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

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Background

- Excessively pumping aquifers puts stress on the groundwater supply [Figure 1].
- Adaptive measures have been slow due to a lack of understanding hydrology.
- Vast amounts of scientific data are available but not presented in a way to support making the necessary decisions.
- Challenging to compare multiple datasets simultaneously.

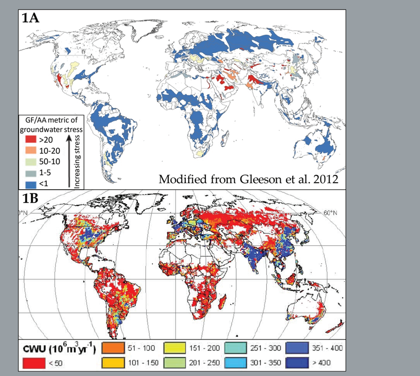


Figure 1A. Distribution of groundwater stress. Figure 1B. Current water use in millions of meters^3 per year. Areas of greatest and water use align with major some of the most impacted aquifers, such the North China Plain, the Krishna and Gadavari systems in India and the High Plains Aquifer in North America

The High Plains Aquifer (HPA)

- Extensive development begans in the 1950s.
- Water level declines exceed more than 50 m (164 ft) in southwest Kansas.
- Concentrated pumping & streamflow decline along the Arkansas River [Figure 2].
- Alluvial deposits link stream systems to the aquifer.
- Surface water declines coincide with groundwater decline converting stretches of perennial rivers to ephemeral.

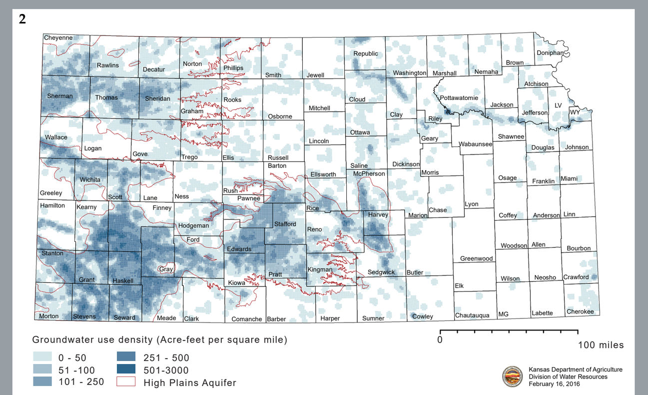


Figure 2. Groundwater use density in Kansas. Shown is the average reported water use from 2003 - 2012 per square mile averaged over a 2-mile radius and summarized by section. The greatest water use is in southwest Kansas along the Arkansas River.

DiscoverWater

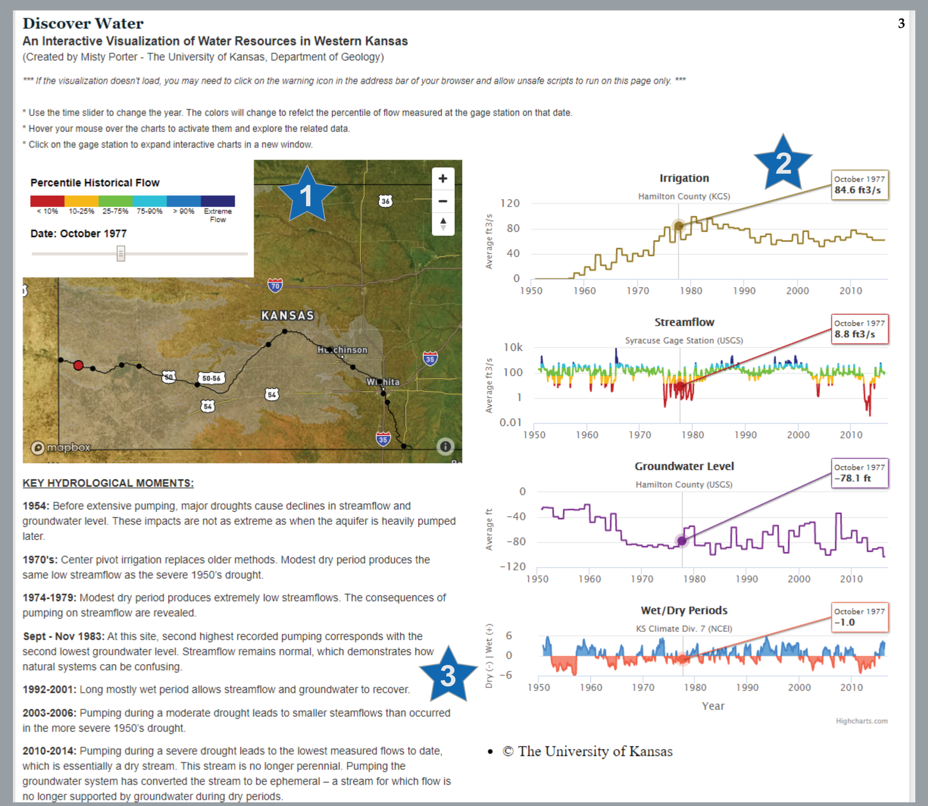


Figure 3. DiscoverWater web app has three components: 1 - Dynamic spatial map representation, 2 - Synchronized time series charts of multiple datasets, 3 - Key hydrological moments and data trends.

http://discover-energy.ku.edu/interact

Objectives

- **Facilitate knowledge discovery through an interactive data visualization to relate data to changes observed across the landscape**
- **Combine multiple time-series datasets to capture important aspects of the hydrologic system**
- **Illustrate spatial trends (local, regional) and temporal trends (annual, seasonal, decadal)**
- **Make the visualization available via a URL to increase accessibility by stakeholders so they can plan wisely**

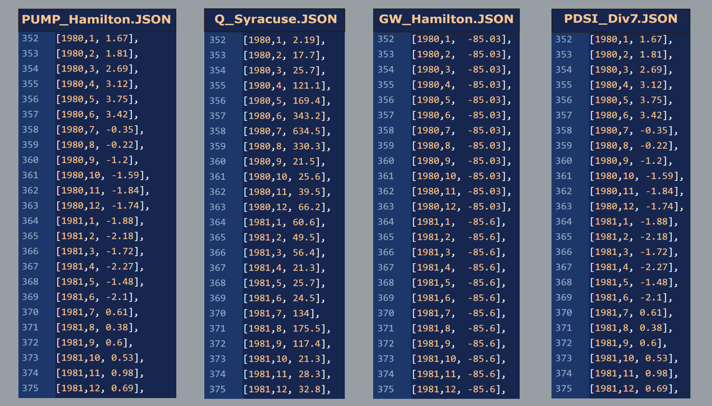
Methods

1. Aqcuire data from federal and state databases:
   - **Streamflow**: monthly average daily mean flow streamflow, USGS NWIS database
   - **Groundwater Level:** annual average depth to water measured from the surface, KGS WIZZARD database
   - **Water-use/Irrigation**: annual average water used specifically for irrigation submitted annually by all water-rights for each county, KGS WIMAS database
   - **Palmer Drought Severity Index (PDSI):** highly responsive monthly index for the intensity of wet and dry periods based on current weather plus cumulative patterns of previous months, NOAA NCEI Climate at a Glance database

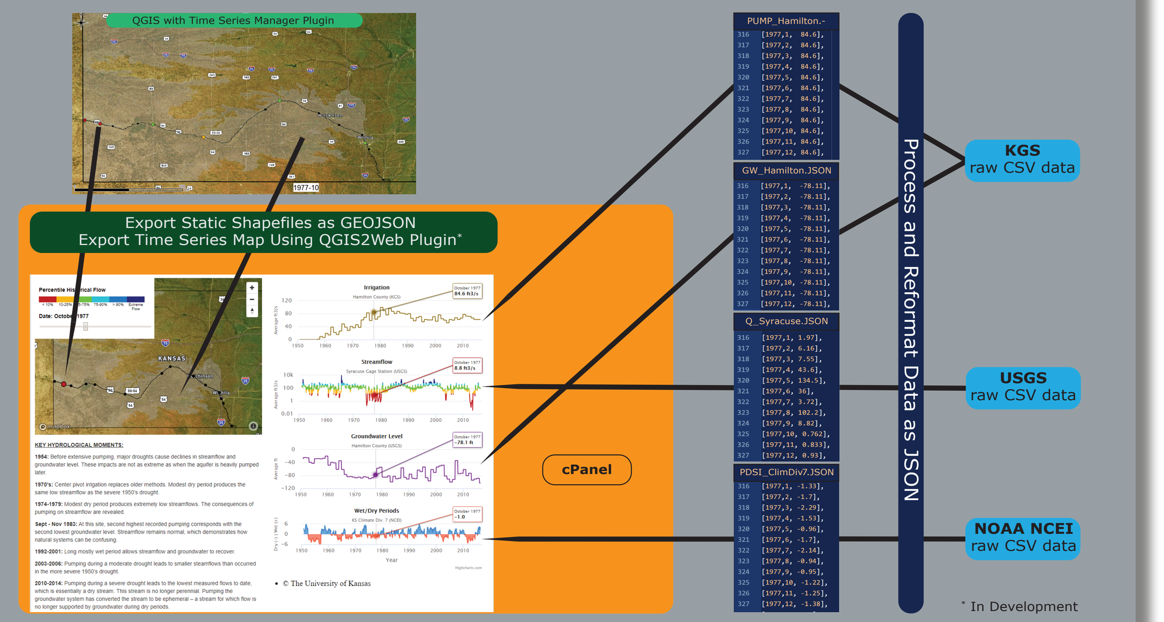
Streamflow		Groundwater		Water-Use		PDSI	
Spatial Scale	Temporal Scale	Spatial Scale	Temporal Scale	Spatial Scale	Temporal Scale	Spatial Scale	Temporal Scale
Gage Station	Monthly	County	Annual	County	Annual	Climate Division	Monthly
Coolidge	1950 – 2017	Hamilton	1939 – 2017	Hamilton	1957 – 2017	7	1950 – 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

Table 1. The spatial and temporal scales vary for each datasetas summarized in this table. These six gage stations were selected for having a historic record going back to at least predevelopment (1950). Water-use data wasn't available until 1956, 57, and 58 for these counties.

2. Coalesce data into one file containing all the relevant data at a gage station:
   To reconcile the different temporal scales, the annual datasets were extended across the monthly records. The table was then reformatted into JSON files, which is file optimized for web-based data query. Each variable is a separate array as shown in Fingure 4.



3. The website for DiscoverWater was developed using JavaScript APIs to call the JSON and GEOJSON files hosted on cPanel, and populate the charts and map with the data.
   - Charts: Highcharts API
   - Map: Mapbox Studio, Mapbox GL JS API, QGIS w/ Time Manager plugins and qGIS2web plugin (exports a QGIS map using Leaflet API



Results and Discussion

Dry Period 1

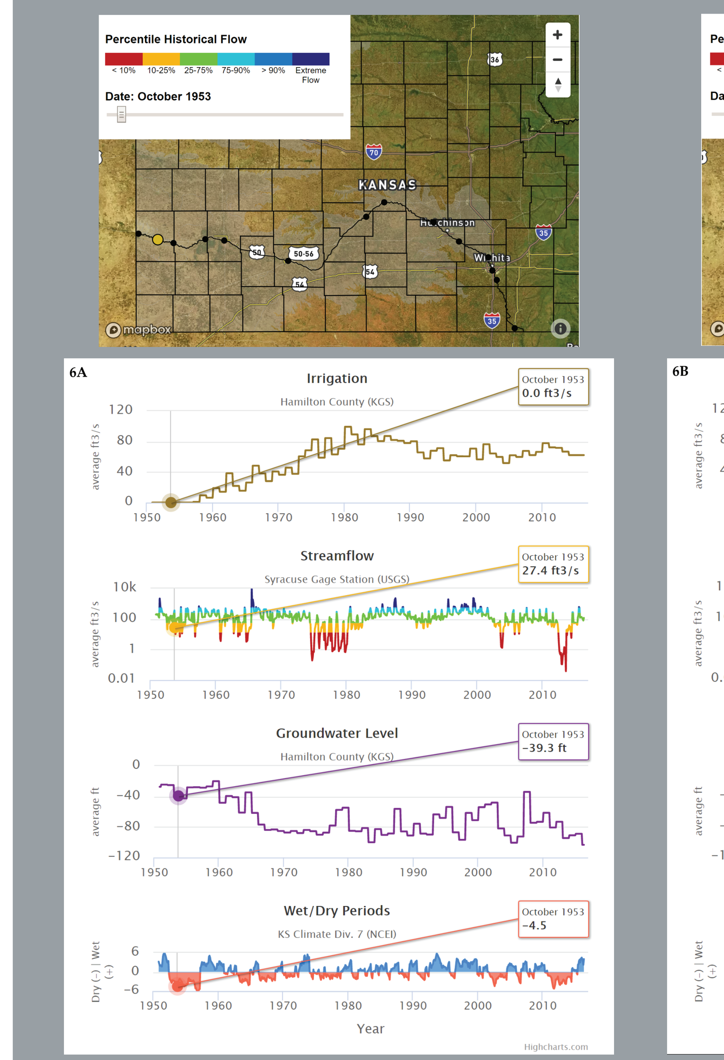


Figure 6A. In October 1953, the point on the streamflow plot is yellow (10 - 25% flow) and the average monthly streamflow measured was 27.4 ft3/s (0.78 m3/s) below the surface. This was a severe dry period indicated by the PDSI value of -4.5, and also by the large red peaks.

At this time the aquifer was in the early stages of development so the impact of pumping was insignificant. Therefore, we can conclude that extremely dry climate is the reason that flow is low and that groundwater declined.

Dry Period 2

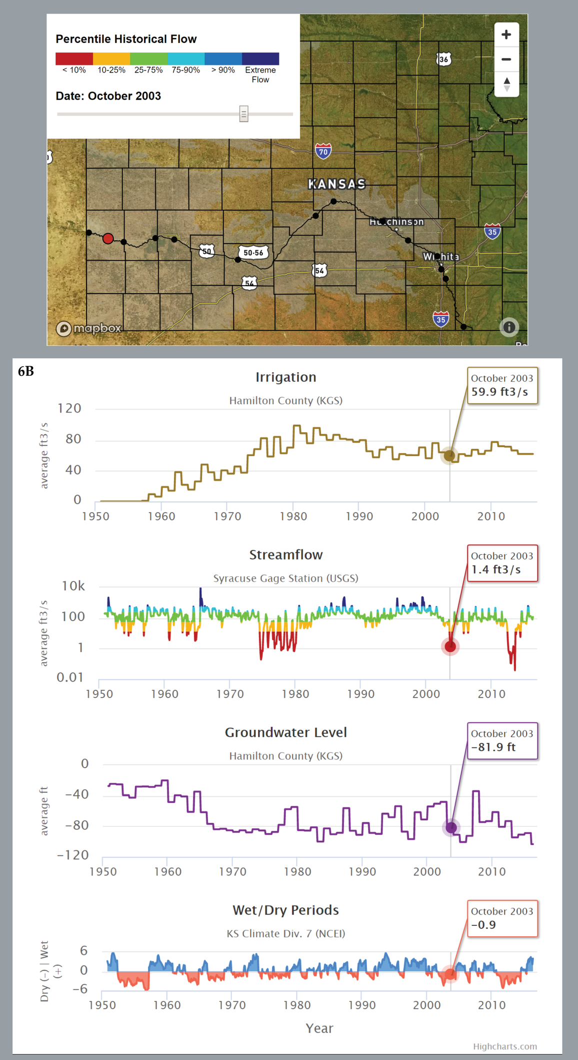


Figure 6B. In October 2003, 50 years later, an average of 60 ft3/s (1.7 m3/s) water was being removed from the HPA. The point on the streamflow plot is red (<10% flow) and the average streamflow was 1.4 ft3/s (0.04 m3/s). The groundwater level was 82 ft (25 m) below the surface, a 34 ft (10.3 m) decline from the previous year. Yet this was a mild dry period with a PDSI of only -0.9.

This shows that pumping the aquifer for irrigation largely impacts the aquifer more than a severe drought does.

Dry Periods & Pumping

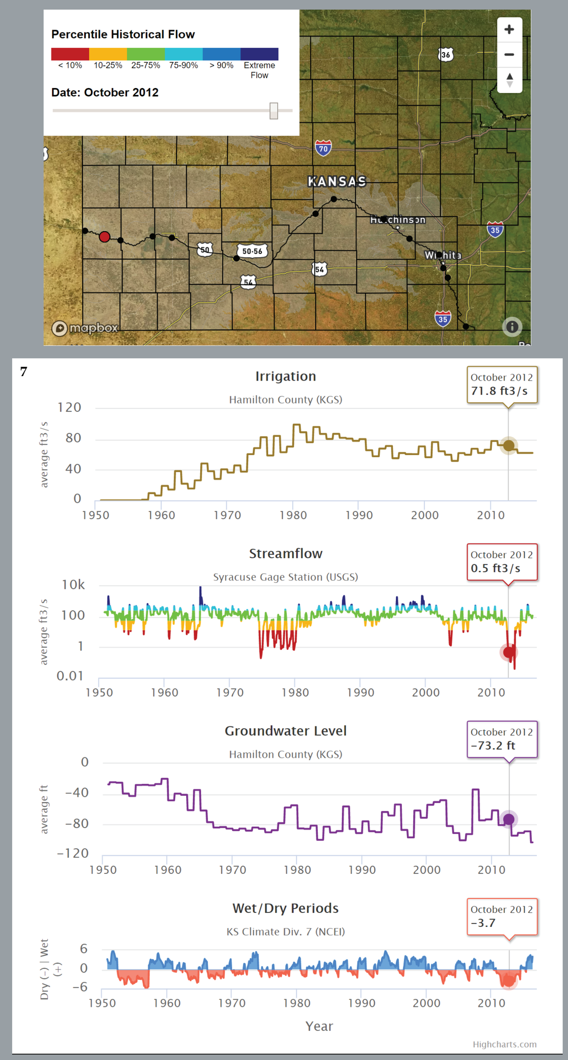


Figure 7. In October 2012, 10 more years later, there is another severe dry period with a PDSI of -3.7, during which the aquifer was pumped at an average of 72 ft3/s (2 m3/s) throughout the year. Streamflow was barely flowing at 0.5 ft3/s (0.01 m3/s), and groundwater was 73.2 ft (22.3 m) below the surface before dropping to 94.5 ft (28.5 m) the following year.

This shows that the impacts of pumping the aquifer are compounded by dry climate.

Wet Periods

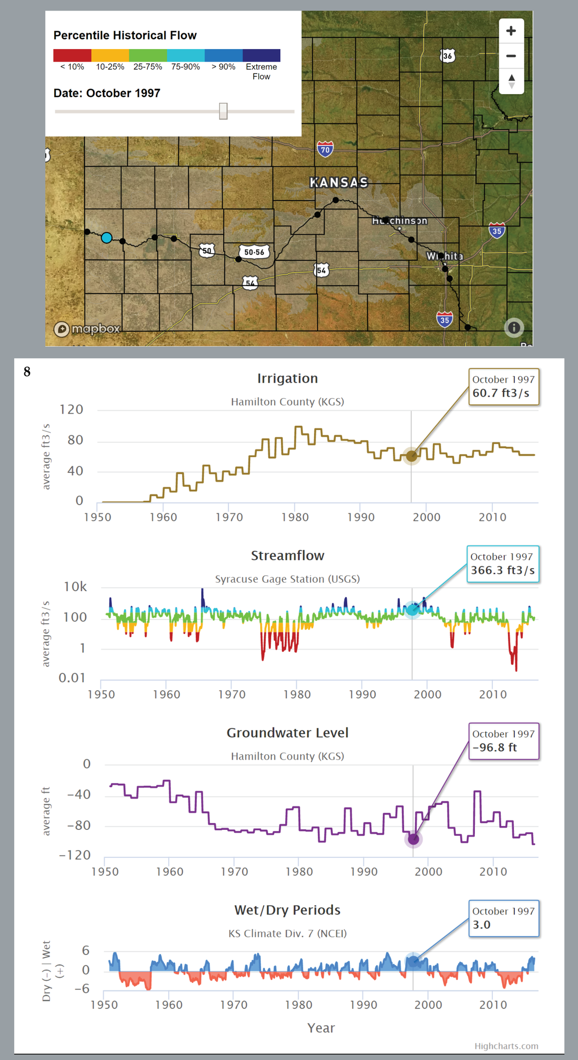


Figure 8. Around the mid-1980s, pumping begins to more or less stabilize. A series of wet periods from about 1987 through 2001, highlighted by the blue boxes, align with increases in groundwater, but some of the peaks extend past the blue boxes indicating there is some delay as the hydrologic system responds.

Again, smaller dry seasons have a greater effect than before pumping, as groundwater sharply declines during short mild dry periods in between these wet periods.

Wet Periods & Pumping

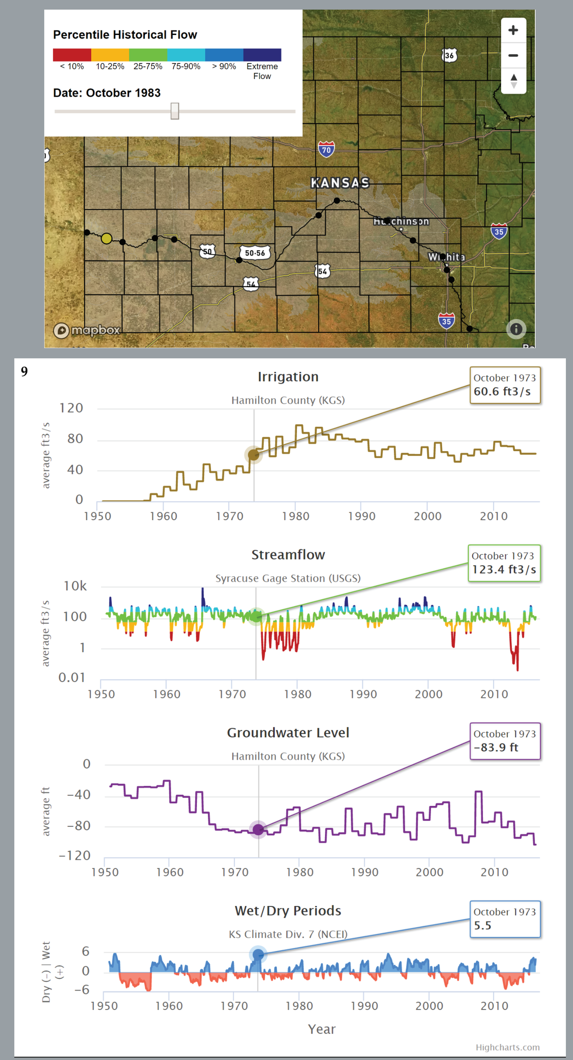


Figure 9. In the 1970s, center-pivot irrigation began to replace older methods as a more efficient way to irrigate. This allowed people to irrigate even more acres of land, further taxing the aquifer. In October 1973, there was an extreme wet period with a PDSI of 5.5, yet neither streamflow nor groundwater were affected due the excess stress on the hydrologic system.

A wet season does not guarantee recharge to the aquifer if it is being over-pumped.

Pumping & Streamflow

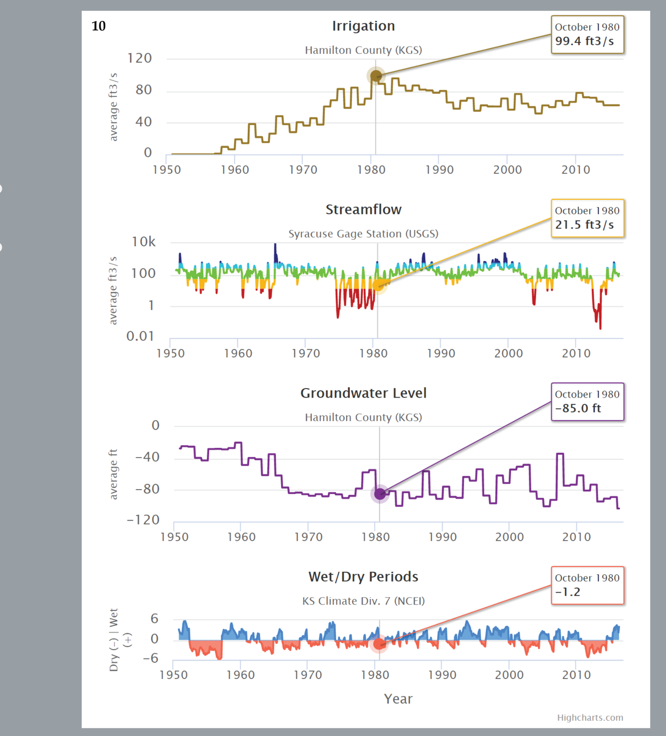


Figure 10. DiscoverWater can be used as an investigatory tool by being able to visually interpret trends. We know that there can be a delay in the response of the hydrologic system so we can look at the months preceding October 1980. Pumping had decreased some through a mild wet season, which finally gave both the groundwater and streamflow some reprieve. Following this mild wet period, the climate switched to a mild dry season in 1980. We might be inclined to assume the groundwater level will decline some and streamflow to return to normal flow as it did in the mid 1960s when similarly, a mild dry period followed a mild wet period.

However, the aquifer was being pumped at an average of almost 100 ft3/s (2.83 m3/s) throughout the year, which is the same as the overall average streamflow measured at the Syracuse gage station, highlighted by the blue line. With groundwater at 85 ft (26 m) below the surface, the hydrologic system is unable to support this much pumping and streamflow drops down to at an average of 21.5 ft3/s (0.6 m3/s).

Conclusion

- Combines data plots with a map display to maintain the overall hydrologic context
  - Data analysis supports tangile observations and experiences
- Elucidates trends across multiple datasets
  - Microscale & macroscale (Local & regional) trends
  - Wet seasons & dry seasons
  - Groundwater & surface water interactions
  - Pumping impacts, climate impacts, & combined impacts
- Visualizes time-series data progressing from past to present
  - Illustrates the story of how present conditions came to be so that future decisions can be made by learning from the past

Future Work

- Add multiple stream gage stations on web app
  - Expand to other areas where data is available to assist with global groundwater decline
- Improved visualization techniques to enforce the degree of landscape
  - Animate streamflow and groundwater level on map
- Improved user-interface and additional interactive features
  - Allow selection of additional datasets and basemaps
- Advanced algorithms to characterized ephemeral streams & focus conservation efforts
- Enable machine learning to provide basic qualitative reasoning of data to suggest potential trends

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