develop spatio-temporal visualization methods to support hydrologic analysis and decision-making for responsible resource management.

Conservation efforts for an entire hydrologic system, both groundwater and surface water, can be informed and motivated through an understanding of its past and present (Haacker et al., 2016). Community understanding of historical water-use trends that have led to the current reduced saturated groundwater thickness of the HPA facilitates the implementation of protection strategies (Butler et al., 2016; Scanlon et al., 2012) and are essential to adopting water conservation efforts. Groundwater management districts (GMDs) in Kansas [Figure 1] administer additional regional and local regulations focused on monitoring, protecting and extending the longevity of groundwater in the HPA (Buchanan et al., 2015). This has resulted in the adoption and implementation of legislation to define Local Enhanced Management Areas (LEMAs) that target reduced water use and transfer of water between water rights holders in a manner that is still favorable to irrigators (Buchanan et al., 2015; Meinzen-Dick, 2014). Other localized voluntary

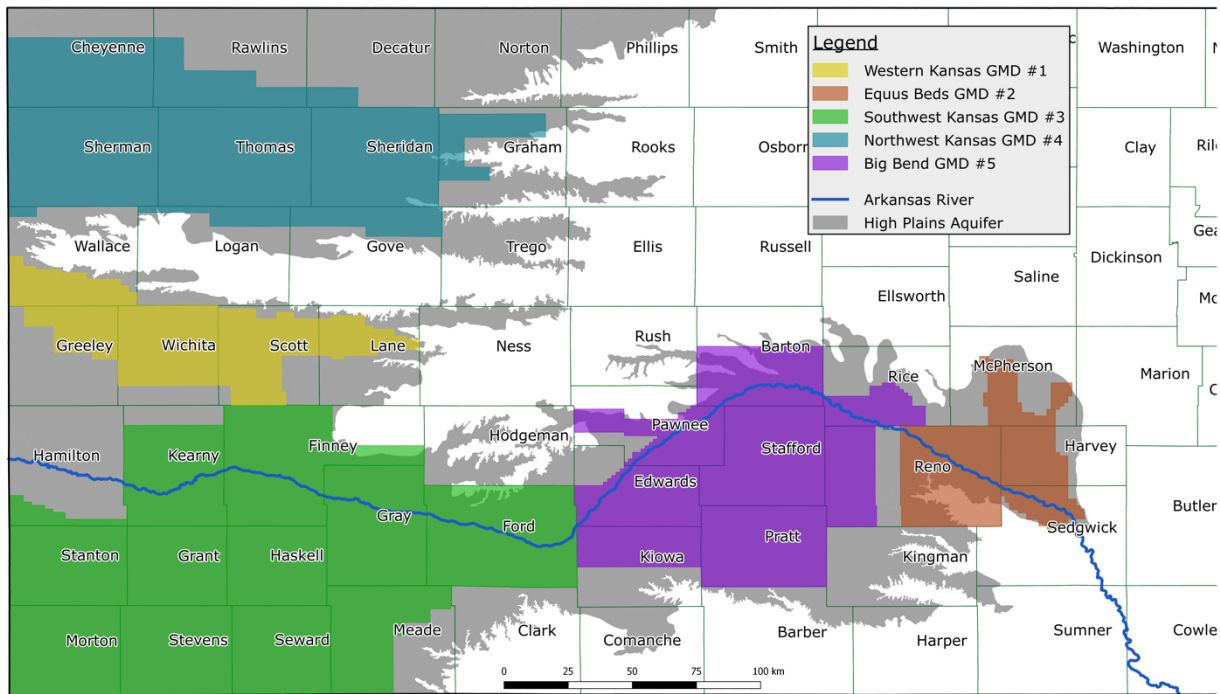


Figure 1. Groundwater management districts (GMDs) (Kansas Department of Agriculture, 1996) oversee stewardship of different areas across the High Plains aquifer (HPA) (U.S. Geological Survey, 1995) in western Kansas, such as implementing efforts to reduce pumping. Map created by Misty Porter using the High Plains Aquifer Extent, Groundwater Management Districts, and Counties shapefiles obtained via the Kansas Data Access Science Center.

conservation efforts from 1996 – 2013 show that a 7 – 22% reduction of pumping to stabilize groundwater decline is realistically achievable (Butler et al., 2016). However, state-wide legislation is necessary to amend water rights and implement water-use regulations held by individuals, companies, and municipalities govern Kansas water law. Stakeholder education, cooperation, and communication prove essential for moving towards achieving sustainable use of the HPA via effective legislature/legislation and conservation efforts (Buchanan et al., 2015; Gleeson et al., 2012a; Smidt et al., 2016).

**Study site**

The HPA is a 450,700 kilometers<sup>2</sup> (174,000 miles<sup>2</sup>) aquifer system spanning eight states, several hydraulically connected geologic units, and is the primary source of water for the agricultural industry (Buchanan et al., 2015; Gutentag et al., 1984). About 79,800 kilometers<sup>2</sup> (30,800 miles<sup>2</sup>) of the aquifer lies within Kansas and its varying geology affects both surface and subsurface hydrology. The Miocene-aged Ogallala deposits make up most of the HPA consisting of up to 215

m of mostly heterogeneous unconsolidated sands, gravel, silt & clay making it easy to pump. Pleistocene deposits make up the eastern reaches of the HPA and are shallower, reaching a maximum thickness of 90 m. Recent overlying alluvium deposits up to 18 m thick and are incised by present-day streams, hydraulically connecting streams to the underlying water table. This can lead to the formation of ephemeral streams, such as the Arkansas River, that play a crucial role

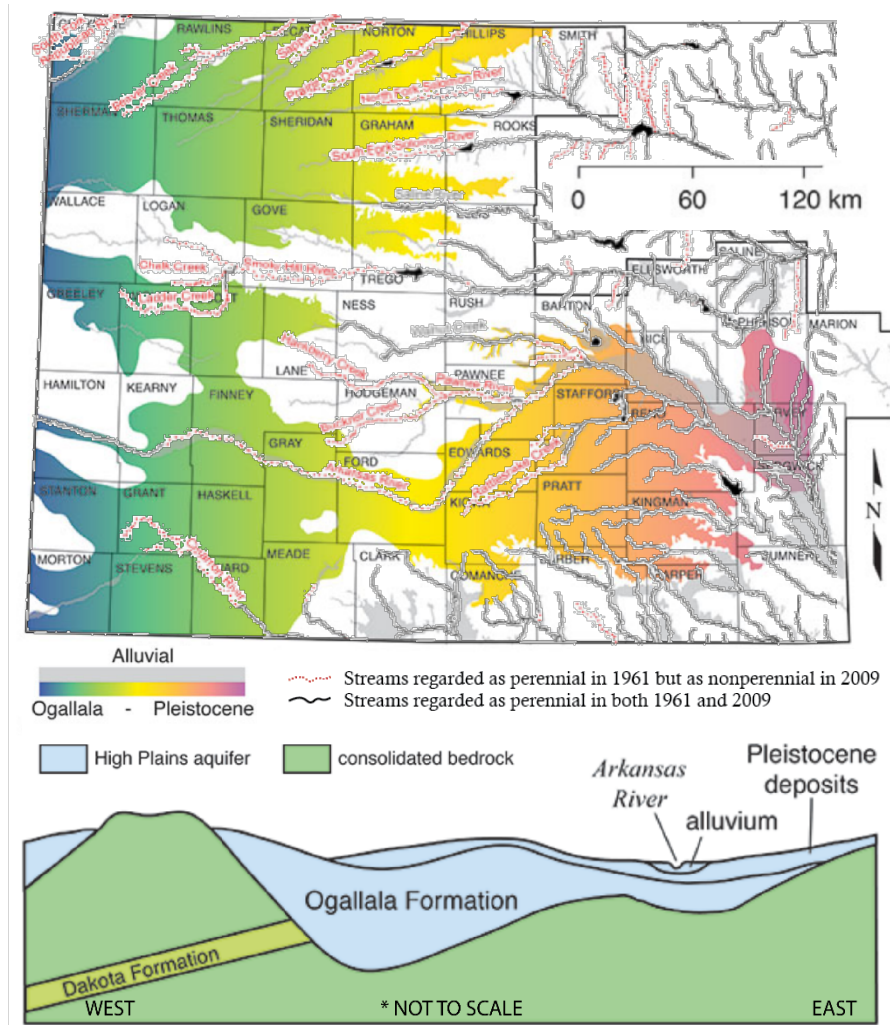


Figure 2. The HPA transitions from the Ogallala (Miocene-aged) in the west to Pleistocene-aged deposits in the east overlain with alluvial deposits that preferentially form rivers, such as the Arkansas River. The regional variation in geology results in different responses to hydrologic changes, which is why a 7% reduction in pumping is suitable in GMD #4 for the Pleistocene-aged Equus beds aquifer, whereas a 22% reduction in pumping is suitable for the Ogallala aquifer in GMD #2 (Buchanan et al., 2015). Hydrologic changes on the surface can also be seen as more streams in the west have converted from perennial to non-perennial in western Kansas over the Ogallala than in central Kansas over the Pleistocene-aged deposits. Modified from (Buchanan et al., 2015) and (Kansas Department of Agriculture, 2010).

in sediment transport, surface water storage, recharge to the aquifer, and fragile ecosystems (Langhoff et al., 2006; O'Connor et al., 2014).

The eastern boundary of the HPA discharges to streams in the east where they typically flow perennially, shown as black lines on the map. However, when streams are no longer connected to water table, they can no longer flow perennially. Without the baseflow from the aquifer, more stream reaches are being regarded as

ephemeral, such as the central stretch along the Arkansas River. The Arkansas River originates in the mountains of Colorado and flows from west to east over valley-fill deposits of sands and clay, silt, and sandy loams. While it is generally ephemeral in its upstream reaches to the west, it flows perennially where the river intersects the water table and groundwater naturally discharges into the river (Gutentag et al., 1984) making it an ideal location to observe hydrologic dynamics and changes in landscape.

**Groundwater Impacts on Ephemeral Streams with Development of the HPA**

The hydraulic properties of the HPA are conducive for pumping because the average hydraulic conductivity of the HPA in Kansas is higher than any of the other 8 states at 25 meters/day (81 feet/day), and the second highest specific yield at 0.16. The saturated thickness, which is the vertical distance between the water table and bottom aquifer, averages 61 meters (200 feet)

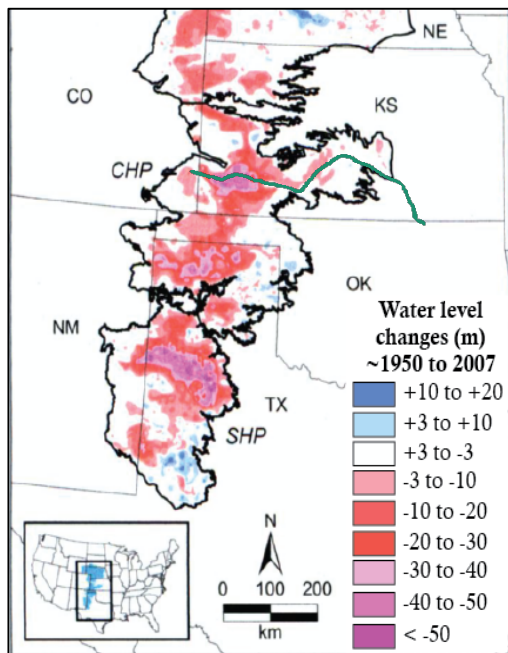


Figure 3. Groundwater declines are greatest (40 to 50+ meters) where the Arkansas River is ephemeral in western Kansas and less (3 to 10 meters) in central Kansas where the Arkansas River is still perennial (Modified from (Scanlon et al., 2012)). Groundwater level decline trends form a silhouette of the Arkansas River (traced with the green line) showing that groundwater decline can greatly affect surface water features.

(Gutentag et al., 1984) and is thickest in southwest Kansas where it exceeded 91 meters (300 feet) prior to the development large-scale irrigation (Buchanan et al., 2015).

In general, pre-1950 is referred to as predevelopment. Since 1950, the High Plains aquifer has been developed to provide access to water for agricultural practices. Center pivot irrigation expanded the agricultural industry by increasing access to new land and crops that previously could not be cultivated (Buchanan et al.,

2015). From predevelopment to 2012, Hacker et al. (2016) calculated a 28% reduction in the central HPA aquifer storage volume, from 887 kilometers<sup>3</sup> to 636 kilometers<sup>3</sup>. Copious pumping for irrigation caused sizable declines in the aquifer storage and water-table

(Butler et al., 2013; Haacker et al., 2016; Scanlon et al., 2012) resulting in a 50-meter decline in groundwater level just in the central HPA [Figure 3] (Haacker et al., 2016). As the groundwater level falls, streams are disconnected from the water table as they are no longer supported by baseflow (Gutentag et al., 1984). Since pre-development of the HPA, longer stretches of streams throughout western Kansas, such as the Arkansas River, are being converted from perennial to non-perennial (Scanlon et al., 2012) affecting ecosystems and reducing the availability of surface water as an alternative to groundwater. Identifying ephemeral streams and stream reaches endangered of becoming ephemeral due to declining water levels and low flows is necessary for focusing remediation efforts to preserve the remaining surface water and restore streamflow to impacted ecosystems.

Irrigation is depleting the aquifer and has raised concerns for the future as the longevity of freshwater to support irrigated agriculture puts the livelihoods of farmers, vitality of the economy, surface water dynamics, and natural ecosystems in jeopardy. Conservation efforts require understanding the complex relationships between groundwater and surface-water interactions, as well as aquifer behavior in response to natural seasonal variation that can create a false sense of water availability. Through knowledge discovery, well-informed collaborative decision-making efforts among irrigators, government agencies, scientists, and the community can be made to work toward extending the longevity of the aquifer.

### **Summary**

The relationships within aquifer discharge-recharge and groundwater-surface water interactions are dynamic and complex (Butler et al., 2013; Scanlon et al., 2012). Variation in aquifer behavior (Butler et al., 2013) and seasonality trends (Zhang et al., 2016) and the timing of pumping within and outside the irrigation season (Butler et al., 2016) cause confusion in interpreting hydrological systems. A false sense of increased water availability is created when ephemeral streams collect and carry runoff during extreme precipitation events playing an integral role in aquifer recharge (Gutentag et al., 1984), especially in late spring to early summer (Zhang et al., 2016).

Differentiating the spatial and temporal effects of climate variability and anthropogenic impacts causing aquifer depletion shows that pumping impacts exceed those of climate and directs the focus for conservation efforts (Knowling et al., 2015). Gleeson et al. (2012a) suggest the need for “a community-based and accessible framework that integrates a variety of data” to support quality decisions and an open dialog among all those affected. In an effort to address this need, the focus of this thesis project has been designing a web-based interactive spatio-temporal geo-visualization tool, DiscoverWater. The prototype demonstrates the capacity to elucidate collective trends and alleviate confusion when analyzing an aquifer system by examining the interactions between these major components through the correlation of multiple datasets—water-use, groundwater level, streamflow, and climate.

## CHAPTER 2: DISCOVERWATER – MANUSCRIPT FOR PUBLICATION

### Introduction

Excessive global groundwater depletion of agriculturally-dependent aquifers jeopardizes livelihoods, the vitality of the economy, and the stewardship of natural ecosystems. The need for intervention is apparent, but current policies, political boundaries, and institutions impede migrating to sustainable practices. A solution that reduces hydrologic impact and maintains the socioeconomic value of water is possible through critical reflection of problem (Gleeson et al., 2012a; Meinzen-Dick, 2014; Sanderson and Frey, 2015) and well-informed collaborative decision-making efforts between government agencies and stakeholders (Gleeson et al., 2012a; Meinzen-Dick, 2014; Smidt et al., 2016). Examining hydrogeological processes provides the scientific basis for implementing adaptive management strategies to achieve long-term water-use goals. Development of a tightly-integrated visual representation of complex inter-dependent datasets is necessary for data discovery that supports understanding past, current, and future pumping impacts on water resource management (Gleeson et al., 2012a; Rübel et al., 2010; Smidt et al., 2016).

Visualization can help people understand correlations between spatial and temporal processes, but current methods are too simple to reveal important aspects of multidimensional data. Statistical or dimensionality reduction, cluttering, and occlusion need to be addressed (Kehrer and Hauser, 2013; Rübel et al., 2010). Advances in computing technology throughout the late 1990s to early 2000s fostered the development of scientific data visualization and animation methods enabling temporal animation to be achieved as chronologically sequenced static maps on a playback loop. Yet, geographic visualization (geo-visualization) has lacked support for interactive animation and effective methods for spatially and temporally displaying multiple heterogeneous datasets. Common concerns around spatio-temporal animations include motion distracting the user's attention, poor retention, lack of clear visual expression of information (e.g. smoothness), and user interface issues hindering animation. (Johnson and Nelson, 1998; Lienert et al., 2009; Rana and Dykes, 2003).

The goal of this work is to create a visualization platform capable of clearly depicting correlations and suggesting interdependencies between time-varying, spatially-distributed quantities; it is called DiscoverWater. DiscoverWater is a time-evolving map with graphs based on time-series data. It is designed and built to display how water resources change on the landscape and in the subsurface in response to climate and pumping rates. This amalgamation makes the changes clear and useful to a wide range of users. Interactive features, such as control of the spatial-temporal display and selection of point-specific time-series data plots, engage users in knowledge discovery. Publishing the interactive spatio-temporal visualization online as a web app increases public awareness of hydrologic conditions and inspires responsible water-use. This work makes the following contribution to existing efforts:

- 1) Framework - construct a website that acts as a user-friendly portal for integrating animated spatio-temporal geographic and hydrologic data making the interactive display technology equably accessible.
- 2) Hydrological Correlations – identify trends in groundwater-surface interdependencies through correlated datasets revealing anthropogenic and climatic impacts to create a cohesive picture of the hydrologic system and where conservation efforts can be focused.
- 3) Display - visualize spatial and temporal hydrologic interactions as a dynamic spatial map-representation combined with synchronized time-series graphs of multiple correlated datasets by moving away from static images, automated animations, and the limited simultaneous display of one or two time-series datasets on a plot.

This project expands upon existing methods by combining multiple time-series datasets and effective spatio-temporal visualization strategies to reveal data interactions and interdependencies. Coalescing datasets in this way captures multiple aspects of the hydrologic system, and illustrates the consequences of natural and anthropogenic impacts on water resources. The improved ability to interact with and relate multivariate time-series data makes decadal-long, seasonal, and annual trends possible.



## **Background**

### **Web GIS Framework**

The framework for constructing DiscoverWater is founded on constructing a web-portal to a compound interactive experience associating heterogeneous multivariate data with geographic visualization (Kehrer and Hauser, 2013; Lienert et al., 2009). Current available datasets are scattered about the internet, hosted by various agencies, and demanding considerable effort to access and plot (García et al., 2015). As commonly presented, the data lack an overall context and require advanced scientific knowledge to understand (Caquard and Fiset, 2014; Kehrer and Hauser, 2013; Lienert et al., 2009; Rübél et al., 2010).

Software, such as CUAHSI's HydroDesktop (<https://hydrodesktop.codeplex.com/>) (Ames et al., 2012) leverages web services and an interactive GUI (graphical user interface) to facilitate discovering and procuring hydrologic data. Web services can also be utilized without a GUI through visual markup languages, such WaterML, and API scripts, most commonly Python and JavaScript. Representational State Transfer (REST) web services, Web Map Services (WMS), and, less commonly, Web Feature Services (WFS) (Li et al., 2015) are examples of web services encountered in this work for acquiring data directly from the host institution's database. The United States Geological Survey (USGS) Statistics Web Service (U.S. Geological Survey, 2016) uses REST to generate a static link with defined parameters that returns a table of daily, monthly, or annual statistics for streamflow and groundwater level data directly from the USGS National Water Information System (NWIS) database (U.S. Geological Survey, n.d.). CUAHSI's WaterML (Water Markup Language) is a type of Extensive Markup Language (XML) specifically designed for dynamic data exchange of hydrological time-series data as NetCDF (Network Common Data Format) data arrays following GML (Geographic Markup Language) encoding rules (Palmer, 2012). The Open Geospatial Consortium (OGC) is working toward making WaterML the universal standard for hydrological data. To avoid bottlenecks delaying data transfer, cumbersome decoding steps using various markup languages (Li et al., 2015), and advanced scripting to implement automated data mining and preprocessing algorithms (García et al., 2015), data is

downloaded and pre-processed manually, then stored on an independent server (Rübel et al., 2010), as in this work.

A (GUI) provides the virtual interface on which users will interact with data, such as a website or web app. The various web development languages and APIs utilized are too vast to document in the scope of this project. Most commonly, HTTP (Hypertext Transfer Protocol) handles internet protocols for accessing the website contents as defined in the HTML (Hypertext Markup Language) file, JavaScript provides intractability with the website, and AJAX (Asynchronous JavaScript And XML) acts as a bridge as it communicates with servers for the transfer of information (Caquard and Fiset, 2014; Rübel et al., 2010). There are numerous open source APIs with code libraries written in these languages, and often it is necessary to use a combination of capabilities from different API libraries (Caquard and Fiset, 2014).

### **Flow Classification**

Criteria for elucidating the evolution of surface water flow on the landscape using available data have been sought for decades. Current options deemed appropriate for water resource development include low-flow indices and statistical analyses to characterize the probability of streamflow using “naturalized historical flow records” to establish a set proportion, or percentage, of flow as preliminary flow targets (Pyrce, 2004; Tharme, 2003). For the state of Kansas, the USGS and Kansas Department of Health and Environment (KDHE) applied  $Q_{90}$ ,  $Q_{75}$ ,  $Q_{50}$  (median flow),  $Q_{25}$ ,  $Q_{10}$  flow durations for the entire record of data at a gaging station. (Perry et al., 2004). Flow index is site-specific and the degree of uncertainty is a function of the period of record and climate stationarity. Thus, gage stations with longer records of historical data and no climatic trend have more accurate flow indices.

Summary statistics generate static visualization (García et al., 2015; Kehrer and Hauser, 2013). In contrast, normalizing time-series data at each gage station to its entire historical record allows for time-dependent comparisons to be made across datasets by using percentiles or quantiles to classify the data for data-level comparison (Kehrer and Hauser, 2013). Percentiles indicate how

far from the median flow the observed values are without conveying frequency or time (e.g. a flow classified within <10% flow means that the flow value is ranked among the lowest 10% of historical flows observed). An example demonstrating classification percentiles is the USGS WaterWatch tool ([https://waterwatch.usgs.gov/index.php?id=ww\\_animation\\_real](https://waterwatch.usgs.gov/index.php?id=ww_animation_real)), which uses a color indicator to illustrate relative daily streamflow conditions at stream gage stations with 30 years or more of recorded measurements. The DiscoverWater tool developed in this work uses normalized time series in temporal and spatial displays to make annual comparisons for revealing decadal trends.

### **Display**

The prevalence of internet access and mobile devices has revolutionized geographic information systems (GIS) promoting web-enabled geo-visualizations. The advent of cloud-computing facilitates incorporating spatio-temporal analysis of remotely-sensed data provides a new platform for expressing various approaches to visualization, interaction, and analysis of scientific data to illustrate complex Earth systems (Kehrer & Hauser 2013; Tulbure et al. 2016). The move to web-based geo-visualization capacitates a narrative visualization for communicating spatio-temporal characteristics of data is essential for making stronger comparisons than from individual datasets alone. Scientific analyses and comprehension of how complex natural systems change over time require the ability to see when and where the change occurred by viewing time-series data in continuous succession rather than as static events or snapshots (Caquard and Fiset, 2014; Kehrer and Hauser, 2013; Rübél et al., 2010). Dynamic maps animate vector data properties by classifying measured data with varying symbology and color. The implementation of many different visualization strategies is essential to seamlessly and effectively interpret data while embodying the greater context (Dong et al., 2012; Kehrer and Hauser, 2013).

A modern example of spatio-temporal visualization is the 10-day forecast/6-hr interval ArcGIS online map (<https://www.arcgis.com/home/webmap/viewer.html?webmap=8890035d5add40858335f402864df457>) from the National Water Center (2016) showing the forecasted stream flows across the contiguous United States. As time advances on a looped playback, the quantity of streamflow expected in

the stream is depicted by changing the width of the stream segments, and the amount of streamflow relative to historic flow is depicted by changing the color of the stream segments. Interactive web maps, such as the Deltares Aqua Monitor (<https://www.aqua-monitor.appspot.com>) (Donchyts et al., 2016), allows the user to specify a location and then examine land and water changes using a time slider to advance through 30 years of remote sensed data. The Deltares Aqua Monitor web app runs on the cloud-computing power of Google Earth Engine making real-time computations from global Landsat imagery to detect increases and decreases in the water present from image to image. This allows the user to contrast the transformation of the landscape over time. While important advances, these efforts focus on a single type of data and fail to display relations between different data sets.

### **The High Plains Aquifer & Arkansas River in Western Kansas**

Impacts on streamflow are drastic along the Arkansas River, which courses over the High Plains Aquifer (HPA), and was chosen as the study site to demonstrate the potential of the DiscoverWater visualization tool. Groundwater exhaustion is a serious concern and the unsustainable management of the (HPA) is under scrutiny (Buchanan et al., 2015; Gutentag et al., 1984). Extensive irrigation by the agricultural industry in western Kansas has resulted in rapid dewatering of the aquifer (Butler et al., 2013; Haacker et al., 2016; Lilienfeld and Asmild, 2007; Whittemore et al., 2017). These groundwater declines affect surface ecosystems and substantially impact low flows in streams (Castle et al., 2014; O'Connor et al., 2014; Scanlon et al., 2012). With both groundwater and surface water declining simultaneously, surface water will not be available as an alternative resource in western Kansas when groundwater is no longer an option. DiscoverWater will enrich scientific analysis on the interactions of the various components in the system, educate stakeholders and politicians to make informed decisions, and motivate responsible resource management.

## Methods

### Data Acquisition & Processing

Data of interest are obtained from the public databases listed in Table 1 for gage stations along the Arkansas River. Only datasets were used from gage stations with records dating back to at least 1950, or “predevelopment,” which is the time before large-scale irrigation

(Buchanan et al., 2015) as comparative data analysis is constrained by the length of the available historical record (Pyrce, 2004; Tharme, 2003). DiscoverWater visualizes data for streamflow, groundwater level, irrigation, and climate. These four datasets for these variables were downloaded from publically available databases. The monthly average streamflow is calculated from the daily mean flow measured throughout the month at a stream gage station. The annual average groundwater level is the depth to water measured from the surface averaged for the year. This dataset consists of water-level data from the USGS Groundwater Site Inventory index

Table 1. Pumping rates are downloaded from the WIMAS water use trends (Kansas Geological Survey and Kansas Department of Agriculture, 2017), groundwater levels and stream discharge values are downloaded from the National Water Information System (U.S. Geological Survey, n.d.), and Palmer Drought Severity Indices (PDSI) are downloaded from the Climate at a Glance (NOAA National Centers for Environmental Information, 2017) data portal. Retrieved datasets come in different file formats, are on different spatial and temporal scales, and must be processed. Annual groundwater level and pumping must be adjusted to a monthly format. The Syracuse and Coolidge stations have different lengths of historical records limiting data comparisons to 1941 at the earliest.

Streamflow		Groundwater		Water-Use		PDSI	
Spatial Scale	Temporal Scale	Spatial Scale	Temporal Scale	Spatial Scale	Temporal Scale	Spatial Scale	Temporal Scale
Gage Station	Monthly	County	Annual	County	Annual	Climate Division	Monthly
Coolidge	1950 – 2017	Hamilton	1939 – 2017	Hamilton	1957 – 2017	7	1950 – 2016
Syracuse	1902 – 2017	Hamilton	1939 – 2017	Hamilton	1957 – 2017	7	1950 – 2016
Garden City	1922 – 2017	Finney	1934 – 2017	Finney	1956 – 2017	7	1950 – 2016
Dodge City	1902 – 2007	Ford	1938 – 2017	Ford	1958 – 2017	7	1950 – 2016
Great Bend	1940 – 2017	Barton	1942 – 2017	Barton	1956 – 2017	5	1950 – 2016
Wichita	1934 – 2017	Sedgwick	1937 – 2017	Sedgwick	1958 – 2017	8	1950 – 2016

monitoring wells and reports submitted by local GMDs and the Division of Water Resources. Irrigation data is the average water used specifically for irrigation submitted annually by all water-rights for each county. Water-use reporting began in the late 1950s with the development of the aquifer, but didn't become fully mandated until the 1990s. The monthly Palmer Drought Severity Index is a highly responsive index for identifying the intensity of wet and dry periods based on current weather plus cumulative patterns of previous months.

The datasets must be processed by normalizing them to a fixed range among attributes to be consistent for display as they vary on a spatial and temporal scale (García et al., 2015). For example, annual datasets are converted to monthly intervals by assigning the annual value to each month. Water-use data wasn't available until 1956, 57, and 58 for these counties. Prior to those years, pumping data is plotted as 0 to ensure the plots remain aligned on the charts. Both the Coolidge and Syracuse gage stations are within Hamilton County meaning that average annual groundwater level data and average annual pumping data are assumed to be the same at both stations. Since PDSI has a broader spatial scale, the data for climate division 7 applies to the Coolidge, Syracuse, Garden City, and Dodge City stations.

Challenges with data handling in this work shaped strategies for file formatting. LibreOffice Calc version 5.3.4 (The Document Foundation, 2017) is an open source spreadsheet software that grants advanced control of CSV (comma separate values) files when formatting tables of raw data. Uniform formatting of CSV files eliminates errors, such as numbers being read as strings by GIS software leading to being unable to use numerical data-driven formatting. When converting data from CSV files to JSON (JavaScript Object Notation) format for use with JavaScript APIs, field formatting and successful queries to the file are ensured by setting the file properties: the character set is Unicode-8, values are comma-delimited, strings are wrapped in quotation marks, and extra spaces at the beginning or end of field values are removed. JSON files must be stored on either a local server or a within a web-based file service, a critical task with managing large datasets for meaningful display. The HTML, JSON, and API library files for the website were stored

using cPanel version 64.0.24 (cPanel Inc., 2017), a web file hosting control panel, under the management of the University of Kansas.

### **Flow Classification**

For the application of this project, streamflow is classified by percentile of historical flow following the same method currently used for the USGS WaterWatch maps (U.S. Geological Survey, 2008). The monthly average streamflow data downloaded for each gage station in this project are normalized to the entire historic record and each percentile was calculated using the “PERCENTILE” function in LibreOffice Calc. These values are the break points for determining which color will be assigned to that data point. A color scale, as shown in the legend of **Error! Reference source not found.**, is a useful classification approach for direct streamflow visualization (Kehrer and Hauser, 2013). As the map animation plays and the dots change colors along the time-series, the user experiences a red dot 10% of the time, an orange dot 15% of the time, a green dot 50% of the time, a teal dot 15% of the time, and a blue dot 10% of the time. Extreme precipitation events cause very high flows, which create statistical outliers within the dataset. The “extreme flow” classification is a modification of the “greater than 90%” percentile rank to account for these outliers. Formatting for streamflow values is applied using CSS (Cascading Style Sheets) as recent versions of the web-mapping APIs used in this project now require the use of CSS for styling to enable the application of data-driven formatting. For example, the style properties were defined directly within the JavaScript code for layer and series properties in Highcharts version 4.2.6, but Highcharts version 5.0.12 defines the style properties using separate CSS code to increase the efficiency and load time of the website (Highsoft AS, 2017).

### **Display Techniques**

#### *ArcGIS & QGIS:*

There are many different visualization and GIS programs available. QGIS, the leading open source GIS freeware (QGIS, 2017), has a lighter, but sometimes more favorable, GUI and is supplemented with hundreds of user-developed plugins for additional functionality. ArcMap (ESRI, 2015), the

most widely-used commercial program in the ArcGIS software suite, has a streamlined GUI making robust map operations and design less complicated. While ArcMap version 10.3 excels at design, QGIS version 2.18 is superior for time-series data and file handling, especially with conserving imported CSV field types and formatting exported GEOJSON files.

The pre-processed CSV files, explained above in *Data Acquisition and Preprocessing*, are imported into ArcMap/QGIS using the x,y values of longitude and latitude for the geographic location of the gage station, exported as a shapefile, and added to the map as a layer of vector point data. Data-driven formatting is applied to the symbology (ArcMap) and style settings (QGIS) by setting colors corresponding to the percentile ranks unique to each dataset. Time is enabled on each layer to show the change in flow values over time. This is done by generating tracking events through ArcMap's tracking analyst extension and adding layers to QGIS's time manager plugin. These maps are similar to the USGS WaterWatch tool but accessibility and intractability is limited to the time slider within the GIS software.

This work aims to generate spatial displays that can be integrated with chart tools to obtain the multidimensional spatio-temporal display of interest as using multiple views is compelling for interactive data exploration (Rübel et al., 2010). The chart tools included in QGIS and ArcGIS were too limited, so interactive charts were designed with JavaScript APIs. However, the GIS programs lack the ability to integrate the interactive charts designed with JavaScript APIs. This is an enduring difficulty with achieving our fully integrated spatio-temporal vision. Instead, our capability has time-control in the map and the charts that operate independently.

Most geographic web mapping APIs process geographic information as a GEOJSON file, which is a specific type of JSON file that is optimal for querying data for use with a web-mapping API. Creating GEOJSON files was easiest in QGIS by changing the file type from Shapefile to GEOJSON and saving it to the local file system. After extensive debugging, it was discovered that including the geographic projection should not be included with the GEOJSON. GEOJSON files were created



for each element to be displayed on the web map by exporting shapefiles into the GEOJSON format in QGIS.

#### *JavaScript API:*

There are numerous open source web-mapping and data visualization JavaScript APIs available. Successfully re-constructing the framework designed with GIS software for web use is the product of an extensive evaluation of several different APIs. Nonetheless the charts are created with Highcharts version 4.2.6 because of its seemingly unrestricted options and ease-of-use, including in-line JavaScript formatting, to construct interactive aesthetically effective charts as color and style formatting are essential for effective visualization. Data-driven formatting is not applied to irrigation and groundwater level in this project so they are colored to distinguish them from other colors used for the charts and map. Through the use of Highcharts' "zones," streamflow retains the same conditional formatting by percentile as the map. Each percentile color is assigned to the respective calculated break values to designate the maximum value for that zone so that any value within that zone is formatted with the respective color. The Palmer Drought Severity Index (PDSI) also takes advantage of the zone formatting to visually distinguish between a wet period by coloring negative values blue, and a dry period by coloring positive values red. The JSON files containing the data displayed in the charts are called from the cPanel file manager and parsed using jQuery version 2.2.6 (The jQuery Foundation, 2017), which facilitates event handling, animation, and Ajax across multiple browsers. There is one dataset per chart, and each chart has a designated HTML container. These four charts are aligned vertically and wrapped within one main chart HTML container for synchronizing chart features [Figure 6]. When the mouse hovers over the plot on any chart, the points are highlighted and the value at that point is displayed in a fixed tooltip at the top of each chart. As the user slides the mouse or their finger across the charts, a vertical line synchronized with respect to the x-axis temporally connects all four time-series datasets so that they are viewed collectively.

While Highcharts and its complimenting sub-library Highmaps version 5.0.12 (Highsoft AS, 2017) have the potential for developing and seamlessly integrating both the map component and charts

component of the display, Highmaps is not robust enough handle the degree of mapping and formatting time-series data sought in this project. LeafletJS (Agafonkin, 2017) is one of the most common open source web-mapping APIs and, just as with QGIS, can support time-series data with the addition of the Leaflet Time Dimension Plugin (<https://github.com/socib/Leaflet.TimeDimension>). Leaflet version 1.0.3 was easy to use and the framework design was achieved quickly. Unfortunately, the examples in the documentation for using the Time Dimension plugin demonstrate acquiring data through WMS, which is not a feature available for the datasets in this project. Leaflet is commonly used with Mapbox, which is comprised of Mapbox Studio (Mapbox, 2017a), a web-based GUI for designing and building basic maps, and Mapbox GL JS (Mapbox, 2017b), a JavaScript library for advanced development. The map component of DiscoverWater is powered by Mapbox's hybrid development platform, using Mapbox Studio version 2017-06-16-21-24-30 and Mapbox GL JS version 0.36.0. The GEOJSON files containing the spatial data for the location of each gage station on the map are also called and parsed by jQuery, just as with the charts. Each gage station is a separate GEOJSON file containing both its spatial data and streamflow time-series data as a solution to complications in API functionality and data format compatibility when joining a single GEOJSON file of only the spatial data for all the gage stations to the JSON files of the streamflow data corresponding to each site.

## **Results and Discussion**

### **DiscoverWater Map**

The map component of DiscoverWater provides a spatial context for visualizing streamflow. The time slider allows the user to animate the colors as well as select a period of interest. The changing colors illustrate the flow conditions at that point in the river allowing users to perceive dynamics in the amount of water in the river over time. This display convention allows conditions along the entire length of the river to be visualized more thoroughly. As time progresses from past to present in the HPA system, groundwater depletion caused by irrigation is reflected by increasing frequency of very low streamflow. This trend can be observed as the gage stations and stream segments overall express lower percentile colors for flow more frequently within the past

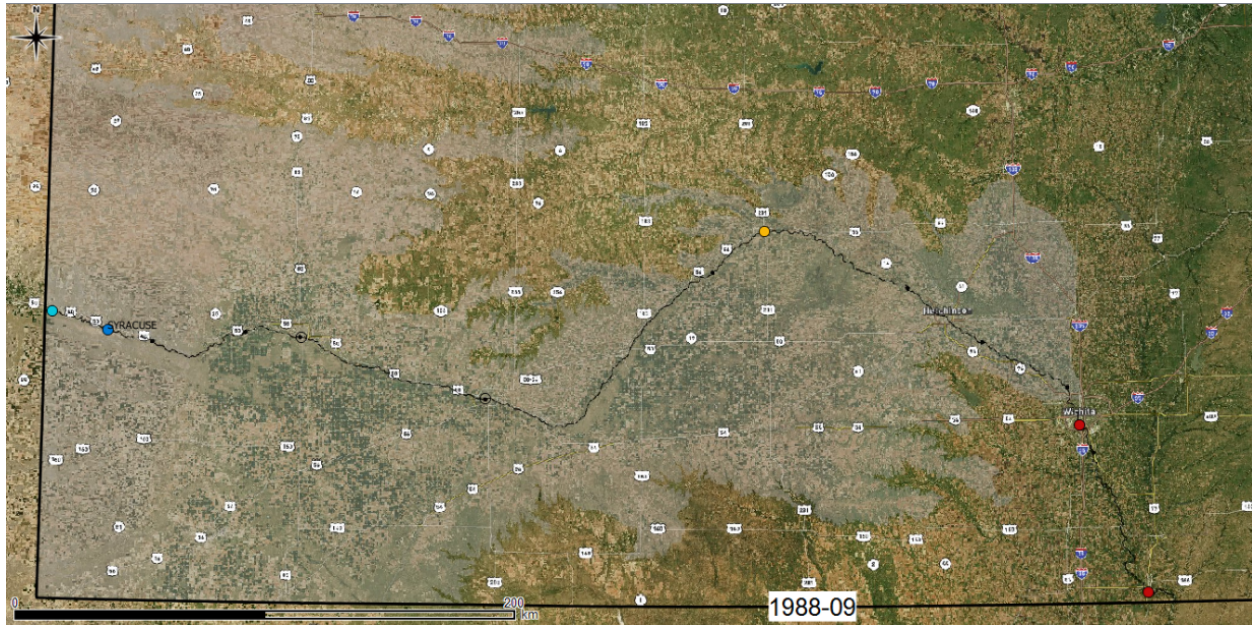


Figure 4. Streamflow at seven gage stations along the Arkansas River (Coolidge, Syracuse, Garden City, Dodge City, Great Bend, Wichita, and Arkansas City) for September 1988. Streamflow is high in the west, but doesn't continue through the ephemeral section of the Arkansas River so flows are low in the eastern stretch of the river.

two decades. At some gage stations, there is no flow for long periods indicating the Arkansas River is ephemeral along those sections, while other gage stations never or rarely reach zero flow indicating the Arkansas River is perennial along those sections. Seasonal variability (e.g. floods and storm events, or droughts) also heavily streamflow and groundwater level, and is exasperated by pumping the water.

**Error! Reference source not found.** shows macroscale trends in streamflow is observed across several decades. In October 1954, the Arkansas River experienced reduced flow (10-25%) at the Syracuse gage station. In October 1987, streamflow had recovered to high flows (75-90%).

In October 2012, streamflow drastically declined to very low flows (<10%). Microscale trends across years can also be observed, as advancing the slider through the 1980s and 1990s reflects very few yellow and red dots at this location. Figure 5 shows spatial macroscale trends along the entire stretch of the Arkansas River in Kansas using streamflow data at seven gage stations. While streamflow is high (>75%) in the west, shown with blue colors, the river has no flow until the Great Bend station, after which flow is present but low (<25%). A closer examination of other

data at that site is necessary for finding an explanation for these trends keeping in mind that flow is accumulated over the entire upstream portion of the river and there may be considerable, though undefined, subsurface influence. The DiscoverWater charts provide the insight for explaining the observed surficial trends.

### **DiscoverWater Charts**

The DiscoverWater charts component spatially and temporally aligns data for irrigation, streamflow, groundwater level, and climate. Users interact with the chart by moving their mouse across the chart area while a vertical line synchronizes the data displayed on each chart. Arranging multiple datasets in this manner allow for observing trends within a dataset and across datasets providing a more coherent explanation of conditions at that time. Ephemeral streams were not given an exclusive classification to separate them from low-flow perennial streams because it is a complex challenge to quantitatively classify ephemeral streams without considering both streamflow and baseflow. Streamflow data alone are insufficient because ephemeral streams typically have dry streambeds except during high precipitation events, but lack of streamflow does not indicate a lack of baseflow. However, using the DiscoverWater charts to identify consistent periods where low streamflow aligns with low groundwater levels helps identify potential ephemeral streams. Additionally, examining periods of very high flow in relation to periods of low groundwater level guides insight into aquifer response to recharge from ephemeral streams following an extreme precipitation event.

For example, Figure 6 shows data during August 1995 highlighting the importance of recharge to the aquifer through streams during recharge events. The climate plot indicates this point was in the middle of a wet period, in which a combination of temperature and amount of precipitation increased the amount of meteoric water. The prevalence of water is reflected in elevated stream flows, rarely below normal (25-75%) and several other extreme flow events. Despite the abundance of water, pumping for irrigation remained relatively stable. Since the 55 m<sup>3</sup>/s of streamflow during this extreme precipitation event far exceeds the 1.6 m<sup>3</sup>/s of pumping, the aquifer was able to recover as groundwater levels increased through infiltration from the stream.

This is reinforced by the waves of groundwater recovery following the same waves of climatic wet periods throughout the 1990s. While the focus here was on recharge from precipitation and aquifer recovery through surface water, the DiscoverWater charts allows the user to focus on many other inter-data relationships, such as pumping and the response by streamflow and groundwater level.

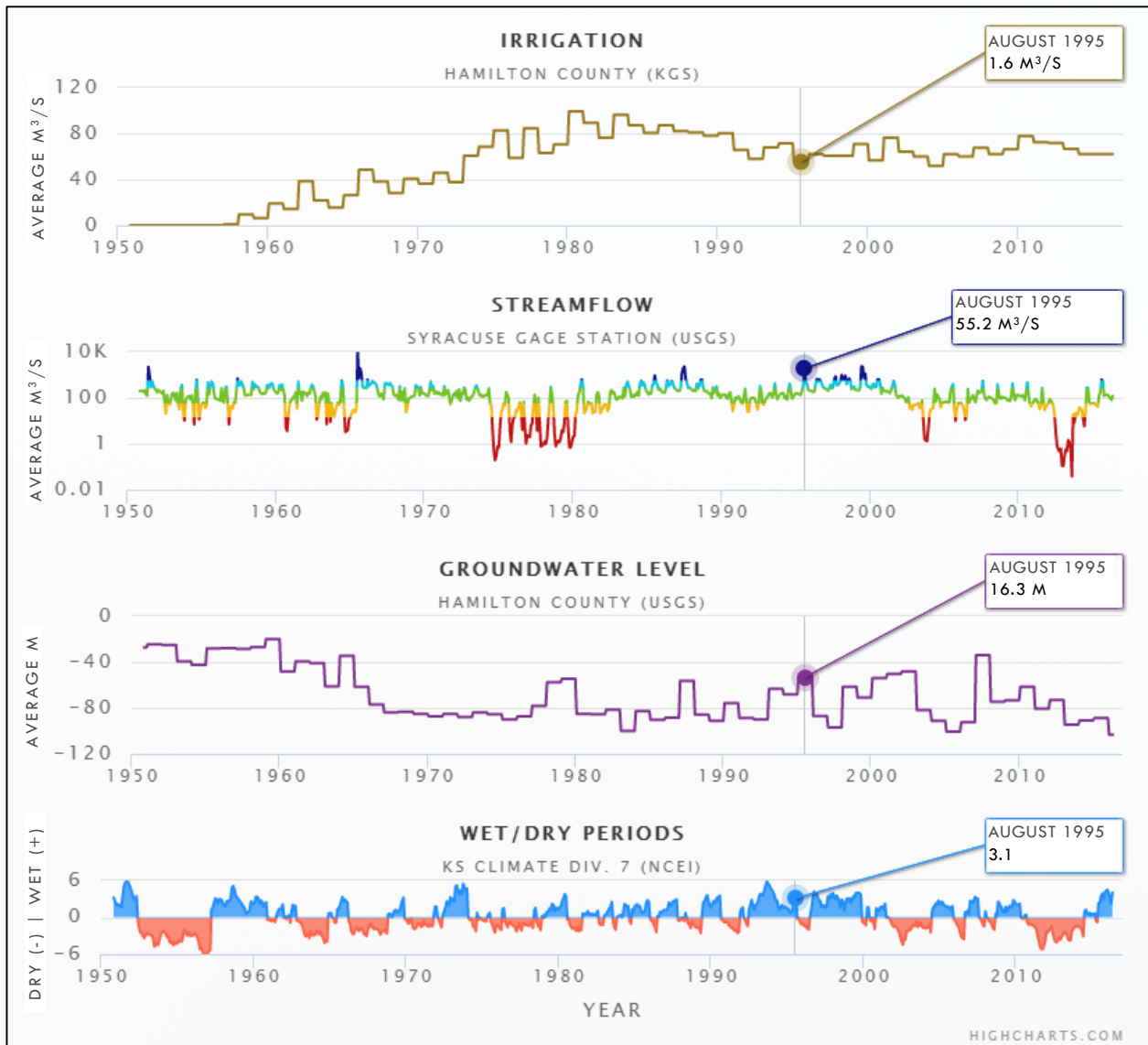


Figure 5. The charts component of DiscoverWater, which has four different datasets aligned and displayed with a synchronized marker. Here, August 1995 is selected to find correlations between streamflow and groundwater level during a wet season.

## DiscoverWater Web App

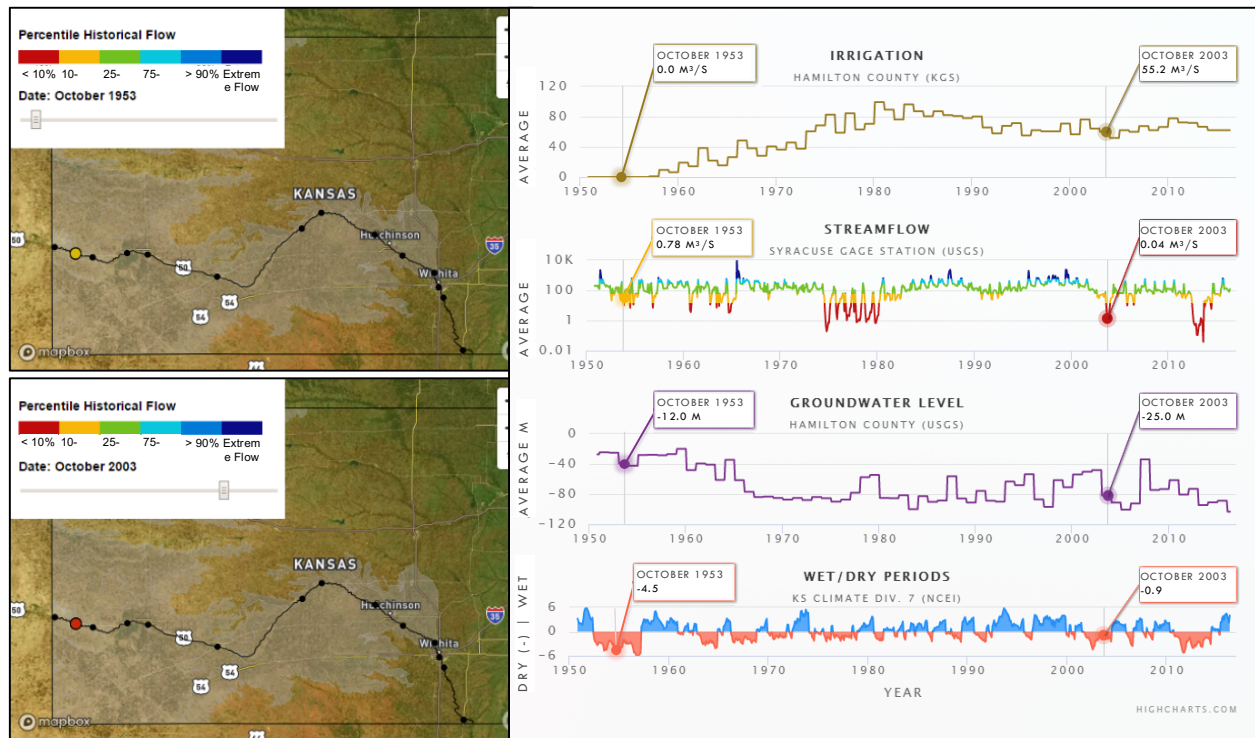


Figure 6. Maps and charts appear side-by-side in DiscoverWater to provide a spatial context for the data displayed in the charts. Here, two different years, 1953 and 2003, have been superimposed to facilitate comparisons over a 50-year time period. In 1953, prior to heavy pumping with the development of the aquifer for irrigation, streamflow and groundwater experienced some decline during a dry period. In 2003, streamflow and groundwater declined substantially more during a less severe dry period while pumping the aquifer showing that human impact exceeds climate impact

The DiscoverWater web app (<http://discover-energy.ku.edu/interact>) pairs the map and charts components side-by-side with the description of key hydrological moments to guide users through some of the insights that can be gleaned such as the severe decline in streamflow coinciding with excessive pumping from development of the aquifer with center-pivot irrigation. Figure 7 shows a condensed version of the DiscoverWater web app with snapshots of two different years superimposed. In 1953, the data displayed shows water-use for irrigation as 0  $m^3/s$ , but this is an artifact of a lack of records. In the early stages of development there was not much water-use data until the 1970s when the aquifer came under scrutiny requiring water-use reporting, but weren't considered accurate until the 1990s. 1953 was a dry year reflected by a Palmer Drought Severity Index (PDSI) of -4.5. Streamflow decreased to 0.78  $m^3/s$ , dropping it into the 10-25th percentile, and groundwater declined to 12 m below the surface—a 4.3-meter

reduction from the year before from the surface. However, 50 years later, a less severe dry period with a PDSI of -0.9 occurs. Streamflow was reduced to less than 10% flow, barely flowing at  $0.04 \text{ m}^3/\text{s}$ , and groundwater plummeted to 25 m below the surface—a 10.3-meter decline from the previous year. At this time, the aquifer was being pumped at almost  $1.7 \text{ m}^3/\text{s}$ , which far exceeds  $0.04 \text{ m}^3/\text{s}$  and results in the drop in baseflow supporting the river. It is apparent that pumping the aquifer for irrigation is substantially impacting streamflow and groundwater level, and the degree of impact is heavily influenced by climate.

Declines in streamflow and groundwater level within the HPA occur naturally during climatic dry period prior to major pumping. Yet, when center-pivot irrigation is established, declines in streamflow and groundwater level are even greater due to over-allocated groundwater rights and the perception of an endless supply of water. These trends are reinforced numerically as the point value for each dataset is displayed at the top of each chart showing that often the water being removed from the aquifer is far exceeding the amount of water in the streams that are recharging the aquifer. This provides the necessary evidence for why the HPA lacks the base flow to support instream flow for much of the Arkansas River that is observed as ephemeral.

## **Conclusions**

There are many visualization techniques to illustrate anthropogenic impact to the hydrologic system. Truly understanding human influence since pre-development requires seeing the big picture of how different natural components interact and affect each other by bringing together their respective datasets with a long historical record--groundwater level, streamflow, climate, and water use for irrigation. Combining stacked plots of these data into a synchronized, interactive visualization allows comparisons to be made from the period of pre-agricultural development to present time. Through data-driven visualization methods, this dynamic map allows for analyses to be made on various temporal scales, from across historical record to a select season, and spatial scales, from individual gage stations to the entire Arkansas River.

In the early stages of development for irrigation when pumping is minimal, streamflow and groundwater level declines are the result of a 5-year drought. Expansion of center-pivot irrigation from the 1950s through the 1970s created massive declines in streamflow and groundwater level while climate remained relatively neutral. The aquifer is so heavily impacted by pumping that even during a high wet period in 1972, there was no recovery of streamflow and groundwater level. Pumping peaked in the early 1980s, yet streamflow-groundwater interaction is still impacted with over 23 m of groundwater lost just along the Arkansas River since predevelopment. Two decades of mostly wet climate allows some temporary recovery of the aquifer until the next dry period showing recharge from precipitation runoff through streams is critical. Constant pumping, even during wet years, does not allow the aquifer to recover enough to withstand major dry periods and droughts, as seen in 2002 – 2004 and 2010 – 2014, causing concern for longevity of the aquifer, especially with a changing global climate. These complex relationships are best understood through the visual comparisons between multiple variables made possible by DiscoverWater, and provide insight for where remediation efforts are most needed. Local and regional trends support the need for collaborative conservation to protect water use for both irrigation and streamflow-dependent ecosystems.



## **CHAPTER 3: FUTURE WORK AND PUBLICATION**

### **Future Work**

Developing the prototype of DiscoverWater for this thesis has opened the door for scientifically strengthening and visually enriching this tool. This is a promising step towards achieving the most effective multivariate visualization platform for hydrologic analysis in areas where groundwater has been extensively impacted by pumping for irrigation. Expanding this framework provides a way to analyze other hydrologically critical regions in the United States, as well as global groundwater depletion, where data are available. Automating data retrieval directly from databases and pre-processing will populate the tool real-time with the most recent data at any chosen location. This adaptability will require streamlining the code for the web app to be more computationally frugal. A strategy for an optimal workflow was not carried out in the scope of this thesis as actualizing a working prototype was the priority.

### **Better Identification and Classification of Ephemeral Streams**

Visualizing low-flows (<10%) measured at the stream gage station with the color red, has a powerful impact on illustrating declines in streamflow. A separate classification for a stream in the ephemeral state would empower advancements in understanding ephemeral streams. An algorithm that integrates flow-duration curves for rainfall runoff (Costa et al., 2014), total sensitivity scores for land-use impact (O'Connor et al., 2014), and very-high-spatial resolution remotely sensed imagery to detect the extent of ephemeral landscapes (Hamada et al., 2016) would produce a more holistic environmental flow method for characterizing streamflow (Pyrce, 2004). Temporally animating the evolving landscape in conjunction with percentile flow classifications, would portray the river flowing and desiccating in the same manner as would a real river instead of as segments, like in the DiscoverWater prototype.

### **Improving Interactive Features**

DiscoverWater brought interactability to the visualization of spatio-temporal data with a user-controlled slider bar to temporally scroll through the flow data displayed on the map and synchronized tooltip to align charts of multiple time-series datasets. The augmentation of

interactive features, such as turning on and off map layers and datasets, would make the tool more captivating so users would spend more time manipulating the data and exploring its story. Aggregating additional datasets, as suggested by Butler et al. (2013), such as evapotranspiration, precipitation, temperature, and geochemical analyses, would allow users to construct a profile of datasets relative to many environmental problems from ephemeral streams and ecological preservation (O'Connor et al., 2014) to agricultural impacts and aquifer contamination (Gleeson et al., 2012a). Enabling pop-up markers activated by the user's mouse to highlight key hydrological moments would navigate the user through understanding trends in the visualized data. Streamlining the user-interface by improving existing interactive features, such as linking control of the map and charts so that they progress simultaneously, would increase the user's ability to focus on the spatio-temporal patterns between them. User-experience surveys and case studies would identify strengths and weaknesses in the tool and guide the design to accommodate a wide-range of users and applications.

### **Publication**

The manuscript in Chapter 2 of this thesis will be published in a peer-reviewed journal. The DiscoverWater website will remain hosted by The University of Kansas at <http://discover-energy.ku.edu/interact>. Continuing work on this project will lead to publishing the optimized code on GitHub.

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## APPENDICES

### Appendix A: Supplemental Figures

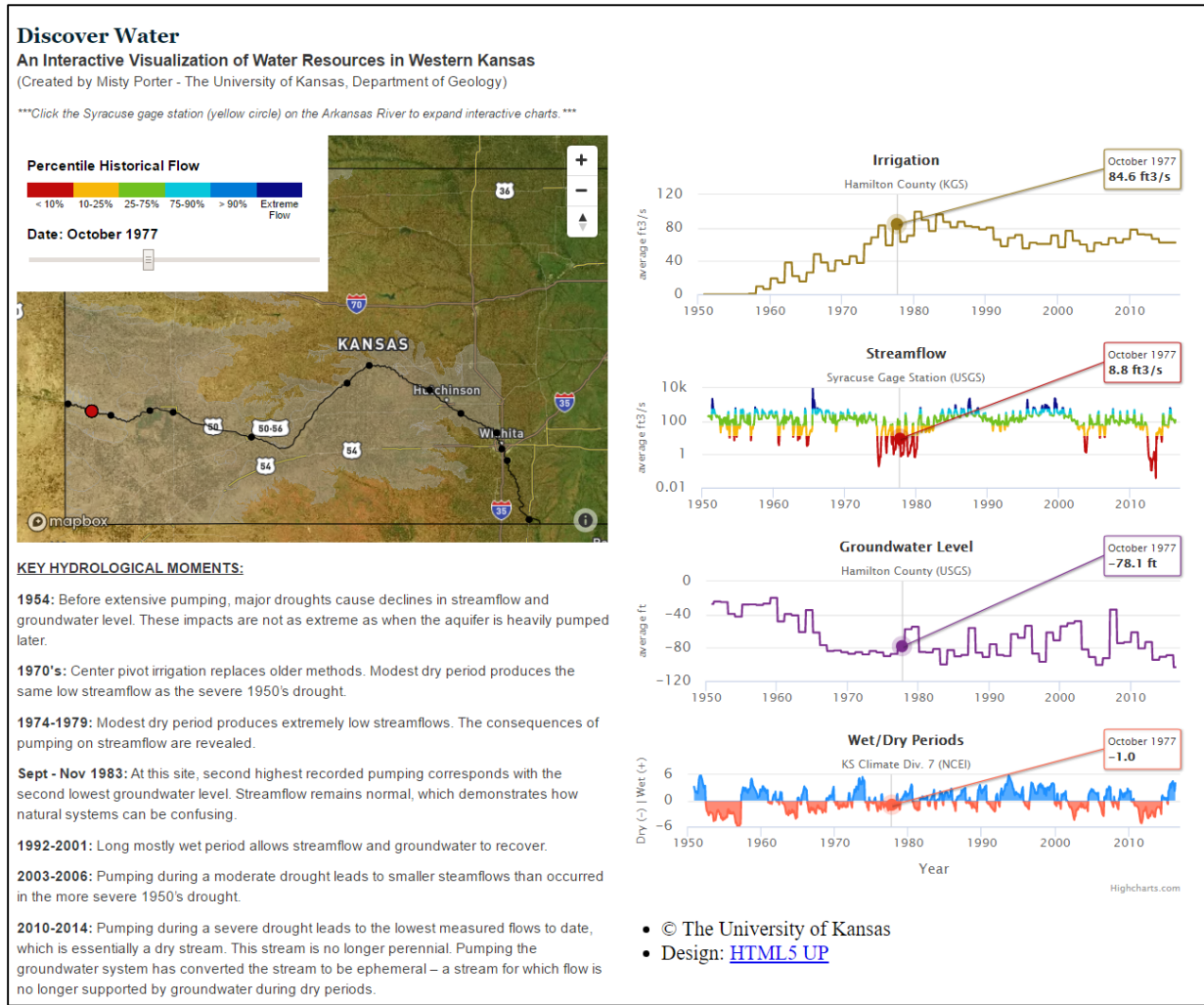


Figure 7. DiscoverWater tool website available at <https://discover-energy.ku.edu/interact>. Map component and charts component appear side-by-side with explanation of key hydrological components guiding the user through some of the major trends.

### Appendix B: Supplemental Tables

Table 2. Terminology defined as used within the context of this project.

TERM	DEFINITION
Time-series data	Quantitative data of a specific type collected over time.

Geographic data	Data that characterizes specific locations (latitude-longitude coordinates), geographic features, or areas.
Spatio-temporal data	A combination of geographic data and time-series data that varies spatially and temporally.
Geographic visualization (geo-visualization)	An illustration of data in a spatial context only on a map (no temporal component/spatially-fixed), typically through the use of geographic information systems (GIS) software. This has also been referred to as geo-visualization.
Dynamic visualization	An animated portrayal of time-series data so that each event may be observed (temporally-varying/no spatial component); the opposite of static.
Spatio-temporal visualization	An animated portrayal of the changes in data measurements over time within a geographic context (temporally-varying/spatially-fixed or temporally-varying/spatially-varying). This has also been referred to as dynamic cartography and animated geo-visualization.
Interactive visualization	Any type of visualization that allows user interface and control.
Web app	An interactive application accessible on the web/internet/online via a URL.

Table 3. CSV of data imported into the GIS software for the Syracuse gage station.

long	lat	site_no	site_nm	date	Q_m	GW_m	PDSI	PUMP_m
-101.75684	37.96612	7138000	SYRACUSE	1950-10	5.59	-8.32	0.6	0
-101.75684	37.96612	7138000	SYRACUSE	1950-11	5.92	-8.32	0.6	0
-101.75684	37.96612	7138000	SYRACUSE	1950-12	5.38	-8.32	0.6	0
-101.75684	37.96612	7138000	SYRACUSE	1951-01	5.24	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1951-02	5.96	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1951-03	4	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1951-04	3.51	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1951-05	62.5	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1951-06	23.7	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1951-07	8.34	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1951-08	14.38	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1951-09	9.5	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1951-10	7.29	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1951-11	6.31	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1951-12	4.94	-7.45	4	0
-101.75684	37.96612	7138000	SYRACUSE	1952-01	6.17	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1952-02	5.43	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1952-03	5	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1952-04	4.4	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1952-05	5.66	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1952-06	1.96	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1952-07	0.59	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1952-08	3.76	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1952-09	1.55	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1952-10	1.44	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1952-11	2.35	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1952-12	4.16	-7.64	-0.5	0
-101.75684	37.96612	7138000	SYRACUSE	1953-01	4.67	-11.96	-3.5	0
-101.75684	37.96612	7138000	SYRACUSE	1953-02	3.9	-11.96	-3.5	0
-101.75684	37.96612	7138000	SYRACUSE	1953-03	2.19	-11.96	-3.5	0
-101.75684	37.96612	7138000	SYRACUSE	1953-04	4.59	-11.96	-3.5	0
-101.75684	37.96612	7138000	SYRACUSE	1953-05	1.42	-11.96	-3.5	0
-101.75684	37.96612	7138000	SYRACUSE	1953-06	0.92	-11.96	-3.5	0
-101.75684	37.96612	7138000	SYRACUSE	1953-07	6.59	-11.96	-3.5	0
-101.75684	37.96612	7138000	SYRACUSE	1953-08	10.34	-11.96	-3.5	0
-101.75684	37.96612	7138000	SYRACUSE	1953-09	0.78	-11.96	-3.5	0
-101.75684	37.96612	7138000	SYRACUSE	1953-10	0.29	-11.96	-3.5	0
-101.75684	37.96612	7138000	SYRACUSE	1953-11	1.98	-11.96	-3.5	0

## Appendix C: Programming Code

### **Code 1. Highcharts JavaScript code for the Syracuse charts website component of DiscoverWater.**

```
<!DOCTYPE HTML>

<!-- Identity by HTML5 UP
html5up.net | @n33co
Free for personal and commercial use under the CCA 3.0 license (html5up.net/license) -->
<html>

<head>
  <title>Visualizing Water Resource Evolution in Southwest Kansas</title>
  <meta charset="utf-8" />
  <meta name="viewport" content="width=device-width, initial-scale=1" /> <!-- Scales website
for device screen size. -->
  <link rel="stylesheet" href="assets/css/main.css" /> <!-- Uses a CSS template from cPanel. -->
  <noscript><link rel="stylesheet" href="assets/css/noscript.css" /></noscript>
</head>

<body class="is-loading">
  <!-- HTML Wrapper -->
  <div id="wrapper">
    <!-- Main Content Area -->
    <section id="main">
      <!-- Sets up containers for each chart and one container that combines all charts for
synchronization -->
      <div id="syncChart" style="width: 100%; margin-left: auto; margin-right: auto">
        <div id="pumpChart" style="width: 100%;height: 190px; margin-left: auto; margin-right:
auto"></div>
        <div id="qChart" style="width: 100%;height: 190px; margin-left: auto; margin-right:
auto"></div>
```

```
<div id="gwChart" style="width: 100%;height: 190px; margin-left: auto; margin-right: auto"></div>
```

```
<div id="pdsiChart" style="width: 100%;height: 170px; margin-left: auto; margin-right: auto"></div>
```

```
</div>
```

```
<script>
```

```
if ('addEventListener' in window) {  
  window.addEventListener('load', function() {  
    document.body.className = document.body.className.replace(/\bis-loading\b/, "");  
  });  
  document.body.className += (navigator.userAgent.match(/(MSIE|rv:11\.\.0)/) ? ' is-ie' : "");  
}
```

```
</script>
```

```
<!-- Calls script libraries -->
```

```
<script src="http://cdnjs.cloudflare.com/ajax/libs/jquery/2.2.4/jquery.js"></script>
```

```
<script src="https://code.highcharts.com/highcharts.js"></script>
```

```
<script src="https://code.highcharts.com/modules/data.js"></script>
```

```
<script src="https://code.highcharts.com/modules/no-data-to-display.js"></script>
```

```
<script> // Begin Highcharts
```

```
$(function() {
```

```
  /* In order to synchronize tooltips and crosshairs, override the
```

```
  * built-in events with handlers defined on the parent element.
```

```
  * (Modified from Highcharts API documentation to add indexing)*/
```

```
  $('#syncChart>div').bind('mousemove touchmove touchstart', function(e) {
```

```
    var chart,
```

```
    point,  
    index, // Created a variable for indexed data so that the arrays all have the same positions  
starting at 0, which fixed the problem with the data being misaligned even though the crosshairs  
were synced.
```

```
    i,  
    event;  
chart = $(this).highcharts()  
event = chart.pointer.normalize(e.originalEvent);
```

```
// Find events within the charts  
point = chart.series[0].searchPoint(event, true);  
if (point) {  
    index = point.index  
    for (i = 0; i < Highcharts.charts.length; i = i + 1) {  
        chart = Highcharts.charts[i];  
        point = chart.series[0].points[index]  
        if (point) {  
            point.highlight(e);  
        }  
    }  
}  
});
```

```
Highcharts.Pointer.prototype.reset = function() { // Override the reset function because we  
don't need to hide the tooltips and crosshairs.
```

```
    return undefined;  
};
```

```
Highcharts.Point.prototype.highlight = function(event) { // Highlight a point by setting hover
state, showing tooltip, and draw the crosshairs that form the vertical line connecting the data.
```

```
  this.onMouseOver(); // Show the hover marker
```

```
  this.series.chart.tooltip.refresh(this); // Show the tooltip
```

```
  this.series.chart.xAxis[0].drawCrosshair(event, this); // Show the crosshair
```

```
};
```

```
function syncExtremes(e) { // Synchronize zooming through the setExtremes event handler.
```

```
  var thisChart = this.chart;
```

```
  if (e.trigger !== 'syncExtremes') { // Prevents a feedback loop.
```

```
    Highcharts.each(Highcharts.charts, function(chart) {
```

```
      if (chart !== thisChart) {
```

```
        if (chart.xAxis[0].setExtremes) { // It is null while updating/refreshing.
```

```
          chart.xAxis[0].setExtremes(e.Date.UTC(1950, 10), e.Date.UTC(2016, 04), true, true, {
```

```
            trigger: 'syncExtremes'
```

```
          });
```

```
        }
```

```
      }
```

```
    });
```

```
  }
```

```
};
```

```
//
```

```
// PUMP chart
```

```
//
```

```
$.getJSON("PUMP_Hamilton.json").done(function(rawData) { // Call JSON file with PDSI
data from cPanel.
```

```
  var data = []
```

```
$.each(rawData, function(index, item) { // Parses JSON file - indexes the array values and  
puts it in the format used by Highcharts.
```

```
    data.push([Date.UTC(item[0], item[1]), item[2]])  
})
```

```
Highcharts.chart('pumpChart', {
```

```
  title: {
```

```
    text: '<b>Irrigation</b>', //'Average Annual Water Use for Irrigation in Hamilton County'
```

```
    margin: 5,
```

```
    style: {
```

```
      fontSize: '14px'
```

```
    }
```

```
  },
```

```
  subtitle: {
```

```
    text: 'Hamilton County (KGS)',
```

```
    style: {
```

```
      fontSize: '11px'
```

```
    }
```

```
  },
```

```
  credits: {
```

```
    enabled: false // Disables Highcharts.com stamp at the bottom of each chart. Only appears  
on the last chart.
```

```
  },
```

```
  legend: {
```

```
    enabled: false // Disables legend because the series are explained by title and axes labels.
```

```
  },
```



```
xAxis: { // X-axis formatting
  type: 'datetime',
  crosshair: true, // Creates vertical line that is synchronized across all the charts.
  dateTimeLabelFormats: {
    year: '%Y' // Labels x-axis with the year.
  },
  showFirstLabel: true, // Forces the first label (1950) to be displayed.
  showLastLabel: true, // Forces the last label (2016) to be displayed.
  startOnTick: true, // Forces the first label to start on the first tick interval.
  labels: {
    style: {
      fontSize: '12px'
    }
  },
},
```

```
yAxis: { // Y-axis formatting
  title: {
    text: 'average ft<sup>3</sup>/s',
    style: {
      fontSize: '11px'
    },
  },
  labels: {
    style: {
      fontSize: '14px'
    },
  },
},
```

```

    max: 120,
    tickInterval: 40
  },

  tooltip: {
    positioner: function() { // Forces to tooltip to a fixed location instead of hovering with the
mouse cursor.
      return {
        x: this.chart.chartWidth - this.label.width - 10, // Right aligned.
        y: 5
      };
      relativeTo: 'pumpChart'
    },
    shadow: true,
    borderWidth: 1,
    backgroundColor: 'rgba(255,255,255,0.8)',
    pointFormat: '<b>{point.y}</b><br/>', // Inherit series formatting.
    valueSuffix: ' ft<sup>3</sup>/s', // Append units to values displayed in tooltip.
    valueDecimals: 1,
    padding: 4
  },

  plotOptions: {
    series: {
      marker: {
        enabled: false,
        fillColor: null, // Inherit color from series to make the marker red as it enter a red area on
the plot, and the same with blue, like with the streamflow chart. Could not override default CSS.
Perhaps just works best with more than two color zones.

```

```

    states: {
      hover: {
        lineWidthPlus: 0, // Don't expand line when mouse hovers. Could not override default
        CSS.
      }
    }
  },
  followPointer: true
},

series: [{
  name: '(ft<sup>3</sup>/s)', // Appends "cubic ft per second" to data labels. Superscript
  style doesn't show up in all browsers.
  data: data, // Uses data stored in the variable "data" after parsing fuction.
  lineWidth: 1,
  color: '#99791a' // brown
}],
}); // End pumping/irrigation chart.
}) // End JQuery for pumping/irrigation data.

//
// Q chart
//
$.getJSON("Q_Syracuse.json").done(function(rawData) { // Call JSON file with PDSI data from
cPanel.
  var data = []
  $.each(rawData, function(index, item) { // Parses JSON file - indexes the array values and
puts it in the format used by Highcharts.

```

```

    data.push([Date.UTC(item[0], item[1]), item[2]])
  })

Highcharts.chart('qChart', {
  title: {
    text: '<b>Streamflow</b>', // 'Average Monthly Streamflow measured at the Syracuse gage
station'
    margin: 5,
    style: {
      fontSize: '14px'
    }
  },

  subtitle: {
    text: 'Syracuse Gage Station (USGS)', // 'Syracuse Stream Gage Station (USGS)'
    style: {
      fontSize: '11px'
    }
  },

  credits: {
    enabled: false // Disables Highcharts.com stamp at the bottom of each chart. Only appears
on the last chart.
  },

  legend: {
    enabled: false // Disables legend because the series are explained by title and axes labels.
  },

```

```
xAxis: { // X-axis formatting
  type: 'datetime',
  crosshair: true, // Creates vertical line that is synchronized across all the charts.
  dateTimeLabelFormats: {
    year: '%Y' // Labels x-axis with the year.
  },
  showFirstLabel: true, // Forces the first label (1950) to be displayed.
  showLastLabel: true, // Forces the last label (2016) to be displayed.
  startOnTick: true, // Forces the first label to start on the first tick interval.
  labels: {
    style: {
      fontSize: '12px'
    }
  },
},
```

```
yAxis: { // Y-axis formatting
  title: {
    text: 'average ft<sup>3</sup>/s',
    style: {
      fontSize: '11px'
    },
  },
  labels: {
    style: {
      fontSize: '14px'
    }
  },
},
```

```

    type: 'logarithmic', // Sets y-axis a logarithmic, which is preferred for viewing streamflow
data.
    max: 10000,
    tickInterval: 2
},

tooltip: {
    positioner: function() { // Forces to tooltip to a fixed location instead of hovering with the
mouse cursor.
        return {
            x: this.chart.chartWidth - this.label.width - 10, // Right aligned.
            y: 5
        };
        relativeTo: 'qChart'
    },
    shadow: true,
    borderWidth: 1,
    backgroundColor: 'rgba(255,255,255,0.8)',
    pointFormat: '<b>{point.y}</b><br/>', // Inheret series formatting.
    valueSuffix: ' ft<sup>3</sup>/s', // Append units to values displayed in tooltip.
    valueDecimals: 1,
    padding: 4
},

plotOptions: {
    series: {
        marker: {
            enabled: false,

```

fillColor: null, // Inherit color from series to make the marker red as it enter a red area on the plot, and the same with blue, like with the streamflow chart. Could not override default CSS. Perhaps just works best with more than two color zones.

```
states: {
  hover: {
    lineWidthPlus: 0, // Don't expand line when mouse hovers. Could not override default
    CSS.
  }
}
},
followPointer: true
},
```

```
series: [{
  name: '( ft<sup>3</sup>/s)', // Appends "cubic ft per second" to data labels. Superscript
  style doesn't show up in all browsers.
```

```
  data: data, // Uses data stored in the variable "data" after parsing fuction.
```

```
  lineWidth: 1,
```

```
  color: '#000000', // Default line color is black.
```

```
  zones: [{ // Apply data-driven formatting
```

```
    value: 0, // no flow
```

```
    color: '#000000' // black
```

```
  }, {
```

```
    value: 13.8, // <10% flow
```

```
    color: '#c10b0b' // red
```

```
  }, {
```

```
    value: 54.975, // 10-25% flow
```

```
    color: '#f7b709' // orange-yellow
```

```

    }, {
      value: 267.425, // 25-75% flow
      color: '#70c11f' // green
    }, {
      value: 530.05, // 75-90% flow
      color: '#08c6db' // cerulean blue
    }, {
      value: 586.1, // > 90% flow
      color: '#007ad6' // medium blue
    }, { // else extreme flow
      color: '#090b86' // indigo
    }
  ]
},
}); // End streamflow (Q) chart.
}) // End JQuery for streamflow data.

//
// GW chart
//
$.getJSON("GW_Hamilton.json").done(function(rawData) { // Call JSON file with PDSI data
from cPanel.
  var data = []
  $.each(rawData, function(index, item) { // Parses JSON file - indexes the array values and
puts it in the format used by Highcharts.
    data.push([Date.UTC(item[0], item[1]), item[2]])
  })

Highcharts.chart('gwChart', {
  title: {

```



```
text: '<b>Groundwater Level</b>', // Annual average groundwater level for Hamilton
county.
```

```
margin: 5,
style: {
  fontSize: '14px'
}
},
```

```
subtitle: {
  text: 'Hamilton County (KGS)',
  style: {
    fontSize: '11px'
  }
},
```

```
credits: {
  enabled: false // Disables Highcharts.com stamp at the bottom of each chart. Only appears
on the last chart.
},
```

```
legend: {
  enabled: false // Disables legend because the series are explained by title and axes labels.
},
```

```
xAxis: { // X-axis formatting
  type: 'datetime',
  crosshair: true, // Creates vertical line that is synchronized across all the charts.
  dateTimeLabelFormats: {
    year: '%Y' // Labels x-axis with the year.
  }
},
```

```
},  
showFirstLabel: true, // Forces the first label (1950) to be displayed.  
showLastLabel: true, // Forces the last label (2016) to be displayed.  
startOnTick: true, // Forces the first label to start on the first tick interval.  
labels: {  
  style: {  
    fontSize: '12px'  
  }  
},  
},
```

```
yAxis: { // Y-axis formatting.
```

```
  title: {  
    text: 'average ft',  
    style: {  
      fontSize: '11px'  
    },  
  },
```

```
},
```

```
labels: {  
  style: {  
    fontSize: '14px',  
  },
```

```
},
```

```
min: -120,  
tickInterval: 40
```

```
},
```

```
tooltip: {
```

positioner: function() { // Forces to tooltip to a fixed location instead of hovering with the mouse cursor.

```
    return {
      x: this.chart.chartWidth - this.label.width - 10, // Right aligned.
      y: 5
    };
    relativeTo: 'gwChart'
  },
  shadow: true,
  borderWidth: 1,
  backgroundColor: 'rgba(255,255,255,0.8)',
  pointFormat: '<b>{point.y}</b><br/>', // Inherit series formatting.
  valueSuffix: ' ft', // Append units to values displayed in tooltip.
  valueDecimals: 1,
  padding: 4
},
```

```
plotOptions: {
  series: {
    marker: {
      enabled: false,
      fillColor: null, // Inherit color from series to make the marker red as it enter a red area on the plot, and the same with blue, like with the streamflow chart. Could not override default CSS. Perhaps just works best with more than two color zones.
```

```
      states: {
        hover: {
          lineWidthPlus: 0, // Don't expand line when mouse hovers. Could not override default CSS.
        }
      }
    }
  }
}
```

```

    }
  }
},
followPointer: true
},

series: [{
  name: '(ft)', // Appends "ft" to data labels. Superscript style doesn't show up in all browsers.
  data: data, // Uses data stored in the variable "data" after parsing fuction.
  lineWidth: 1,
  color: '#7c2f8e' // purple
}],
}); // End GW chart
} // End JQuery for GW data

//
// PDSI chart
//
$.getJSON("PDSI_ClimDiv7.json").done(function(rawData) {
  // Call JSON file with PDSI data from cPanel.
  var data = []
  $.each(rawData, function(index, item) { // Parses JSON file - indexes the array values and puts
it in the format used by Highcharts.
    data.push([Date.UTC(item[0], item[1]), item[2]])
  })

  Highcharts.chart('pdsiChart', { // Begin PDSI chart
    title: {

```

```

    text: '<b>Wet/Dry Periods</b>', // 'Palmer Drought Severity Index for Kansas Climate
Division 7'
    margin: 5,
    style: {
      fontSize: '14px'
    }
  },

  subtitle: {
    text: 'KS Climate Div. 7 (NOAA NCEI)',
    style: {
      fontSize: '11px'
    }
  },

  legend: {
    enabled: false // Disables legend because the series are explained by title and axes labels.
  },

  xAxis: { // X-axis formatting.
    type: 'datetime',
    crosshair: true, // Creates vertical line that is synchronized across all the charts.
    dateTimeLabelFormats: {
      year: '%Y' // Labels x-axis with the year.
    },
    showFirstLabel: true, // Forces the first label (1950) to be displayed.
    showLastLabel: true, // Forces the last label (2016) to be displayed.
    startOnTick: true, // Forces the first label to start on the first tick interval.
    title: {

```

```
text: 'Year',
style: {
  fontSize: '14px'
}
},
labels: {
  style: {
    fontSize: '12px'
  }
},
},

yAxis: { // Y-axis formatting.
  title: {
    text: 'Dry (-) | Wet (+) <br />',
    style: {
      fontSize: '11px'
    },
  },
  labels: {
    style: {
      fontSize: '14px'
    }
  },
  min: -6,
  max: 6,
  tickInterval: 3
},
```

```

tooltip: {
  positioner: function() { // Forces to tooltip to a fixed location instead of hovering with the
mouse cursor.
    return {
      x: this.chart.chartWidth - this.label.width - 10, // Right aligned.
      y: 5
    };
    relativeTo: 'pdsiChart'
  },
  shadow: true,
  borderWidth: 1,
  backgroundColor: 'rgba(255,255,255,0.8)',
  pointFormat: '<b>{point.y}</b><br/>', // Inherit series formatting.
  valueDecimals: 1,
  padding: 4
},

plotOptions: {
  series: {
    marker: {
      enabled: false,
      fillColor: null, // Inherit color from series to make the marker red as it enter a red area on
the plot, and the same with blue, like with the streamflow chart. Could not override default CSS.
Perhaps just works best with more than two color zones.
    }
  }
  states: {
    hover: {
      lineWidthPlus: 0, // Don't expand line when mouse hovers. Could not override default
CSS.
    }
  }
}

```

```

    }
  },
},
followPointer: true
},

series: [{
  type: 'area', // Sets chart type as an area plot instead of default line plot.
  name: '(PDSI)',
  data: data, // Uses data stored in the variable "data" after parsing function.
  lineWidth: 1,
  zones: [{
    value: 0,
    color: '#FF6347' // red
  }, {
    color: '#1E90FF' // blue
  }],
}]
}); //End PDSI chart.
}); // End JQuery for PDSI data.

});
</script> //End Highcharts JavaScript.

</section>

<!-- Points to cPanel directory for Ark River Map webpage and associated files -->
<a href=/ArkRiverMap/>Arkansas River Map</a>

```



```
<!-- Footer -->
<footer id="footer">
  <ul class="copyright">
    <li>&copy; The University of Kansas</li>
    <li>Design: <a href="http://html5up.net">HTML5 UP</a></li>
  </ul>
</footer>
</div>
</body>

</html>
```

**Code 2. Mapbox JavaScript code for the maps component of DiscoverWater.**

```
<!DOCTYPE HTML>

<html>
<head>
<!-- CSS formatting for page layout -->
<style>
body {
  margin: 0;
  padding: 0;
  font-family: 'Helvetica Neue', Helvetica, Arial, Sans-serif;
}

#map {
  position: absolute;
  top: 0;
  bottom: 0;
```

```
width: 100%;  
}
```

```
h1 {  
  font-size: 20px;  
  line-height: 25px;  
}
```

```
h2 {  
  font-size: 14px;  
  line-height: 17px;  
  margin-bottom: 5px;  
}
```

```
a {  
  text-decoration: none;  
  color: #2dc4b2;  
}
```

```
#console {  
  position: absolute;  
  width: 285px;  
  padding: 10px 10px;  
  background-color: white;  
}
```

```
</style>
```

```
<!-- CSS for legend -->
```

```
<style>
.session {
  margin-bottom: 10px;
}

.row {
  height: 12px;
  width: 100%;
}

.session .legend-scale ul {
  margin: 0;
  padding: 0;
  float: left;
  list-style: none;
}

.session .legend-scale ul li {
  display: block;
  float: left;
  width: 45px;
  margin-top: 3px;
  margin-bottom: 6px;
  text-align: center;
  font-size: 10px;
  list-style: none;
}

.session ul.legend-labels li span {
  display: block;
```

```

float: left;

height: 15px;

width: 45px;

}
</style>
</head>

<body>

<meta charset='utf-8' />
<title>Arkansas River Map</title>
<meta name='viewport' content='initial-scale=1,maximum-scale=1,user-scalable=no' />

<!-- Build HTML container for map & user control -->
<div id="map" style="width: 580px; height: 400px"></div>

<div id='console'>
  <div class='session'>
    <h2>Percentile Historical Flow</h2>
    <div class='legend-scale'>
      <ul class='legend-labels'>
        <li><span style='background:#c10b0b;'></span></br>< 10%</li>
        <li><span style='background:#f7b709;'></span></br>10-25%</li>
        <li><span style='background:#70c11f;'></span></br>25-75%</li>
        <li><span style='background:#08c6db;'></span></br>75-90%</li>
        <li><span style='background:#007ad6;'></span></br>> 90%</li>
        <li><span style='background:#090b86;'></span></br>Extreme</br>Flow</li>
      </ul>
    </div>
  </div>
</div>

```

```

</div>
<div class='session' id='sliderbar'>
<h2>Date: October <label id='active-year'>1950</label></h2>
<input id='slider' class='row' type='range' min='0' max='66' step='1' value='0' />
</div>
</div>

<!-- Retrieve CSS files for formatting -->
<link rel="stylesheet" href="https://unpkg.com/leaflet@1.0.3/dist/leaflet.css"
  integrity="sha512-
07I2e+7D8p6he1SIM+1twR5TIrhUQn9+I6yjqD53JQjFiMf8EtC93ty0/5vJTZGF8aAocvHYNEDJajGdNx1IsQ=
="
  crossorigin=""/>
<link href="https://api.mapbox.com/mapbox-gl-js/v0.36.0/mapbox-gl.css" rel="stylesheet" />

<!-- Call script libraries -->
<!-- JQUERY API - for accessing files on cPanel webserver -->
<script src="https://code.jquery.com/jquery-3.1.1.min.js"></script>
<!-- Mapbox API - pulls composite satellite imagery for map background -->
<script src='https://api.mapbox.com/mapbox-gl-js/v0.36.0/mapbox-gl.js'></script>
<!-- Leaflet Omnivore plugin - allows compatibility with KML/geoJSON - used for Google Earth and USGS
REST services -->
<script
  src='//api.tiles.mapbox.com/mapbox.js/plugins/leaflet-omnivore/v0.3.1/leaflet-
omnivore.min.js'></script>

<!-- Begin JavaScript -->
<script> // Initialize Mapbox map
mapboxgl.accessToken
'pk.eyJ1IjoibWlzdHIwb3J0ZXJrdSIsImEiOiIjajlyNG9oOGswMDViMndwaDQ3a2ZxY2NwIn0.Y4Paexki1dR1T
qcKoQQO5w';

```

```

var map = new mapboxgl.Map({
  container: 'map', // References container element id.

  style: 'mapbox://styles/mistyporterku/cj27vo2f300032sog0ibuz33x', // Call custom style pre-constructed
  in Mapbox Studio.

  center: [-99.377,38.578], // Set initial map center in [lon, lat].

  zoom: 6

});

// Add zoom and rotation controls to the map.
map.addControl(new mapboxgl.NavigationControl());

// Add Syracuse gage station to map.
map.on('load', function() {
  map.addLayer({
    id: 'SyracuseSite',
    type: 'circle',
    source: {
      type: 'geojson',
      data: "SyracuseSiteData.geojson"
    },
    paint: {
      'circle-radius': 6,
      'circle-stroke-width': 1,
      'circle-color': {
        property: 'Q',
        stops: [ // Apply data-driven formatting.
          [13.8, '#c10b0b'], // <10%
          [54.975, '#f7b709'], // 10-25%

```

```

    [267.425, '#70c11f'], // 25-75%
    [530.05, '#08c6db'], // 75-90%
    [586.1, '#007ad6'], // >90%
    [5962, '#090b86'] // Extreme flow
  ]
}
},
  filter: ['>=', 'year', 1950], // Selects all data because 1950 is earliest year. Filter is required for slider to
work.
});

// Add data & link to time slider.
document.getElementById('slider').addEventListener('input', function(e) {
  var year = parseInt(e.target.value,10) + 1950; // Get the current year as an integer.
  map.setFilter('SyracuseSite', ['==', 'year', year]);
  document.getElementById('active-year').innerHTML = year; // Pass the year to the HTML div to change
the year displayed by the slider.
});

// Link to charts when gage station site is clicked.
map.on('click', 'SyracuseSite', function () {
  window.open("http://interactiveviz.dept.ku.edu/");
});

// Change the cursor to a pointer when it enters a feature in the 'symbols' layer.
map.on('mouseenter', 'SyracuseSite', function () {
  map.getCanvas().style.cursor = 'pointer';
});

```

```
// Change back to a cursor when it leaves.  
map.on('mouseleave', 'SyracuseSite', function () {  
  map.getCanvas().style.cursor = "";  
});
```

```
// Add Kansas State Boundary.  
map.addLayer({  
  id: 'KansasState',  
  type: 'line',  
  source: {  
    type: 'geojson',  
    data: "KansasStateBoundary.geojson"  
  },  
  paint: {  
    'line-width': 1,  
    'line-color': '#000000'  
  }  
});  
}); // END MAP
```

```
</script>
```

```
</body>
```

```
</html>
```

### **Code 3. GEOJSON data for use with Mapbox**

```
{
```



```

"type": "FeatureCollection",

"features": [

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1950-10", "year": 1950, "month": 10, "Q": 197.5, "GW": -27.29, "PDSI":
"0.6475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1950-11", "year": 1950, "month": 11, "Q": 209.2, "GW": -27.29, "PDSI":
"0.6475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1950-12", "year": 1950, "month": 12, "Q": 190.1, "GW": -27.29, "PDSI":
"0.6475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-01", "year": 1951, "month": 1, "Q": 184.9, "GW": -24.45, "PDSI":
"3.965833333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-02", "year": 1951, "month": 2, "Q": 210.5, "GW": -24.45, "PDSI":
"3.965833333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-03", "year": 1951, "month": 3, "Q": 141.3, "GW": -24.45, "PDSI":
"3.965833333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-04", "year": 1951, "month": 4, "Q": 123.9, "GW": -24.45, "PDSI":
"3.965833333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-05", "year": 1951, "month": 5, "Q": 2207.0, "GW": -24.45, "PDSI":
"3.965833333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-06", "year": 1951, "month": 6, "Q": 837.0, "GW": -24.45, "PDSI":
"3.965833333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-07", "year": 1951, "month": 7, "Q": 294.5, "GW": -24.45, "PDSI":
"3.965833333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] } },

```

```

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-08", "year": 1951, "month": 8, "Q": 508.0, "GW": -24.45, "PDSI":
"3.9658333333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] }},

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-09", "year": 1951, "month": 9, "Q": 335.6, "GW": -24.45, "PDSI":
"3.9658333333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] }},

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-10", "year": 1951, "month": 10, "Q": 257.5, "GW": -24.45, "PDSI":
"3.9658333333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] }},

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-11", "year": 1951, "month": 11, "Q": 222.9, "GW": -24.45, "PDSI":
"3.9658333333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] }},

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1951-12", "year": 1951, "month": 12, "Q": 174.4, "GW": -24.45, "PDSI":
"3.9658333333333333", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] }},

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-01", "year": 1952, "month": 1, "Q": 218.0, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] }},

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-02", "year": 1952, "month": 2, "Q": 191.8, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] }},

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-03", "year": 1952, "month": 3, "Q": 176.7, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] }},

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-04", "year": 1952, "month": 4, "Q": 155.5, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] }},

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-05", "year": 1952, "month": 5, "Q": 199.8, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] }},

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-06", "year": 1952, "month": 6, "Q": 69.1, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] }},

```

```

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-07", "year": 1952, "month": 7, "Q": 21.0, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-08", "year": 1952, "month": 8, "Q": 132.8, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-09", "year": 1952, "month": 9, "Q": 54.9, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-10", "year": 1952, "month": 10, "Q": 50.7, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-11", "year": 1952, "month": 11, "Q": 83.0, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1952-12", "year": 1952, "month": 12, "Q": 146.9, "GW": -25.05, "PDSI": "-
0.5475", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387, 37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1953-01", "year": 1953, "month": 1, "Q": 164.8, "GW": -39.25, "PDSI": "-
3.47666666666667", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] } },

{ "type": "Feature", "properties": { "long": -101.7568387, "lat": 37.9661241, "site_no": 7138000,
"site_nm": "SYRACUSE", "date": "1953-02", "year": 1953, "month": 2, "Q": 137.6, "GW": -39.25, "PDSI": "-
3.47666666666667", "PUMP": 0.0 }, "geometry": { "type": "Point", "coordinates": [ -101.7568387,
37.9661241 ] } },

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