Drought recovery in terrestrial and riverine ecosystems of the CONUS: Considering vegetation productivity and water quality

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Abstract

Drought has severe impacts on the structure and functionality of terrestrial and riverine ecosystems. The mechanism and duration of drought recovery are critical subjects that can have crucial ramifications for ecology, crop yield, carbon uptake, and ecosystem services, and it has not been thoroughly investigated. This study assesses drought recovery of terrestrial and riverine ecosystems for agricultural and hydrological droughts, respectively. Soil moisture simulations from Phase 2 of the North American Land Data Assimilation System (NLDAS-2) are employed to characterize agricultural drought, and streamflow data from the United States Geological Survey (USGS) are utilized for assessing hydrological droughts. Drought recovery for riverine ecosystems is studied considering both quantity and quality of streamflow. Water temperature, dissolved oxygen, and turbidity are the water quality variables considered in this study. Riverine drought recovery is assessed using a multi-stage framework that is applied to 400 streamflow stations across the CONUS for the study period of 1950-2016. On the other hand, terrestrial drought recovery is investigated utilizing ecosystem Gross Primary Productivity (GPP), a metric of photosynthetic activity, for the regions impacted by agricultural drought. GPP data is acquired from the Moderate resolution Imaging Spectroradiometer (MODIS) sensor onboard Terra satellite at 1km spatial resolution and 8-day temporal resolution across the CONUS during 2000 to 2015. The drought affected regions are assumed to be recovered when the post-drought GPP reverts to its regional average value. Results show that in general, riverine drought recovery takes about two months when considering water quality variables, whereas terrestrial drought recovery duration varies between 1 to 4 months depending on drought severity. Additionally, results indicate that drought recovery duration is positively correlated with drought severity.

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Background and Objectives

- Drought has severe impacts on the structure and functionality of terrestrial and riverine ecosystems.
- The mechanism and duration of drought recovery are critical subjects that can have crucial ramifications for ecology, crop yield, carbon uptake, and ecosystem services, and it has not been thoroughly investigated.
- Analyzing hydrological drought recovery considering both water quality and quantity criteria.
- Assessing terrestrial drought recovery duration for various drought events with diverse intensities.

Study Area and Data

Table 1- Summary of the data used for terrestrial and Hydrological drought analysis

	Data	Spatial Resolution	Temporal Resolution	Unit	Type
Terrestrial Drought	Gross Primary Productivity (GPP) (MOD17A3)	1 km	8 days	gC/kg H_2O	Remotely sensed by MODIS
	Evapotranspiration (ET) (MOD16A3)	1 km	8 days	mm/m^2	Remotely sensed by MODIS
	Soil Moisture (NLDAS-2)	1/8^o	8 days	cm/cm	Simulated by VIC
Hydrological Drought	Streamflow (USGS)	400 stations	daily	cfs	In situ
	Water Temperature (USGS)	400 stations	daily	^{o}C	In situ
	Dissolved Oxygen (USGS)	287 stations	daily	mg/L	In situ
	Turbidity (USGS)	234 stations	daily	FNU	In situ

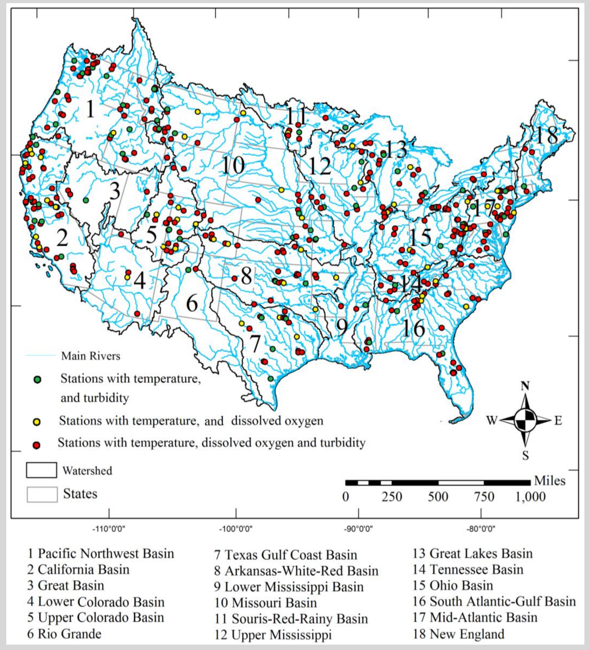

Figure 2- Study area, river basin boundaries, and location of the selected streamflow/water quality stations.

Table 1: USDM soil moisture drought categories

Category	Description	Percentiles (%)
D0	Abnormally dry	21 to 30
D1	Moderate drought	11 to 20
D2	Severe drought	6 to 10
D3	Extreme drought	3 to 5
D4	Exceptional drought	0 to 2

Methodology

- **Persistence:** the period that streamflow remains below the normal threshold level for at least 30 consecutive days. If there are more than one period fulfilling this condition during a drought episode, the longest period is considered as the drought persistence stage.
- **Growth:** moving backwards from the beginning of drought persistence, drought onset is the point when streamflow falls below the threshold level for less than 15 days in a T-day window. Drought growth stage starts from drought onset until the beginning of drought persistence.
- **Retreat:** moving forward from the end of drought persistence stage, drought termination is the time when streamflow falls below the threshold level for less than 15 days in a T-day window. Drought retreat stage starts following the end of drought persistence until drought termination.

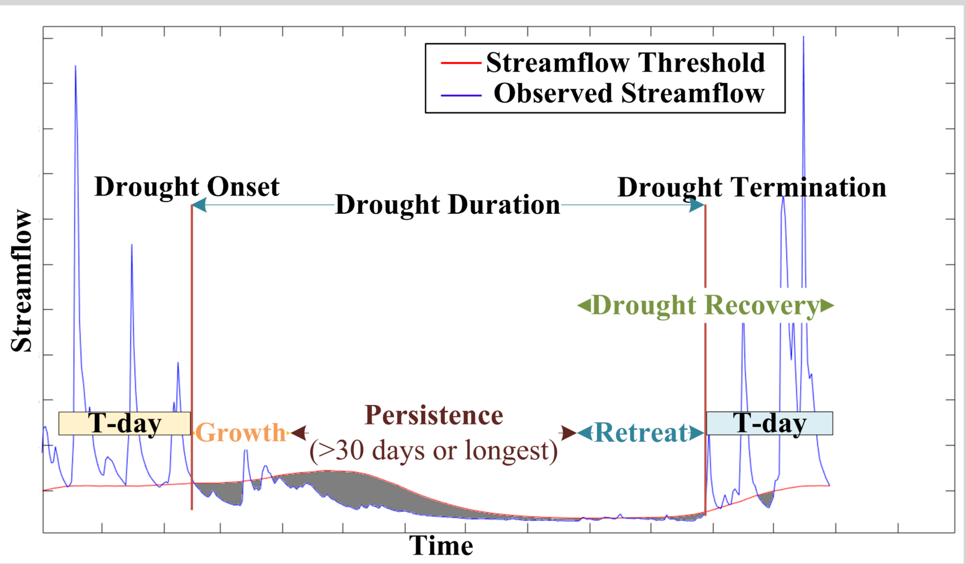

Figure 2 – A conceptual diagram of drought growth, persistence, retreat, and recovery stages.

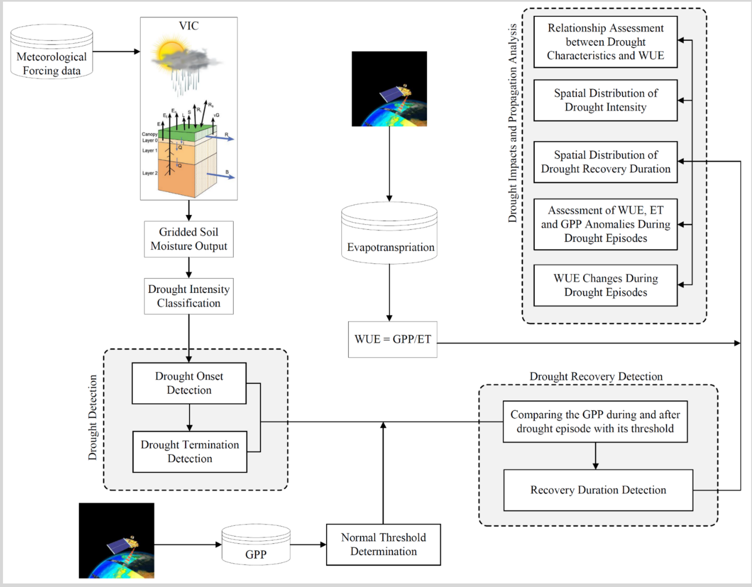

Figure 3 - The framework for analyzing terrestrial drought recovery considering Gross Primary Production (GPP), and assessing Water Use Efficiency (WUE) response to drought and decomposing the influential factors.

- The sensitivity of GPP to drought is well documented, and its spatiotemporal patterns can be estimated in several ways.
- First, the normal GPP threshold, which is the average of GPP over the study period, is calculated for each grid at 8-day time step.
- Then, the ecosystem recovery from a drought episode is defined when the post-drought GPP within one-month (4 consecutive 8-day period) reverts and stays above the normal condition (GPP normal threshold).

Results

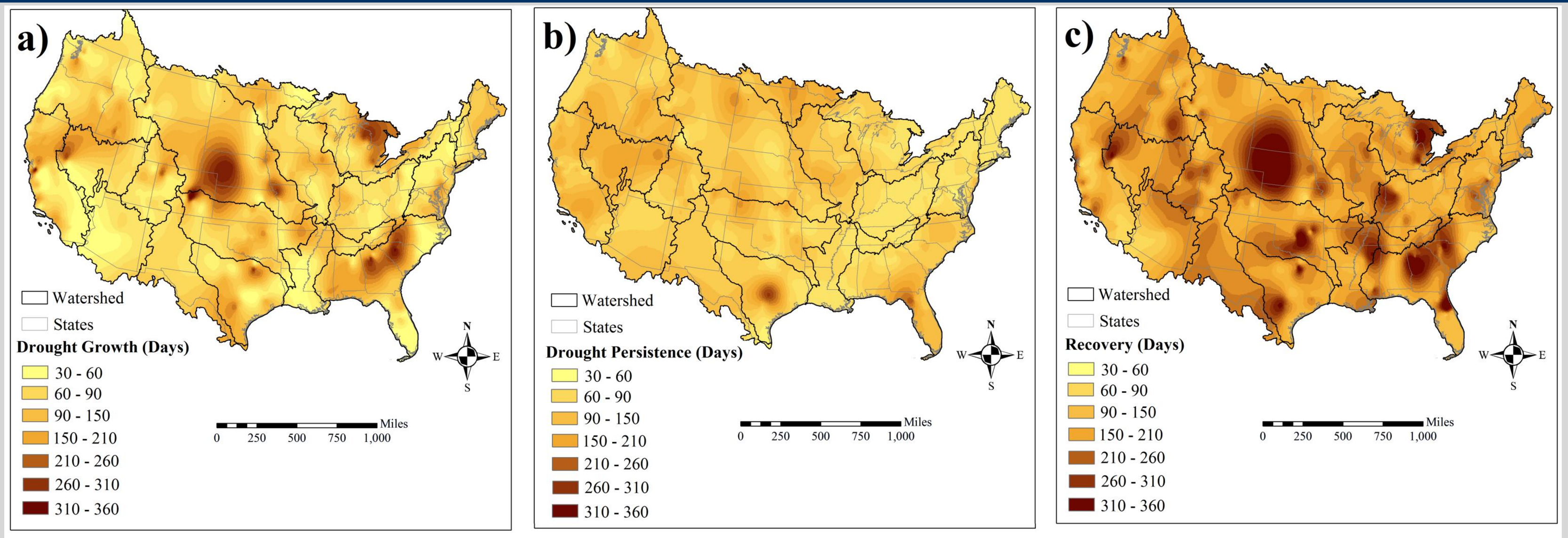

Figure 4- Mean duration (in days) of a) drought growth; b) persistence; and c) recovery in the historical period of 1950-2016.

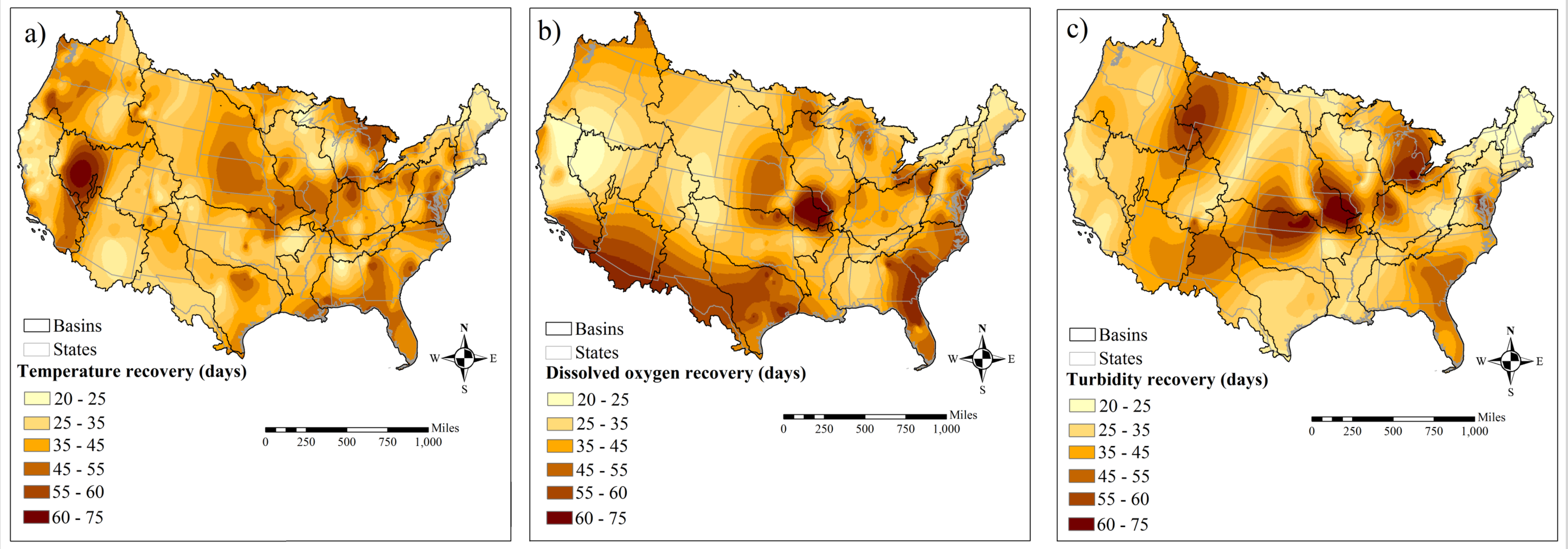

Figure 5 - Spatial distribution of average time needed for; a) water temperature, b) dissolved oxygen, and c) turbidity to recover from drought after the hydrological drought termination (i.e. after the streamflow has reached normal conditions).

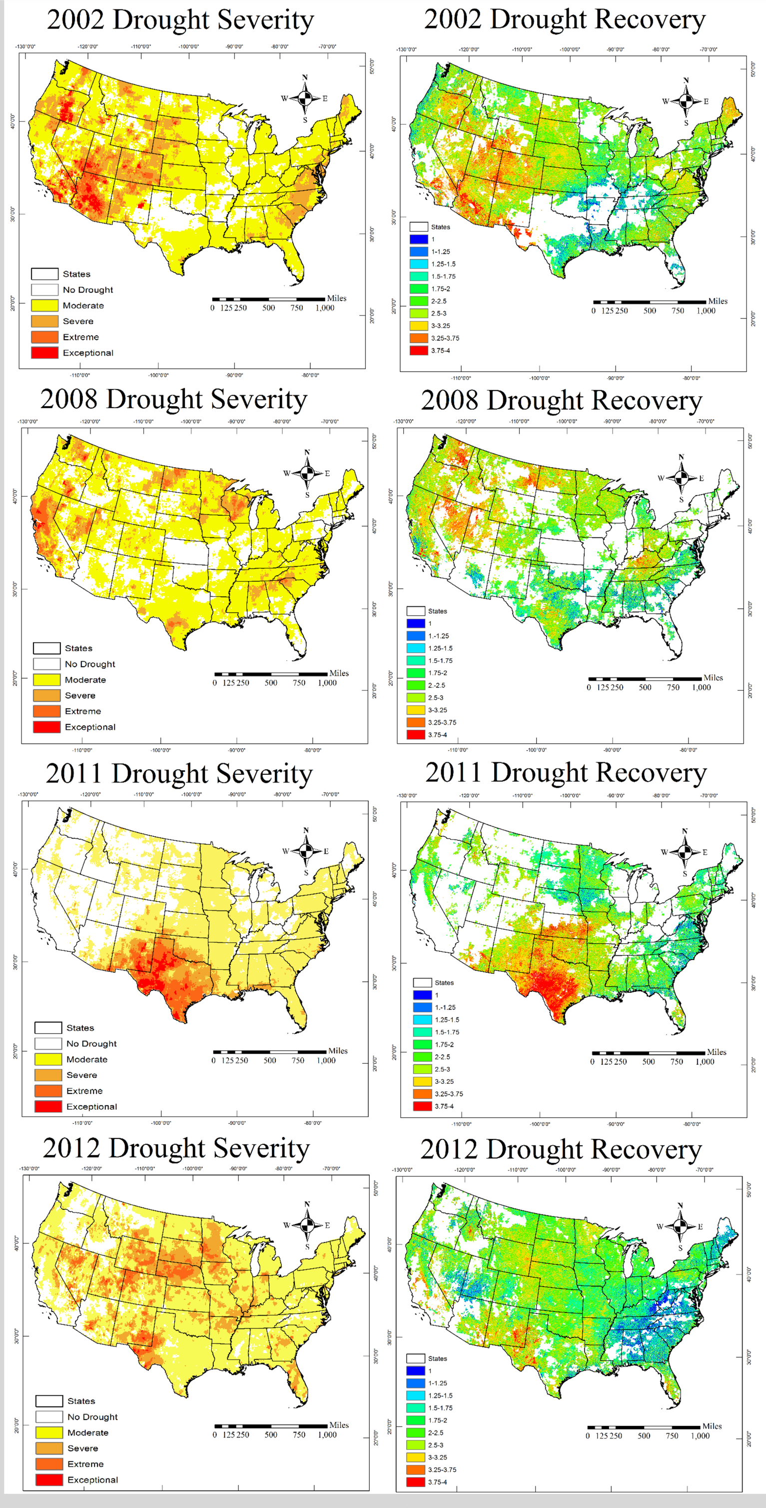

Figure 6 - Spatial distribution of agricultural drought severity (left) and drought recovery duration (right) for 2002, 2008, 2011, and 2012 drought episodes.

Discussion

An inverse relation between hydrological drought severity and frequency in areas located in the Pacific Northwest, California, Great Basin, Upper Colorado, Texas, Arkansas, Ohio, New England, Upper Mississippi, and Mid-Atlantic river basins.

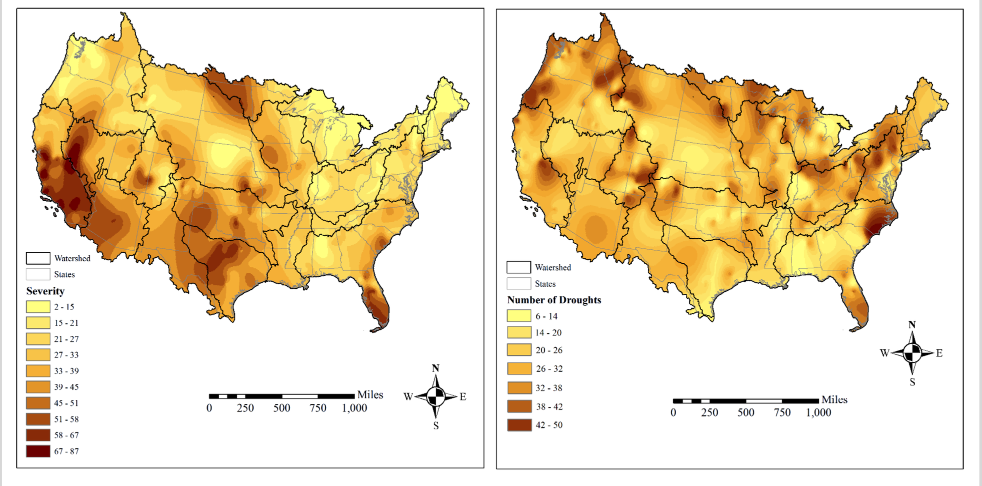

Figure 7- Spatial distribution of normalized drought severity and drought frequency over the CONUS during 1950-2016.

A more severe agricultural drought episode is expected to result in longer recovery time compared to moderate droughts, which is approved by the results of Figure 8. Additionally, a longer drought episode increases the likelihood of protracted drought recovery.

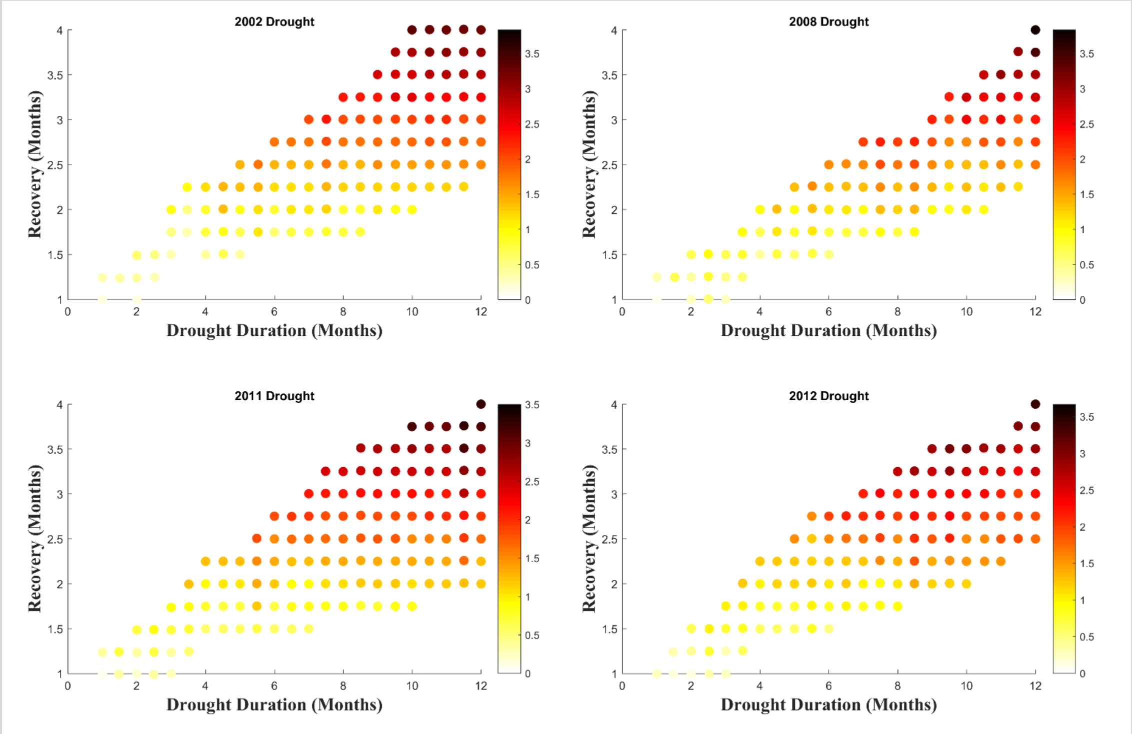

Figure 8 - The relation between drought recovery time, drought duration, and drought intensity for 2002, 2008, 2011, and 2012 drought episodes.

Conclusion

- Terrestrial drought recovery analysis reveals that, required time for each region to revert to its pre-drought condition is positively correlated with drought severity and when a region experienced more severe drought, a longer drought recovery is more likely.
- Additionally, a longer drought episode increases the likelihood of protracted drought recovery.
- Hydrological drought frequency is negatively correlated with drought severity and duration, whereas drought duration and recovery time are positively correlated.
- Average recovery time for water temperature, turbidity and dissolved oxygen were 52, 42 and 51 days following hydrological drought termination, respectively.

Reference

- Ahmadi, B., Ahmadalipour, A., Moradkhani, H., (2019). Hydrological Drought Persistence and Recovery in the CONUS: a Multi-stage Framework Considering Water Quantity and Quality, *Water Research*, 150(1), 97-110.