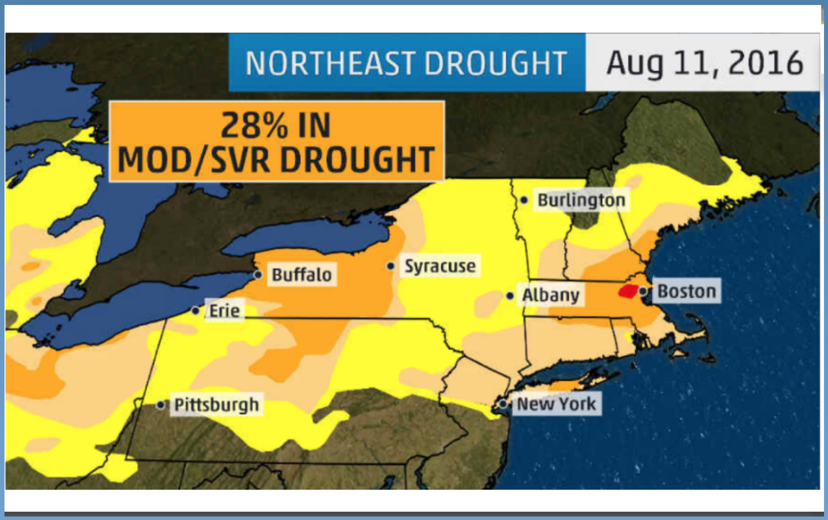
USGS Northeast Region Drought Forecasting Pilot Effort



Northeast Monthly Climate Update
Mark Bennett and Keith Robinson
July 31, 2018

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Droughts in the NE

* Tend to be short-term and recover quickly
* Local to regional extent
* Drought of 1960s generally drought of record, local and short-term droughts exceed this
* 2016 was the most severe drought since the early 1980s

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Who Cares?

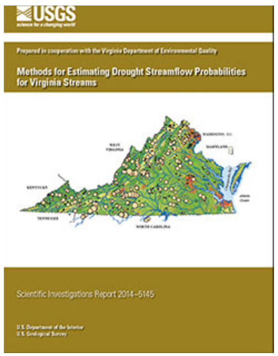
- Water shortage and droughts impact public water supplies, industries, agriculture and the quality of both aquatic and terrestrial environments
- State drought committee involving emergency management and water resource agencies depend on streamflow and groundwater data and climate forecasts for decision making
- 2016 showed that many states are not prepared and up-to-date on drought preparedness/plans

2 regional approaches for assessing potential future drought conditions

- Streamflow: Probability of stream flow levels in the summer
- Groundwater: probability of water levels exceeding a threshold

Both approaches are based on existing published methods

Virginia Drought Streamflow Studies



This statewide cooperative study with

DEQ
VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Methods for Estimating Drought Streamflow Probabilities for Virginia Streams

Led to a nationwide study…

Modeling Summer Month Hydrological Drought Probabilities in the United States Using Antecedent Flow Conditions

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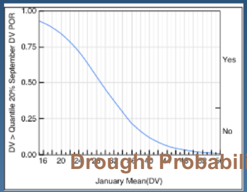
Modeling Drought Probabilities: Background



- **We investigated the likelihood of a relation between winter streamflow and summer streamflow based on local water availability.**

- **We found that a relation exists, and identified it. *(Austin, S.H., 2014, Methods for estimating drought streamflow probabilities for Virginia streams: U.S. Geological Survey Scientific Investigations Report 2014–5145, 20 p., http://dx.doi.org/10.3133/sir20145145.)***

- **Funding from 2 USGS programs (the *Groundwater and Streamflow Information Program,* and the *Water Availability and Use Science Program*) was used to determine whether similar relations could be identified nationwide.**

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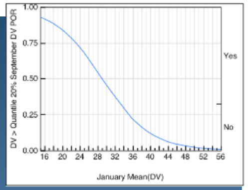
Modeling Drought Probabilities: Purpose and Scope



Drought Probabilities

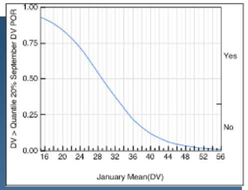
- **We developed and tested a method for estimating hydrological drought probabilities for rivers and streams in the United States using maximum likelihood logistic regression (MLLR).**

- **Hydrological drought streamflow probabilities for summer months are estimated 5 to 11 months in advance of their occurrence using streamflow data from previous winter months.**

- **Scope is limited to characterizing hydrological drought probability in 9,152 basins across the United States using USGS streamflow data spanning each basin's period of record.**

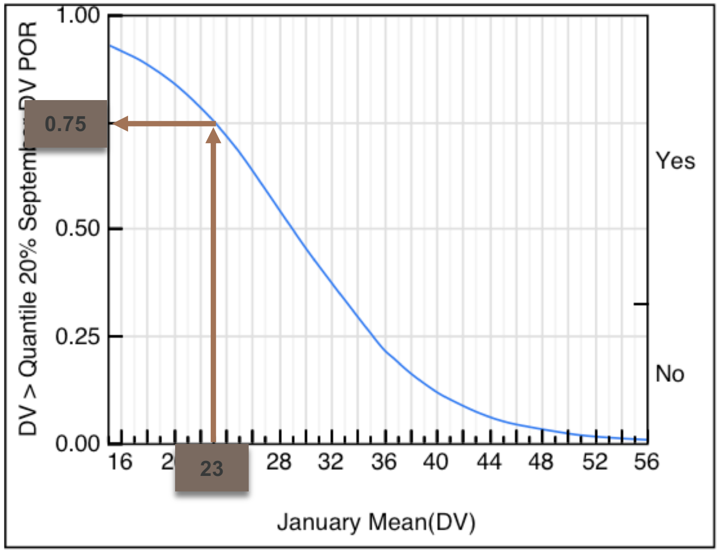
- **A test of predictions of September 2013 hydrological droughts for these sites using data from October 2012 resulted in an overall correct classification rate of 91%.**

Modeling Drought Probabilities: Maximum Likelihood Logistic Regression (MLLR)



Drought Probabilities

- MLLR is used to fit Y responses (P[No] and P[Yes]) to linear models of X terms.
- The chance (likelihood) that a streamflow daily value (DV) in a particular month will not exceed (P[No]), or exceed (P[Yes]), a hydrological drought flow threshold as a function of mean monthly flow from an earlier month, is described.
- Each logistic curve is fitted using the difference in the logs of each binary response (Y's of P[No] and P[Yes]), as a linear function of a factor variable (X's of mean streamflow from a previous month).



Each logistic function has the form:

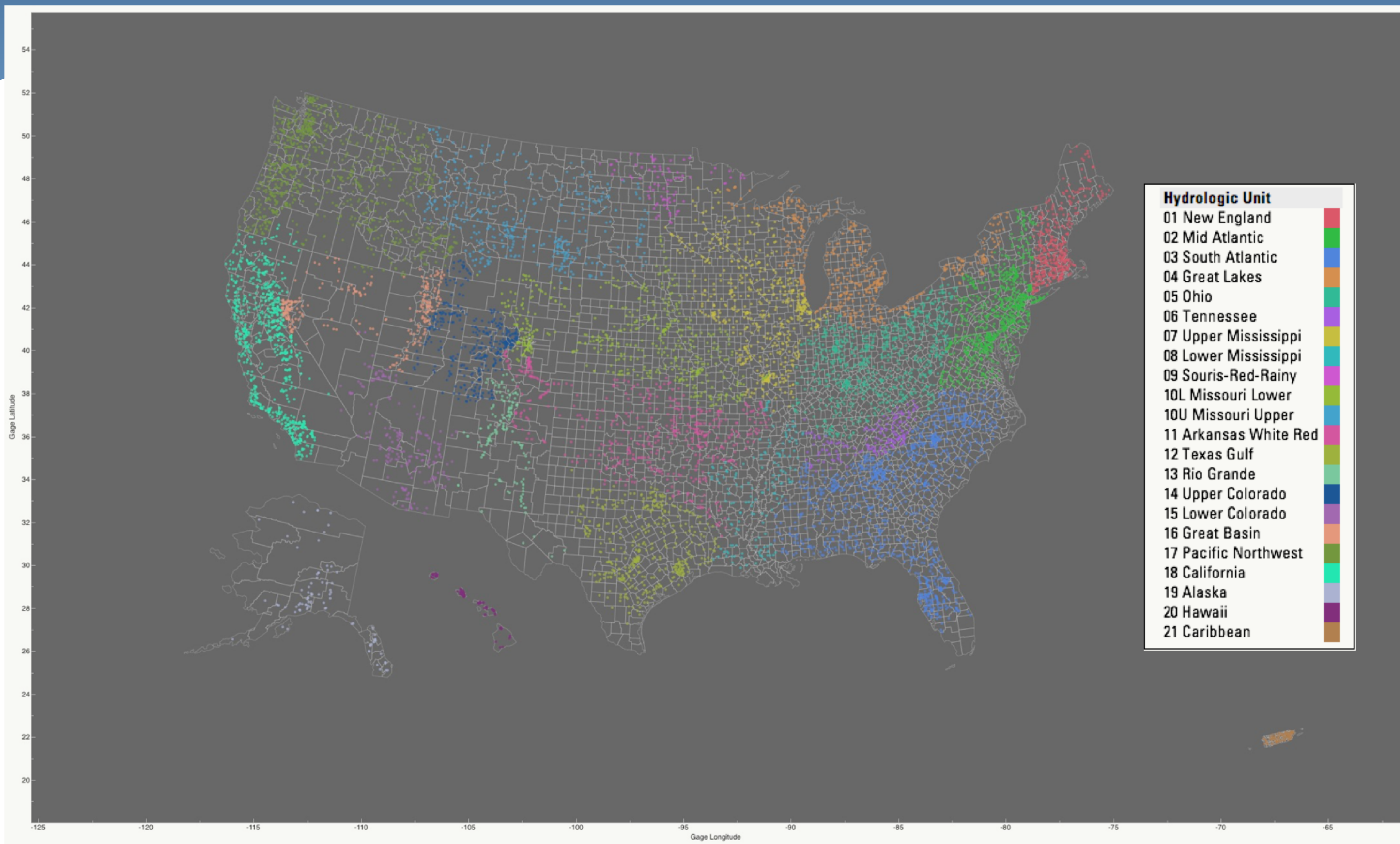
$$p = 1/[1 + e^{+ \text{ or } - (\beta_0 + \beta_1 \cdot X)}]$$

where: e is the base of the natural logarithm
β_0 is an intercept parameter
β_1 is a slope parameter
x is a factor variable

15 equations for each of 9,152 basins describe July, August, and September hydrological drought probabilities as functions of mean streamflow from the previous October, November, December, January, and February.

All (y) responses use a 20th-percentile drought flow threshold.

Gages Used in the Study



- **Study Gages In 21 USGS National Water Information System (NWIS) Hydrologic Units (HUC). County boundaries are shown. Alaska and Hawaii are drawn at a reduced scale.**

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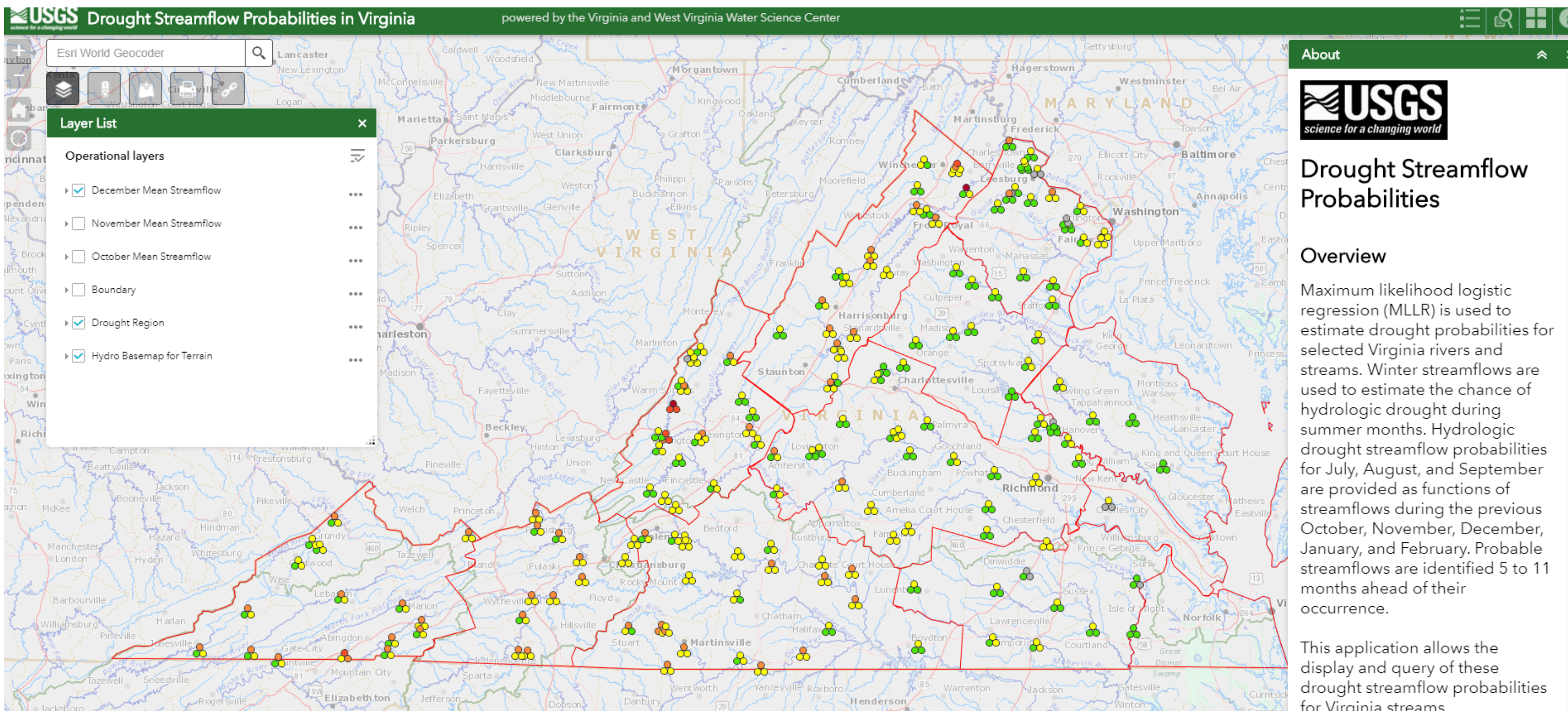
Hydrological Drought
Future Streamflow Probabilities

Sam Austin, Chintamani Kandel, Jennifer Rapp

https://va.water.usgs.gov/webmap/drought/



Probability of Future Groundwater Levels Below Specified Thresholds

- Based on regional and national work by USGS Forecasting the Probability of Future Groundwater Levels Declining Below Specified Low Thresholds in the Conterminous U.S. Journal of the American Water Resources Association (JAWR)1-13. https://doi.org/10.1111/1752-1688.12582
- Statistical models to identify probability of water levels going below a set threshold based on numerous input variables
- Predictions best for wells with low month-to-month variability/longer duration low levels

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JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
Vol. 53, No. 6 AMERICAN WATER RESOURCES ASSOCIATION December 2017

FORECASTING THE PROBABILITY OF FUTURE GROUNDWATER LEVELS DECLINING BELOW SPECIFIED LOW THRESHOLDS IN THE CONTERMINOUS U.S.[1]

Robert W. Dudley, Glenn A. Hodgkins, and Jesse E. Dickinson[2]

ABSTRACT: We present a logistic regression approach for forecasting the probability of future groundwater levels declining or maintaining below specific groundwater-level thresholds. We tested our approach on 102 groundwater wells in different climatic regions and aquifers of the United States that are part of the U.S. Geological Survey Groundwater Climate Response Network. We evaluated the importance of current groundwater levels, precipitation, streamflow, seasonal variability, Palmer Drought Severity Index, and atmosphere/ocean indices for developing the logistic regression equations. Several diagnostics of model fit were used to evaluate the regression equations, including testing of autocorrelation of residuals, goodness-of-fit metrics, and bootstrap validation testing. The probabilistic predictions were most successful at wells with high persistence (low month-to-month variability) in their groundwater records and at wells where the groundwater level remained below the defined low threshold for sustained periods (generally three months or longer). The model fit was weakest at wells with strong seasonal variability in levels and with shorter duration low-threshold events. We identified challenges in deriving probabilistic-forecasting models and possible approaches for addressing those challenges.

(KEY TERMS: groundwater hydrology; groundwater management; statistics; time series analysis; wells.)

Dudley, Robert W., Glenn A. Hodgkins, and Jesse E. Dickinson, 2017. Forecasting the Probability of Future Groundwater Levels Declining Below Specified Low Thresholds in the Conterminous U.S. *Journal of the American Water Resources Association* (JAWRA) 53(6): 1424-1436. https://doi.org/10.1111/1752-1688.12582

INTRODUCTION

Many hydrologic and ecological processes depend on the availability of groundwater within a specific depth or ranges of depth to the water table below the land surface. Groundwater levels vary naturally in response to time-varying precipitation, evapotranspiration, and groundwater recharge to aquifers. During dry seasons and years, groundwater levels can decline below a specific threshold that alters the linkages among hydrologic and ecological processes (Van Lanen and Peters, 2000). For example, groundwater discharge to connected springs and streams can diminish or cease when the groundwater levels decline below the elevation of the spring or streambed. Riparian vegetation can be stressed when the groundwater level is below threshold levels related to plant function (*e.g.*, Horton *et al.*, 2001; Hao *et al.*, 2010). Water availability for human needs can depend on groundwater levels being above a threshold related to the well pump depth. Natural-resource managers are faced with the challenge of assessing whether water availability and hydrologic and ecological processes may be impacted in

[1]Paper No. JAWRA-16-0142-P of the *Journal of the American Water Resources Association* (JAWRA). Received June 15, 2016; accepted July 30, 2017. **Discussions are open until six months from issue publication.**

[2]Hydrologist (Dudley) and Research Hydrologist (Hodgkins), New England Water Science Center, U.S. Geological Survey, 196 Whitten Road, Augusta, Maine 04330; and Hydrologist (Dickinson), Arizona Water Science Center, U.S. Geological Survey, Tucson, Arizona 85719 (E-Mail/Dudley: rwdudley@usgs.gov).

Probability of Future Groundwater Levels Below Specified Thresholds

- Logistic regression approach
- 102 wells used
  -not impacted by pumping
  -20 years of record
- Predicted 1, 2, 3, 6 12 months out
  -predictor variables included nearby streamflow sites, Palmer drought index, precip, atmospheric-ocean indices

FIGURE 1. Map Showing Locations of the 102 Wells Selected for Study. Selection criteria included record length and completeness, and exclusion of records with substantial nonclimate related effects.

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Probability of Future Groundwater Levels Below Specified Thresholds

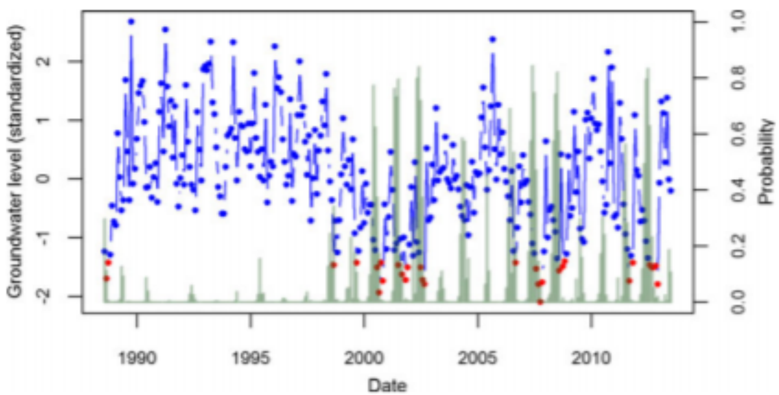

FIGURE 2. Plot Showing an Example Application of a Three-Month Forecast Model for a Well in Georgia. Blue dots and lines represent the monthly groundwater-level time series. Points colored red are groundwater levels at or below the 10th percentile low threshold. The vertical green lines are the monthly estimated probability that the groundwater level will be at or below the 10th percentile three months later. The explanatory variables for this forecast model comprise current groundwater level, a Fourier seasonality term, and the current monthly Atlantic Multidecadal Oscillation index value.

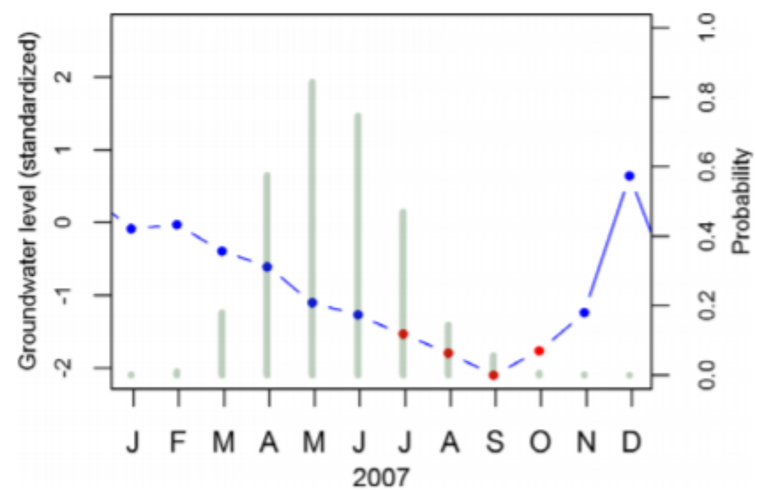

FIGURE 3. Plot Showing an Example Application of the Three-Month Forecast Model for a Well in Georgia from December 2006 to December 2007. The vertical green lines are the monthly estimated probability that the groundwater level will be at or below the 10th percentile three months later.

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Plan Moving Forward in NE Region

- Prepare factsheets and web sites describing methods, results, strengths/weaknesses of methods
- Complete this calendar year; funded by WSCs with discretionary funds
- Provide briefings to partners, agencies, NIDIS and others
- Improving our forecasting skills

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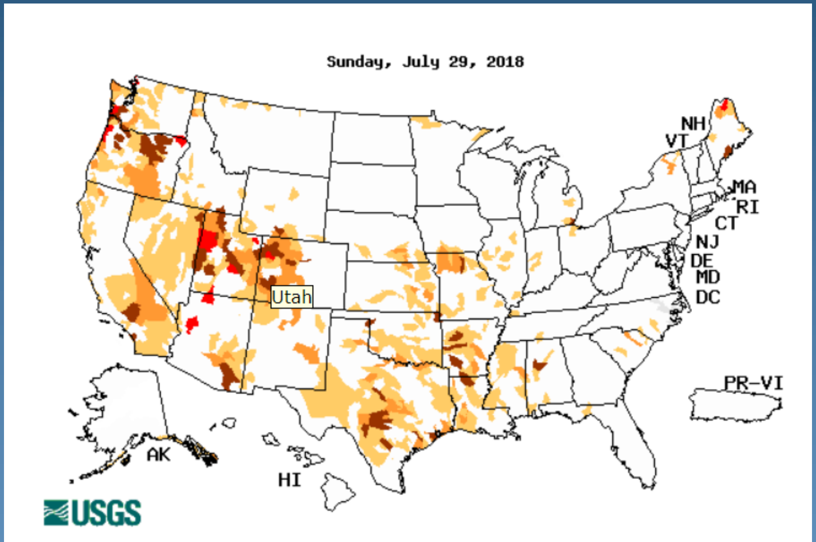
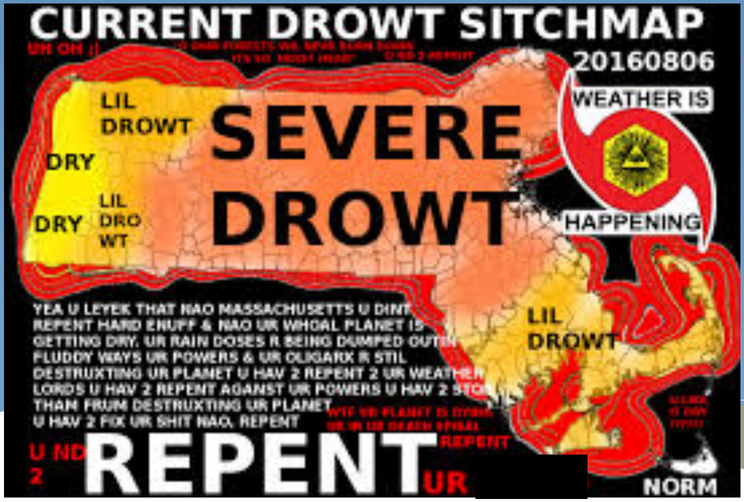
Other USGS Opportunities relating to Droughts

* Update low flow statistics
* Incorporate low flow statistics, Sustainable Yield Estimators, water use into Streamstats
* Evaluate collection networks for efficiency in providing drought conditions for streams or groundwater
* Add new monitoring to help with forecasting (soil moisture probes, ET, snow pack)
* Develop other forecasting tools for surface and ground waters – based on long-term climate forecasts or selected thresholds
* Basin-wide/watershed studies to store excess water for use during dry periods (optimal storage and release)
* Enhanced web pages/data delivery





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Thank you!