Regional Study Subgroup Continuing Research and Future Directions

(1) Identifying locations where streamflow depletion is likely occurring
(2) Using additional low flow and seasonal flow signatures to increase the chances of detecting streamflow depletion. Assessing anomalies in flow vs climate relations to identify likely streamflow depletion.

*Note: If #1 was done before #2, it could used as another line of evidence supporting the identification of sites that have likely experienced depletion as evidenced by these sites having anomalous relationships between streamflow and climate as compared to streamflow vs climate relationships for non-pumping impacts sites.

Github: GitHub - jhammondusgs/powell_streamflow_depletion_regional_analysis: Calculation streamflow signatures, merging with climate data, and identifying sites where streamflow depletion may be occuring

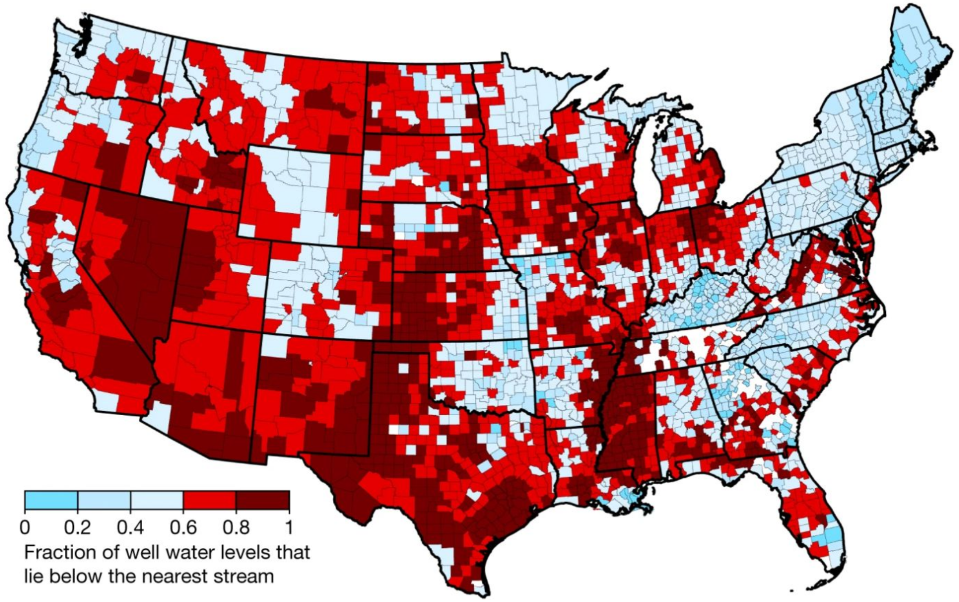
Files github points to: powell_streamflow_depletion_regional_analysis - Google Drive

Continuing Research and Future Directions:

1) Identifying locations where streamflow depletion is likely occurring:

Combining variables across the landscape to identify locations where streamflow depletion is likely occurring:

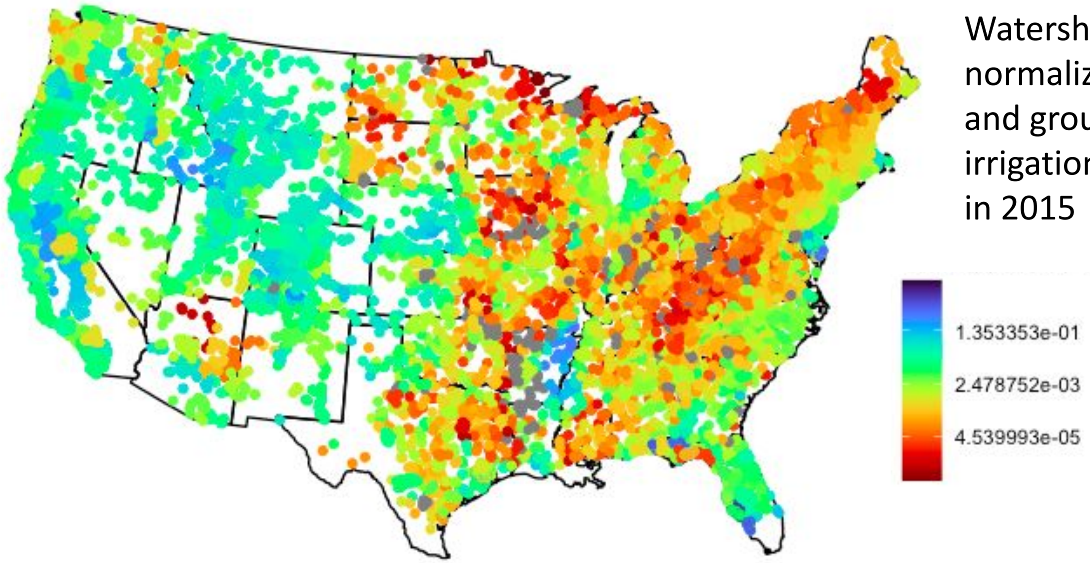
- Sectoral water use through time
- Land use and irrigated agriculture through time
- Crop coverage and type through time
- Aquifer transmissivity



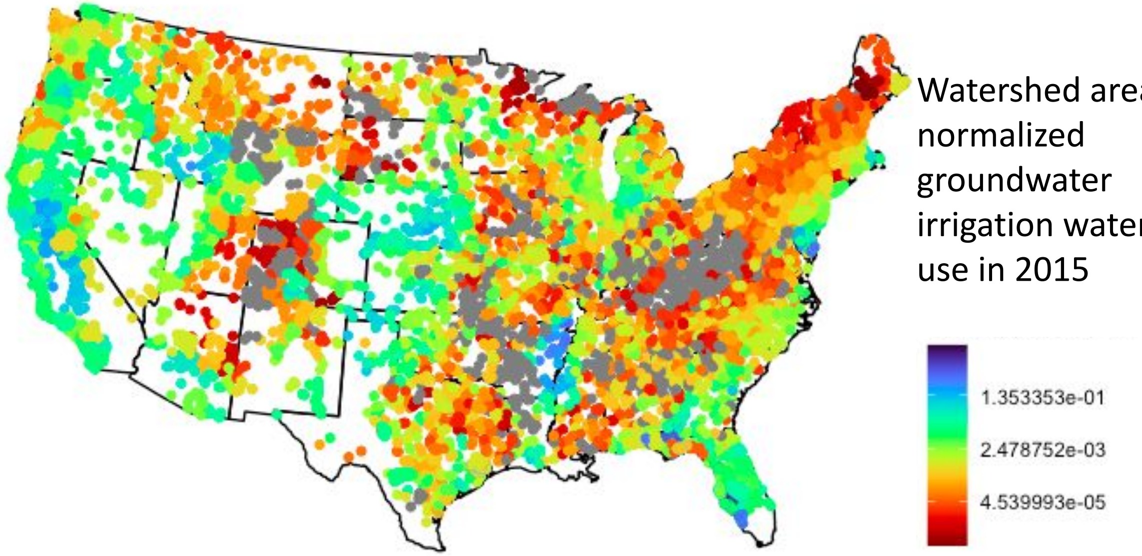
Widespread potential loss of streamflow into underlying aquifers across the USA | Nature

Next steps: set thresholds in variables and rates of change through time based on conditions likely to correspond to streamflow depletion

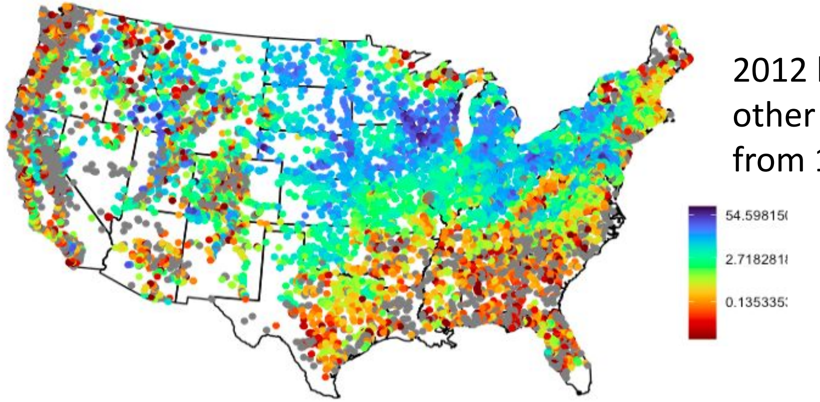
Example plots of variables to include in vulnerability mapping (github code 8)



Watershed area normalized surface and groundwater irrigation water use in 2015



Watershed area normalized groundwater irrigation water use in 2015

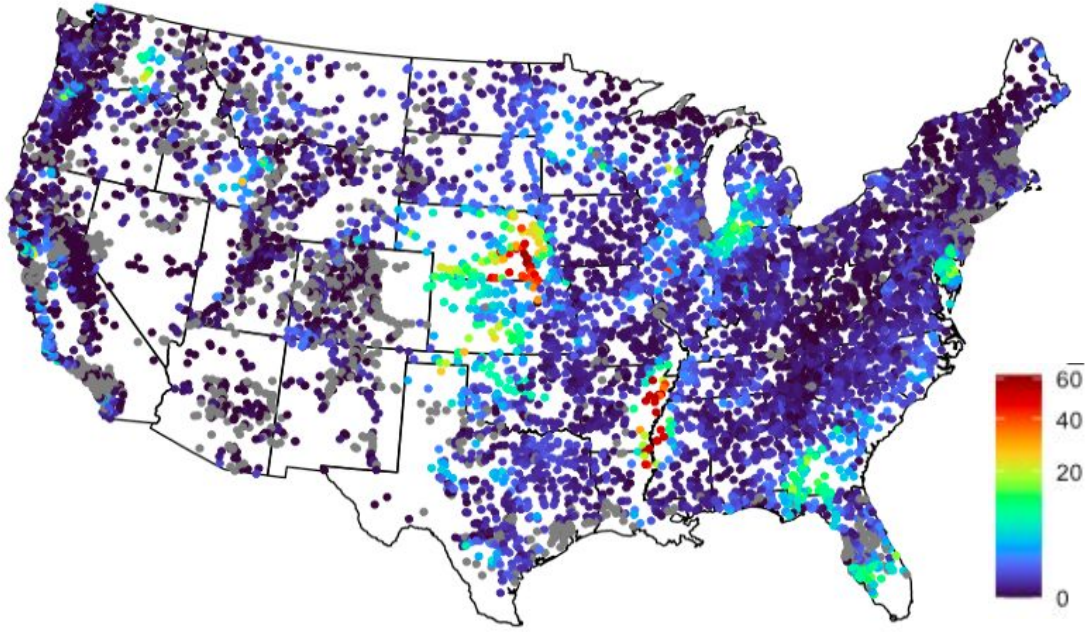


2012 hay (many other crops available from 1950-2012)

All of these variables are available as extracts that are already published as part of the GAGES-II time series dataset

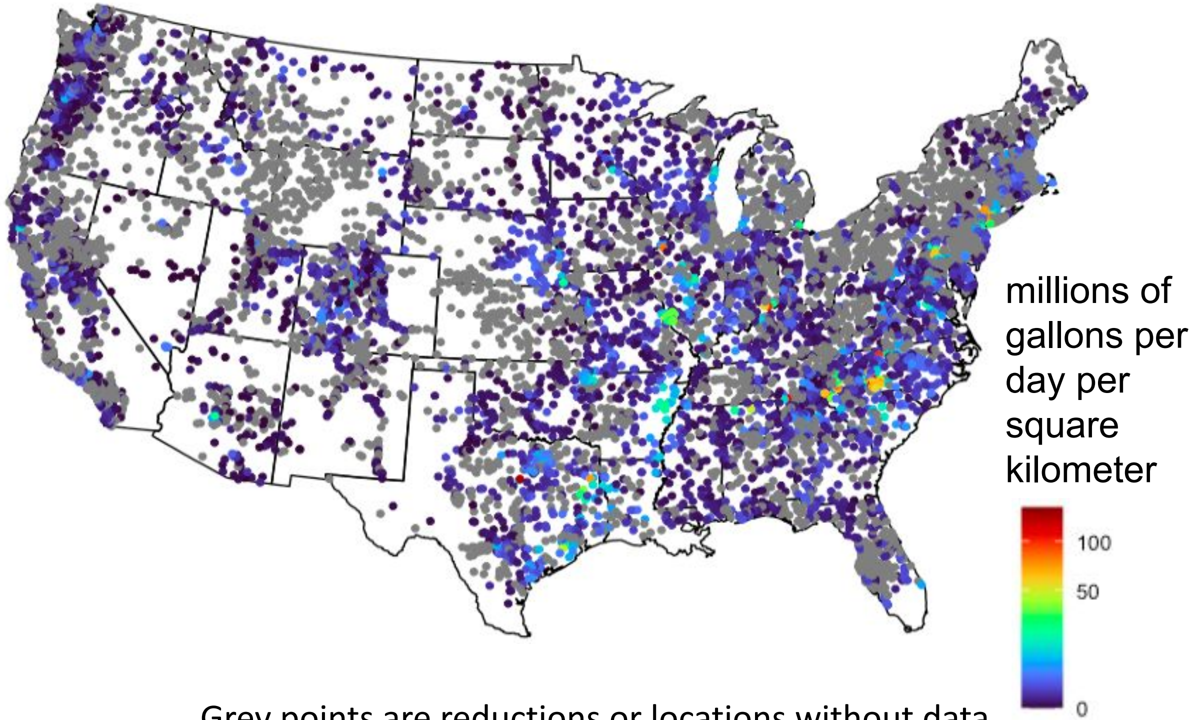
Percent change in irrigated area and water use through time

Percent change in irrigated area for 1950-2012 from linear regression slope * 62 years



Grey points are reductions or locations without data

Change in total water use for 1985-2010 from linear regression slope



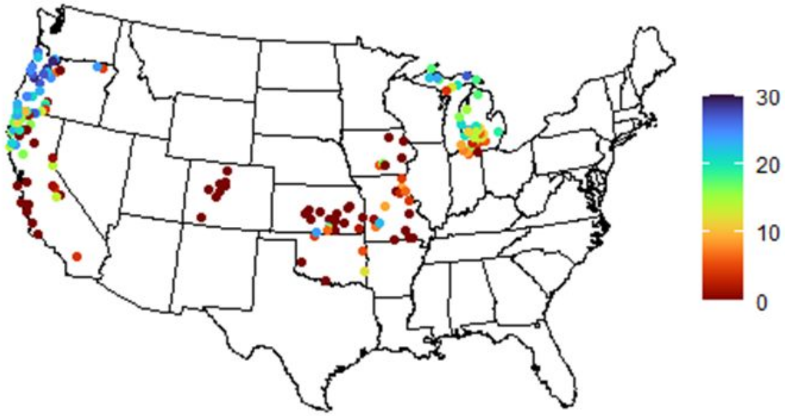
Grey points are reductions or locations without data

Continuing Research and Future Directions:

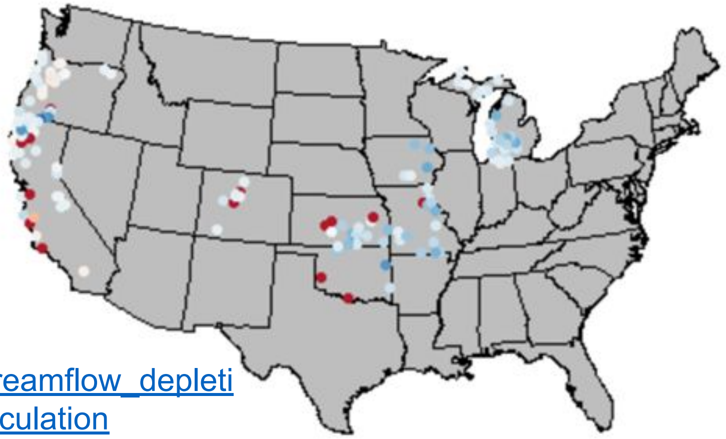
2) Using additional low flow and seasonal flow signatures to increase the chances of detecting streamflow depletion

- Using metrics that focus on summer and fall low flow days, missing flows (deficit volumes), and baseflows
- Detecting anomalies from expected relationships between hydrologic signatures and climate
- Attributing anomalies to streamflow depletion via classification of areas likely impacted by depletion as well as detecting changes across multiple signature vs climate relationships

Summer days below a 10% low flow threshold



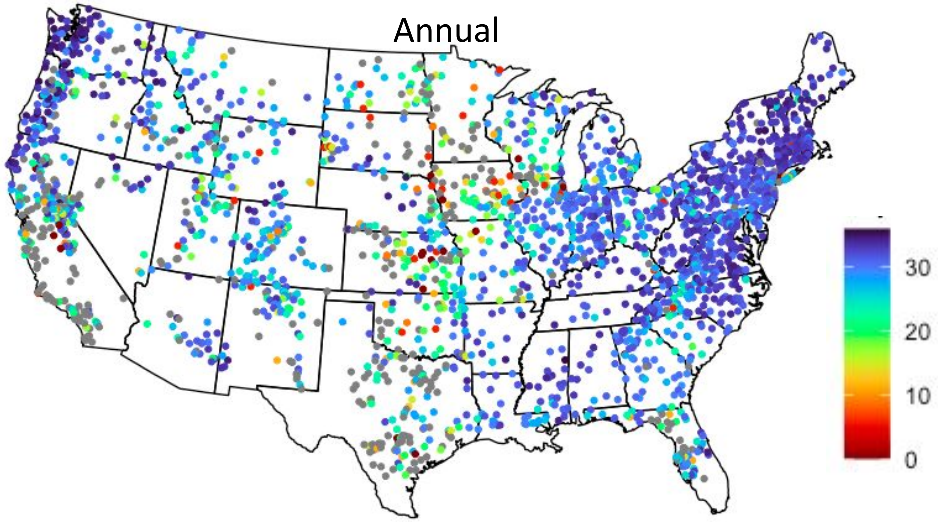
Trends in summer low flow days

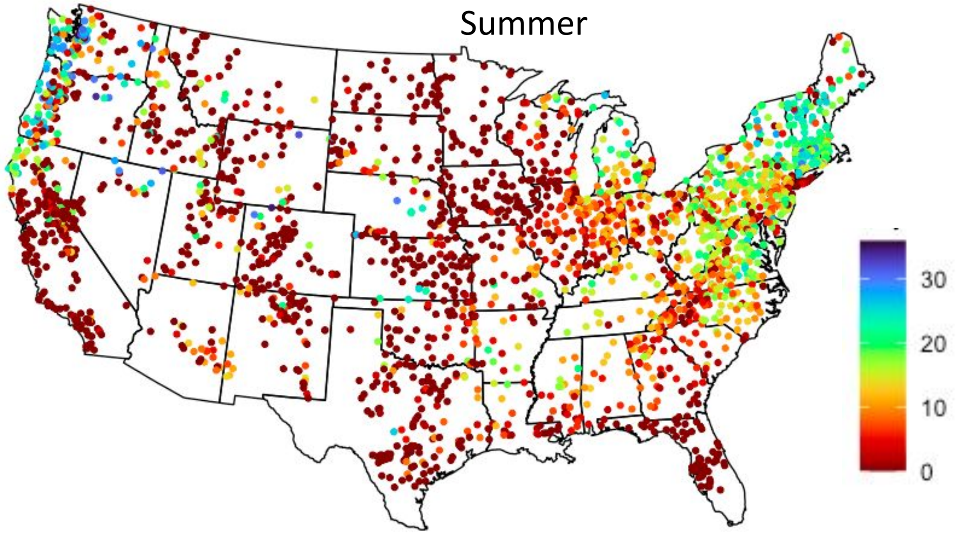


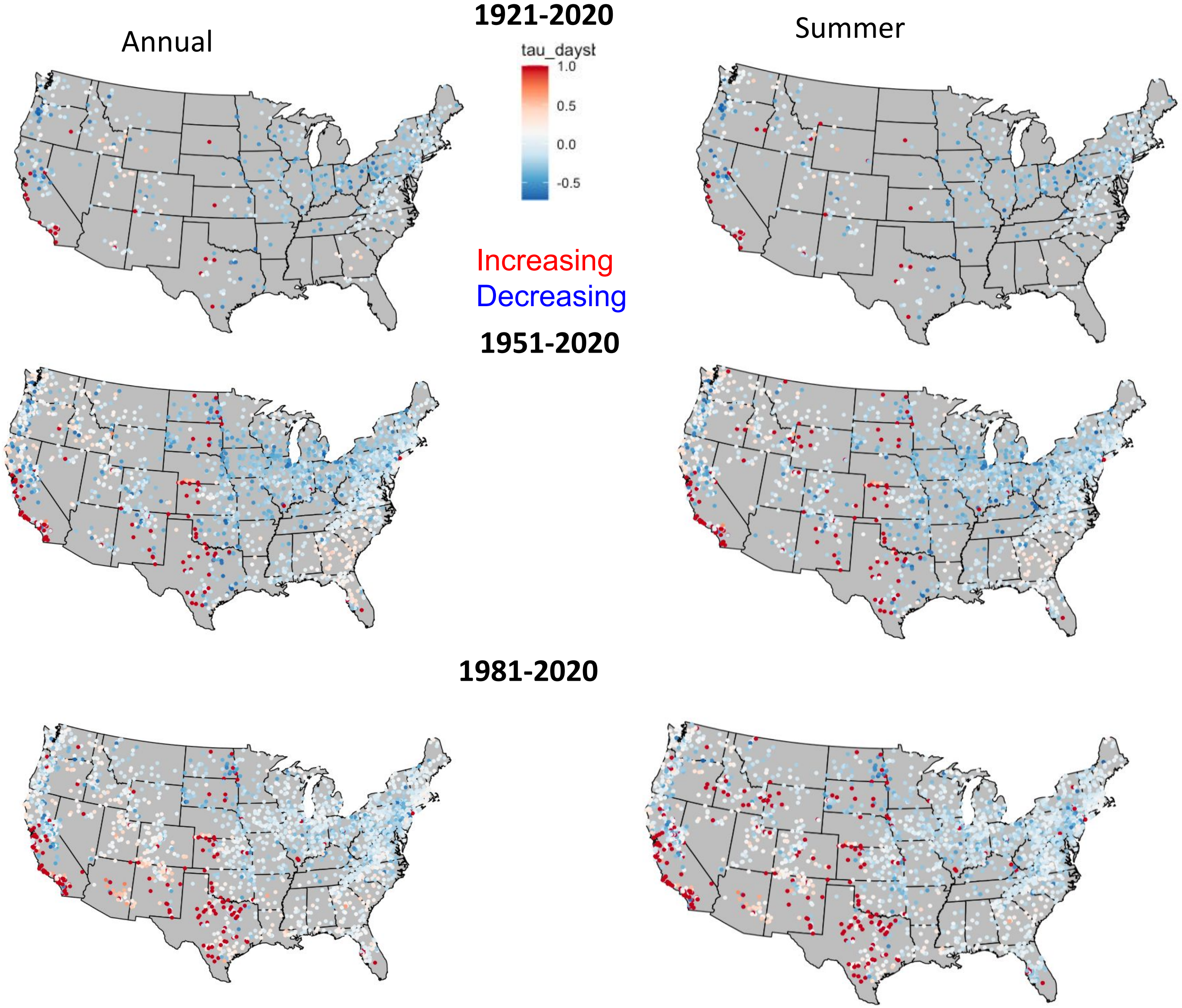
[GitHub - jhammondusgs/powell_streamflow_depletion_regional_analysis: Calculation streamflow signatures, merging with climate data, and identifying sites where streamflow depletion may be occuring]

National # of median low flow days and trends through time

2,449 gages for period 1981-2020 with less than 15 days flow missing per year







Summer and fall low flow signatures most likely to be affected by streamflow depletion

Hydrological Processes

RESEARCH ARTICLE

Identifying Hydrologic Signatures Associated with Streamflow Depletion Caused by Groundwater Pumping

Dana A. Lapides, Sam Zipper, John C. Hammond

First published: 11 April 2023 | https://doi.org/10.1002/hyp.14877

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/hyp.14877.

1. We found that streamflow depletion commonly impacts signatures associated with seasonal and annual low flows and low flow recessions.
2. The largest impacts occurred during dry years, suggesting streamflow depletion may be evident in dry years even where impacts are unmeasurable in wet years.
3. Random forest models indicated that streamflow depletion could significantly impact Annual, Summer, and Fall signatures in most streams.

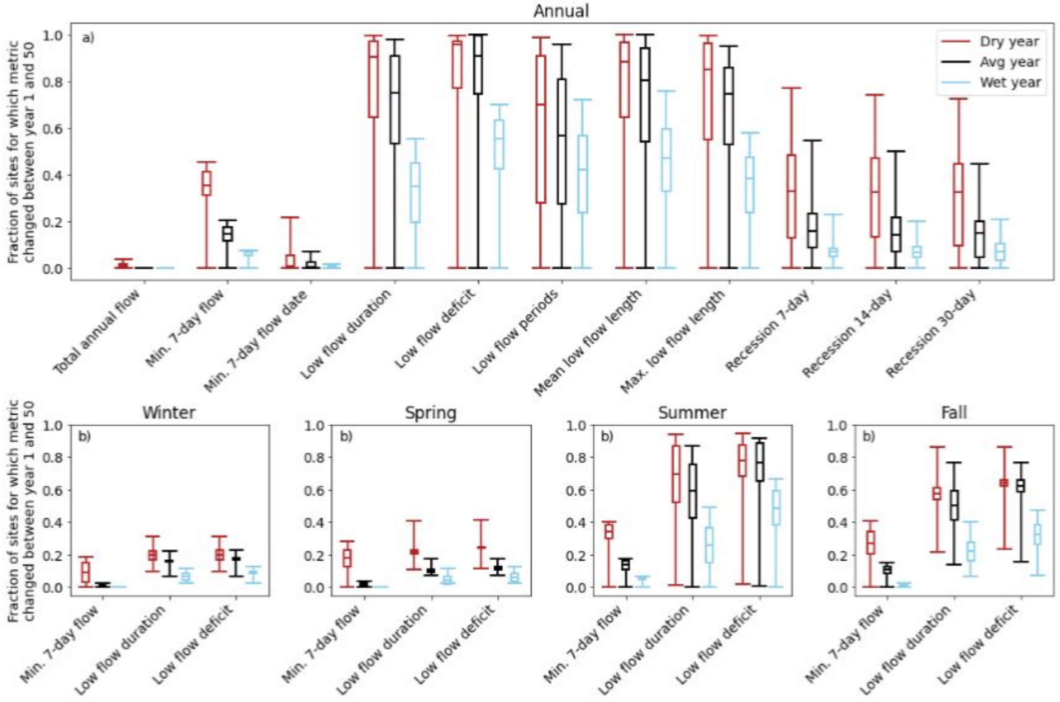
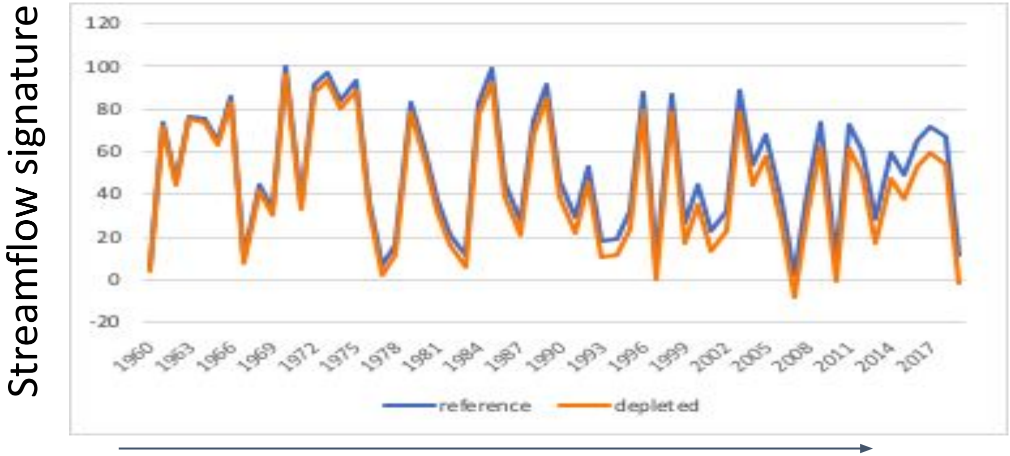


Figure 4: Boxplots for signature sensitivities across all sites, box plots indicate parameter uncertainty for streamflow. Boxplots show the range of sites impacted using the 25-75th percentile across the range of 100 parameter sets for each site with the median number marked. Whiskers denote the minimum and maximum number of sites impacted considering all parameter sets for each site. Results are shown using the periodic pumping scenario and a 20% change threshold for percent different from the no-pumping scenario.

Assessing anomalies in flow vs climate relations to identify likely streamflow depletion:

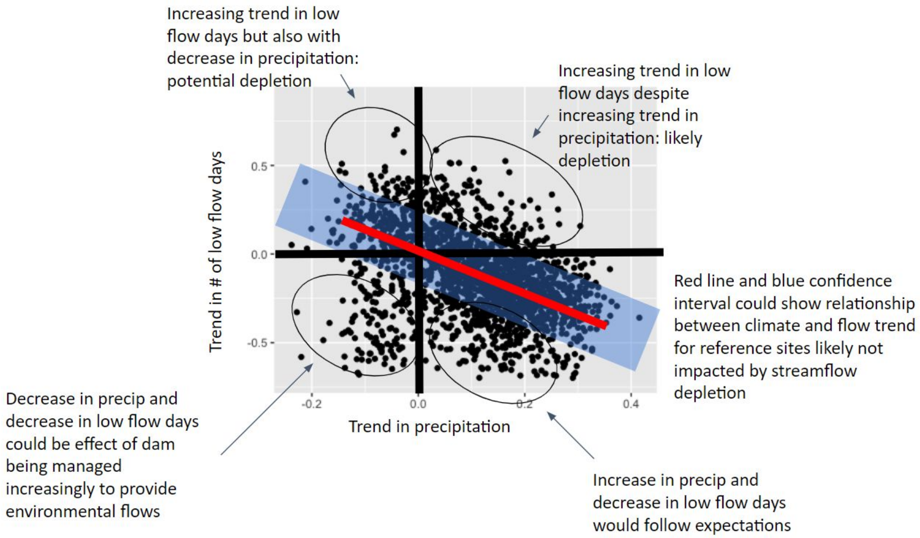
Building models between annual or seasonal flow signatures and climate metrics and identifying residuals from expected regional patterns



Increasing residual from expected streamflow vs climate relationship through time, but especially for dry years, as pumping continues or increases

Examine anomalies from expected relationship between flow and climate through time. Are anomalies consistently in direction that would indicate depletion. For example, count # of years where the number of summer low flow days is greater than expected from gages likely not impacted by depletion. Could also look at if this anomaly is increasing through time.

Using trends in climate and flow signatures to identify sites not following regional trends

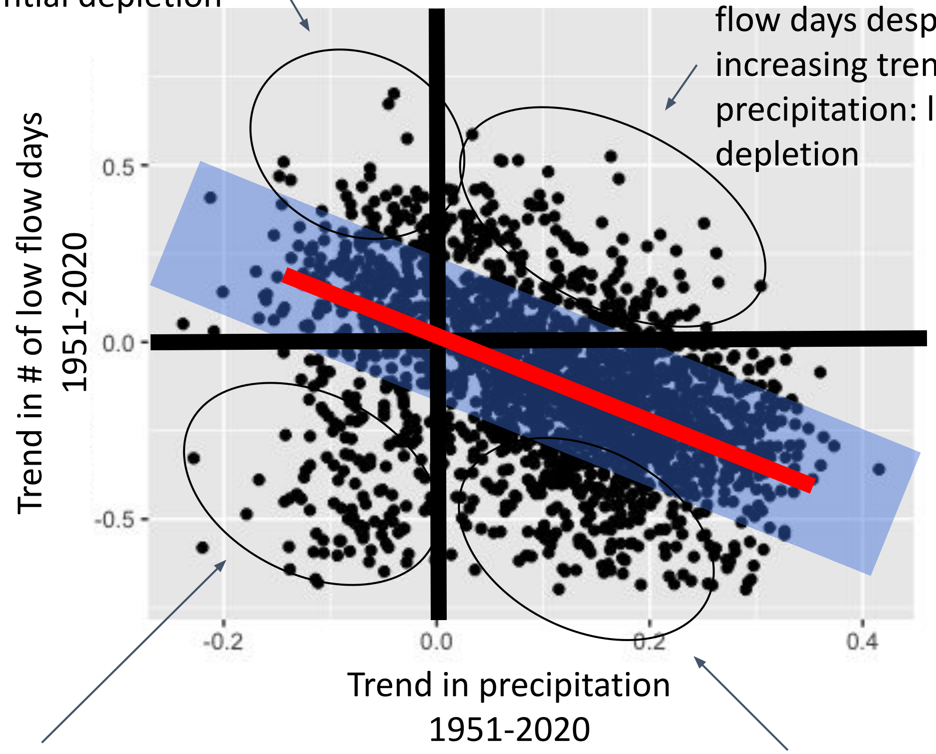


Count # of streamflow signature trend vs climate metric trends falling outside of expected range.

Hypothetical trend vs trend model fit and outliers

Increasing trend in low flow days but also with decrease in precipitation: potential depletion

Increasing trend in low flow days despite increasing trend in precipitation: likely depletion

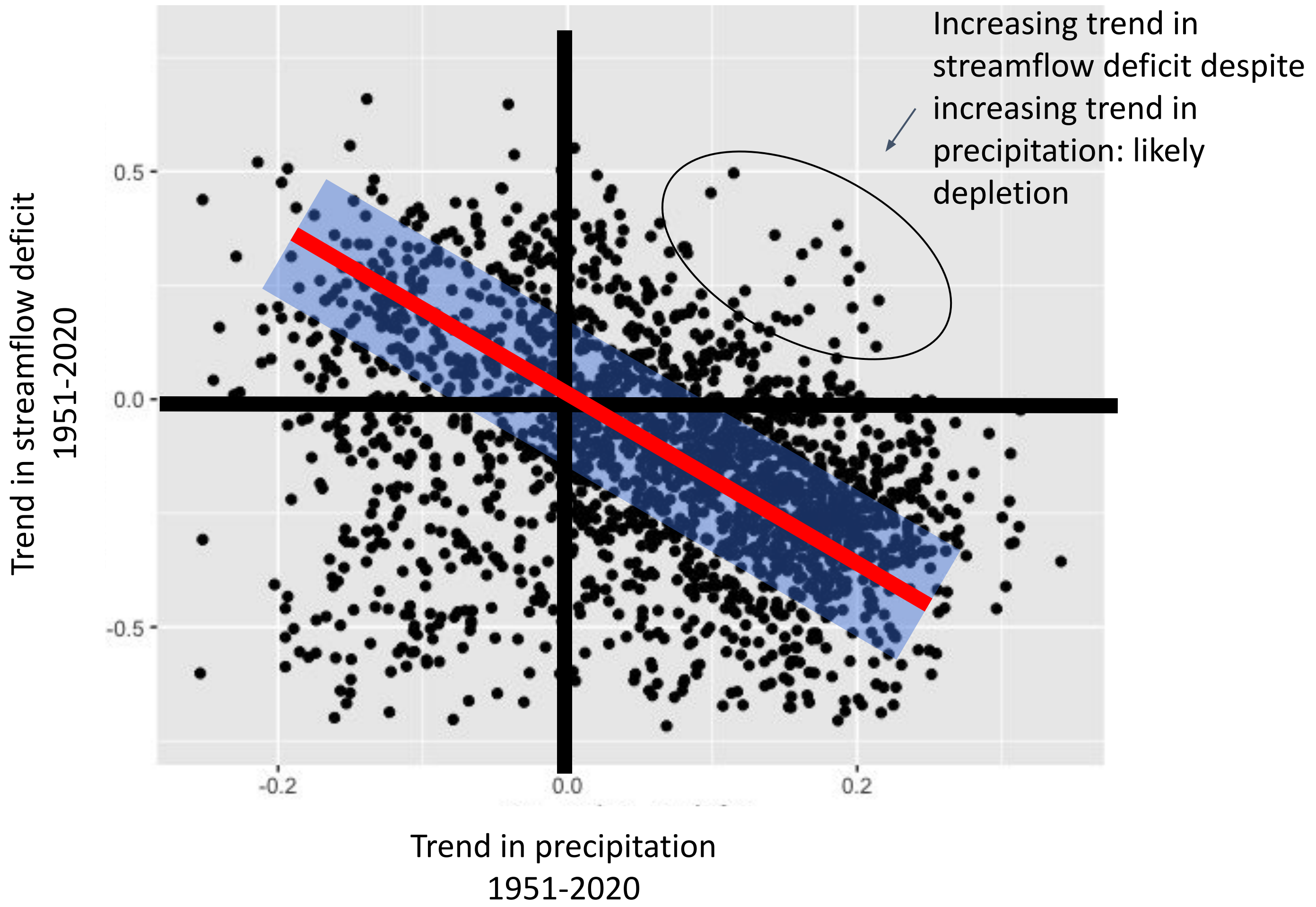


Red line and blue confidence interval could show relationship between climate and flow trend for reference sites likely not impacted by streamflow depletion

Decrease in precip and decrease in low flow days could be effect of dam being managed increasingly to provide environmental flows

Increase in precip and decrease in low flow days would follow expectations

Another example for a different metric combination



Github

- 1_download_streamflow_2_calculate_annual...mflow_signatures_3_join_with_climate_data.R
- 4_merge_all_individual_annual_files_to_one_file_seasonal_to_another.R
- 5_run_trends_on_metrics_for_defined_period.R
- 6_plotting_from_master_files.R
- 7_anomaly_detection.R
- 8_development_of_a_gage_classification_scheme.R

1,2,3) Downloads streamflow data, calculates annual and seasonal streamflow signatures, merges with climate information.

4) Run on personal machine, not adapted to use relative paths. Merges all of the individual gage files of streamflow signatures and climate metrics to create master files

5) Run on personal machine, not adapted to use relative paths. Runs trends in streamflow signatures and climate metrics for 1921, 1951, and 1981 - 2020 and outputs master trend files.

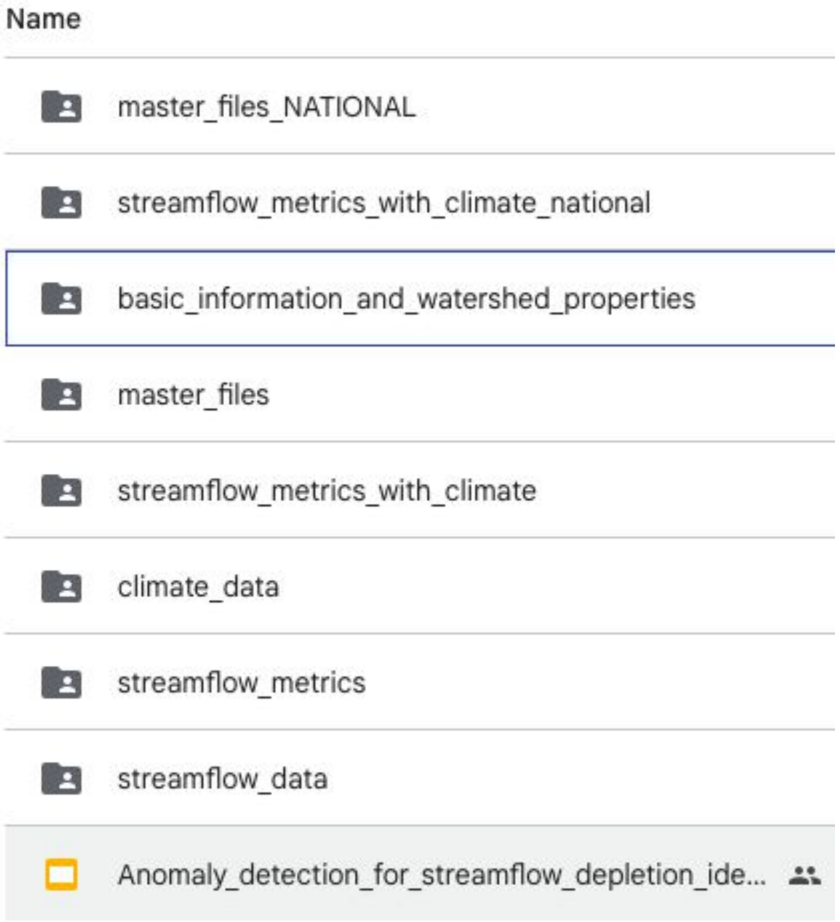
6) Should automatically download relevant files from google drive. Reads in master file data, merges with site info pulled from NWIS. Plots spatial patterns in median annual values and trends. Plots annual time series of signatures. Plots trend in flow vs trend in climate scatterplots. Next step could be to examine many streamflow signature vs climate trend plots to identify sites that have likely experience streamflow depletion.

7) Reads in master files. Next steps: flush out ideas for anomaly detection and implement ways to detect anomalous flow vs climate trends as well as anomalous annual values for sites that deviate from expected regional flow vs climate relationships.

8) Reads in and merges land use, crop, water use information for all gages2 watersheds. Also extracts transmissivity to all USGS gages2 watersheds. Next step could be to examine thresholds in these values, and how water use and crops or land cover have change through time to identify watersheds that have likely experienced streamflow depletion.

Google drive

https://drive.google.com/drive/folders/1GS31PaawF0AGGuGnwQ3ThpFSkOd85-XZ



Files containing annual and seasonal hydrological signatures and climate metrics for sites across CONUS passing data completeness criteria used in https://www.sciencedirect.com/science/article/abs/pii/S0022169419309898?via%3Dihub. Also has files containing trend results of trends run for 1921-2020, 1951-2020, 1981-2020.

Individual site streamflow and climate files before being merged into master files

Contains .xlsx describing columns in master files (see next slide). Also contains a shapefile for all USGS GAGES-II watersheds, .txt and .csv files with water use, crops, for multiple time periods, and a transmissivity estimate across CONUS as .tif)

Same as national master files but just for regional sites in CA, MI, KS originally considered for regional Powell analysis.

Monthly climate data for 1920-2020 from USGS monthly water balance model: https://pubs.usgs.gov/of/2007/1088/pdf/of07-1088_508.pdf

Individual site streamflow signature files

Individual site streamflow signature files

This presentation

“column_definitions.xlsx” (https://docs.google.com/spreadsheets/d/18p13nhDJVSWEOlzje7Nv_BcYLxAy7ShP/edit#gid=22452501) in “basic_information_and_watershed_properties” folder has definitions of the hydrological signature and climate metric columns in the master files

1	**Column Name**	**Definition**
2	wateryear	water year
3	annualflowperwateryear	total water yield for the water year (mm)
4	annualbaseflowfracperwateryear	fraction of the total water yield for the water year that was as baseflow (unitless)
5	lowest7dayperwateryear	7-day minimum streamflow for the water year (mm/d)
6	medianperwateryear	median daily streamflow for the water year (mm/d)
7	lowest7daydateperwateryear	calendar year day of year of the 7-day minimum streamflow for the water year
8	daysbelowlowflowthreshannual	the number of days below the low flow threshold (below the full record Q90 value) (d)
9	volumebelowlowflowthreshannual	the accumulated flow deficit below the low flow threshold (below the full record Q90 value) (mm)
10	annual_duration_curve_slope	the slope of the flow duration curve using all daily flow values for the water year
11	winter_duration_curve_slope	the slope of the flow duration curve using all daily flow values for winter
12	spring_duration_curve_slope	the slope of the flow duration curve using all daily flow values for spring
13	summer_duration_curve_slope	the slope of the flow duration curve using all daily flow values for summer
14	fall_duration_curve_slope	the slope of the flow duration curve using all daily flow values for fall
15	recess7	the recession rate of streamflow in log space for the 7 days leading up to the 7-day minimum streamflow for the water year
16	recess14	the recession rate of streamflow in log space for the 14 days leading up to the 7-day minimum streamflow for the water year
17	recess30	the recession rate of streamflow in log space for the 30 days leading up to the 7-day minimum streamflow for the water year
18	gage	USGS station ID
19	wy_p_mm	total water year precipitation (mm)
20	wy_pet_mm	total water year potential evapotranspiration (mm)
21	wy_tmean_c	mean daily water year temperature (degrees C)
22	wy_spei_6m	6 month rolling calculation of standardized precipitation evapotranspiration index averaged for the water year
23	wy_spei_1y	1 year rolling calculation of standardized precipitation evapotranspiration index averaged for the water year
24	wy_spei_5y	5 year month rolling calculation of standardized precipitation evapotranspiration index averaged for the water year
25	octmar_p_mm	See the above descriptions, but calculated only for the months October to March
26	octmar_pet_mm	See the above descriptions, but calculated only for the months October to March
27	octmar_tmean_c	See the above descriptions, but calculated only for the months October to March
28	octmar_spei_6m	See the above descriptions, but calculated only for the months October to March
29	octmar_spei_1y	See the above descriptions, but calculated only for the months October to March
30	octmar_spei_5y	See the above descriptions, but calculated only for the months October to March
31	octjun_p_mm	See the above descriptions, but calculated only for the months October to June

A few other notes on files

- Master trend files have a row for each site and metric combination. If suitable_length column = NA, there were not enough years to run the trend for this site. If suitable_trend = yes, there were enough years and the gage, kendalls tau, pval, and sensslope columns are filled in. Total change is the sensslope multiplied by the length of the trend period (e.g. 40 years for 1981-2020).
- Master annual metric files contain seasonal climate information as well. Master annual trend files also contain trends in seasonal climate. Merging master annual (master annual trend) files with the master seasonal (master seasonal trend) files will allow you to plot values (trends) in seasonal climate vs seasonal streamflow signatures.
- Seasons used: season <- ifelse(current$month > 3 & current$month < 7, "spring", #Spring = April, May, June
- ifelse(current$month > 6 & current$month < 10, "summer", #Summer = July, August, September
- ifelse(current$month > 9 & current$month, "fall","winter"))) # Fall = October, November, December, Winter = January, Feb, Mar

Summary of potential next steps / potential areas of focus for concentrated work this week, on in the weeks/months that follow

1. Code 6: Examine many streamflow signature vs climate trend plots to identify sites that have likely experienced streamflow depletion.
2. Code 7: Flush out ideas for anomaly detection and implement ways to detect anomalous flow vs climate trends as well as anomalous annual values for sites that deviate from expected regional flow vs climate relationships.
3. Code 8: Examine thresholds in mean annual watershed values, and how water use and crops or land cover have change through time to identify watersheds that have likely experienced streamflow depletion.
4.

Notes on classification of watersheds

Goal:

Develop a classification of watersheds that gives an indication of whether or not a watershed is likely impacted by streamflow depletion. Ideally develop a classification that can tell us whether depletion likely constant through time, or whether depletion has likely increased substantially through time.

To do:

- Experiment with setting thresholds in watershed attributes to identify sites likely to have experienced depletion

Notes on anomaly detection

Goal:

Use anomalies from expected relationships between climate and annual or seasonal flow metrics to detect streamflow depletion

To do:

- Determine method for identifying sites/years with anomalous flow vs climate values
- Try to keep track of false positive (type 1 error: site shows anomaly, but anomaly due to factor other than GW pumping) and false negative (type 2 error: site shows no anomaly, but impacted by pumping)
- Compute % of flow metric vs climate metric combinations that have anomalous values for each site and each time period. Consider focusing on annual, summer and fall streamflow metrics shown by Lapides et al to be sensitive to depletion.
- Consider non-linear trends
- Implement change point identification methods
- Consider rolling trend periods (eg trends for each 30 year period along record) as a way to further analyze the potential occurrence of streamflow depletion once a site is identified as having an anomaly in flow vs climate relations

Notes on anomaly detection cont’d

- Where depletion has been occurring for many decades, it might be more likely to detect this depletion during summer or fall months in dry years only
- Where depletion has increased through time, more likely able to detect it in normal and wet years as well