Spring 5-2011

Spatial Patterns of Drought Triggers and Indicators

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Spatial Patterns of Drought Triggers and Indicators

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An Undergraduate Thesis

Presented to the faculty of

The Environmental Studies Program at the University of Nebraska-Lincoln

In Partial Fulfillment of Requirements

For the Degree of Bachelor of Science

Major: Environmental Studies

With Emphasis of: Applied Climate Sciences

Under the Supervision of Dr. Deborah Bathke
Faculty Reader Mr. Mark Svoboda

Lincoln, NE
April 2011

Abstract

Drought is a reoccurring phenomenon with widespread economic, social, and environmental impacts. Unlike other disasters, a drought cannot be easily detected. In addition, droughts are widespread and develop slowly over time making it difficult to detect its onset and monitor its severity and impacts. To assist in monitoring the severity and spatial extent of droughts, drought managers frequently use indicators and triggers. Drought indicators are meteorological or hydrological variables or indices that quantify or describe the level of drought severity. A drought trigger is a value of an indicator that initiates management and response actions. Despite the clear importance of drought indicators and triggers, they are not well understood and are often arbitrarily chosen. This is evidenced by the fact that many states in different climate regimes use the same indicators and triggers. Furthermore, stakeholders from across the country identified the need for a better understanding of drought triggers and indicators as a research priority.

The purpose of this research is to indentify spatial patterns of drought indicators and triggers. This was accomplished by identifying the types and numbers of indicators and triggers used in all currently available state drought plans. Each state's indicators and triggers were then organized in a database and analyzed using ArcGIS software to identify the numbers of indicators and triggers used by each state as well as any spatial patterns. Results show that some patterns do exist and that the indicator or trigger used is not necessarily appropriate for the geographic location in which it is being used. Additionally, wide variability exists among the number of indicators and triggers used by each state. This information may help drought managers coordinate the use of critical indicators and triggers at the regional or basin level.

Introduction

Drought is a reoccurring phenomenon with widespread economic, social, and environmental impacts. Unlike other disasters such as tornadoes, floods, and blizzards, a drought is widespread and develops slowly over time. Thus, it can be difficult to detects its drought onset and monitor its severity and impacts. The lack of a universal definition for drought further complicates drought monitoring and assessment efforts. In general, a drought is a water-related natural hazard resulting from a period of deficient rainfall which, in turn, results in a water shortage. However, dozens of drought definitions are in use around the world. The particular definition used often depends on things such as the length of the rainfall shortage, the region in which it occurs, or the sectors of society which are impacted (Wilhite and Glantz 1985).

Drought definitions can be broadly categorized as belonging to one of the following: meteorological, agricultural, hydrological, or socio-economic drought (Wilhite and Glantz, 1985). A meteorological drought is often referred to as a prolonged period of time without significant rainfall in comparison to some long-term average. Droughts defined in this way must be considered regionally specific since rainfall is highly variable with location. Agricultural droughts focus on linking agricultural impacts, such as plant stress and soil water deficiency, to characteristics of meteorological drought. Defining drought in this way may require additional data such as soil moisture, crop type, and the stage of crop development. Hydrological droughts are concerned with the effect of dry periods on streamflow, reservoirs, ground water, and soil moisture. Hydrological droughts often lag meteorological droughts because it takes a while for rainfall shortages to affect surface and subsurface water supplies. Detecting hydrologic droughts can be complicated by the diversity and competing interests of water users. Finally, socio-economic droughts occur when the demand for some economic good, such as corn and wheat, exceeds the supply as a result of a weather-related shortfall in the water supply. The occurrence of socio-economic drought is influenced by precipitation deficiencies as well as the demand for a good due to factors such as population growth. While these four broad categories of definitions may help identify drought onset and severity through the analysis of impacts in a given sector, they are not tailored to specific regions of the United States.

To aid in drought monitoring, local, state, and federal agencies and communities frequently use drought triggers and indicators as a way to determine drought onset and severity and to communicate drought information to the public. Drought triggers and indicators are also used to determine the timing and level of drought responses and to characterize and compare drought events (Steinemann et al. 2005). Drought indicators are meteorological or hydrological variables or indices that quantify the level of drought (Steinemann et al. 2005). For example, when a drought index is at a certain level, the area affected may be classified as being in a moderate drought. A drought trigger is a value of an indicator that initiates management and response action (Steinemann et al. 2005). An example of a drought trigger would be that when a drought index reaches a certain level, the state may enact water conservation restrictions.

Because there is no federal standard for monitoring drought, states develop their own methods for detecting the onset and severity of drought and, as a result, use a wide range of indicators and triggers (Quiring 2009). In an analysis of 33 state drought plans, Quiring (2009) showed that most states use between 3 and 5 indicators for classifying drought severity. Drought researchers stress that it is important to use multiple indicators and triggers since no single one is likely to capture all types of drought (Steinneman et al. 2006). However, drought indicators and triggers are not well understood and are often chosen by states based on thresholds described in the literature or on other arbitrary measures (Steineman et. al 2006; Quiring 2009). In fact, recent research has shown that states in very different climatic regimes use the same indicators and triggers even though the probability of getting a certain indicator value can be a function of the climate (Quiring 2009). Furthermore, case studies suggest that discrepancies can exist between indicators at the state level (Mizzell, 2010; Quiring, 2009).

The objective of this paper is to update earlier work done by Quiring (2009) on drought indicators and triggers by examining the 44 currently available state drought plans to identify which drought indicators and triggers are currently being used. In addition, this paper will extend this work by mapping the drought indicators and triggers used by each state to provide a spatial analysis of their use. This spatial analysis may help identify potential discrepancies in the use of these triggers and indicators for the climate of the area in which they are being used. Finally, the results of this study may help state drought managers coordinate the use of drought indicators and triggers at the regional or basin level.

Background on Drought Indicators and Triggers

Drought indicators and triggers are typically developed from meteorological or hydrological indices (Steinemann et al. 2005).While a large number of indices are used fro drought monitoring and response actions, this paper discusses the Palmer Drought Severity Index (PDSI), the Standardized Precipitation Index (SPI), the Surface Water Supply Index (SWSI), and the United States Drought Monitor (USDM). Each index is unique in what it measures and how it classifies drought. A brief description of these indices and their advantages and disadvantages are described below. A comprehensive review of these indices is provided in Heim (2002).

The PDSI was the first comprehensive drought index developed. It was developed to evaluate wet and dry conditions from a water balance view point (Palmer 1965). The PDSI values range from +4.00 to -4.00, with the negative values indicating various levels of drought (Figure1). For example, in figure 1 the PDSI indicates that southern and central New Mexico are in moderate or severe drought. The PDSI is most effective when applied to areas where impacts are sensitive to soil moisture and it used to start or end drought response actions (Heim, 2002). While this index is one of the most widely used for monitoring drought, it has also been one of the most widely criticized (Alley, 1984; Heddinghaus and Sabol, 1991; Heim, 2002). One limitation of the index is that it uses the water balance equation which requires potential evapotranspiration, for which there is no universally accepted computational method (Alley 1984). Additionally, the index uses arbitrary rules for the numbers that indicate the intensity of a drought. This leads to spatial and temporal inconsistencies in the probability of drought occurrence (Steinemann 2006). Finally, these rules were developed from study areas in central Iowa and western Kansas and for annually aggregated data (Heim 2002; Heddinghaus and Sabol 1991).

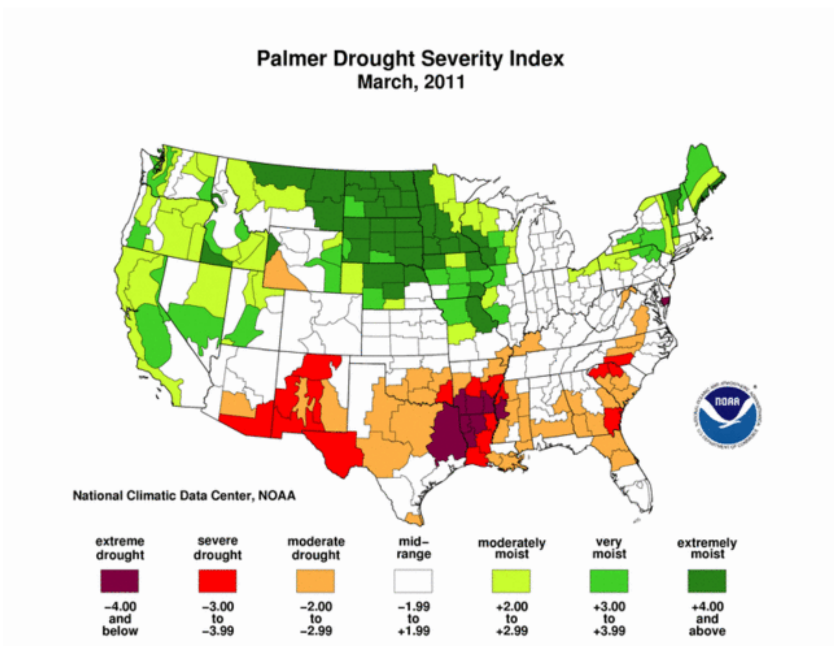

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Figure 1: Map showing the PDSI from March 2011.

The SWSI was developed in the early 1980s as an additional index that Colorado can use in determining drought (Shafer and Dezman1982). The SWSI was developed to compliment the PDSI by taking into account essential water supply variables such as snowpack, streamflow, precipitation, and reservoir storage. During the winter snowpack is used in the calculation, while in the summer streamflow replaces snowpack (Hayes 2002). Like the PDSI, the SWSI also has a scale that ranges from +4.00 to -4.00 with the positive numbers indicating a period of wetness and the negative numbers indicating a period of drought (Figure 2). Like the PDSI, in New Mexico the SWSI indicates that southern and central New Mexico are in moderate or severe drought (Figures 1 and 2). However, the SWSI indicates that the Pecos River basin is in severe drought, while the PDSI indicates that it is in moderate drought. Because of its inclusion of essential water supply variables, the SWSI has proven to be a valuable tool for the majority of western states. The major limitation of this index is that is calculated at the basin level, which limits its ability to be used to compare between regions and basins (Doesken et al. 1991). It is also important to note that research has shown that differences in calculation methods between basins results in

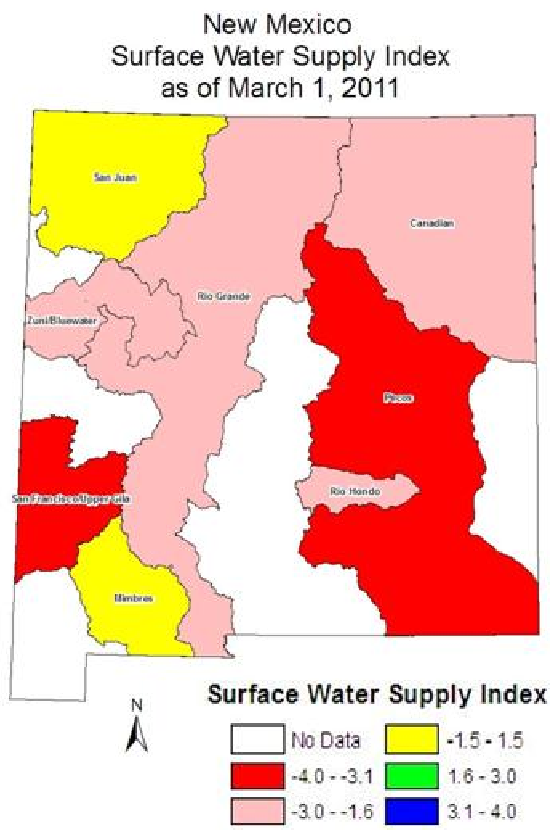

Figure 2: New Mexico SWSI. The red and pink colors indicate drought, yellow indicates near normal, and blue and green indicate wet conditions.

values of the SWSI that may have different meanings for different basins and for different times of the year (Heim 2002). Additionally, if the water management plan for a basin changes the SWSI must be modified to account for the change. The index also has a very short historical record which could lead to a drought that has never been experienced since the SWSI was developed which would require the index to have to be reevaluated to include the extreme events (Hayes 2002).

The SPI was developed at Colorado State University in 1993 (McKee et al. 1993). It is a relatively simple index in that it is based only on precipitation and can be used year round. Like the PDSI, values of the SPI can be either positive or negative with positives value indicating periods of wetness and a negative values indicating drought (Figure 3). Like the PDSI and SWSI, the SPI for New Mexico indicates drought conditions. However, the SPI is showing the entire state is experiencing moderate to extreme drought (Figures 1-3).

The SPI differs from the PDSI in that the SPI values are fit to a normal distribution (Hayes et al. 1999) in which the SPI indicates a mild drought 24% of the time, a moderate drought 9.2% of the time, a severe drought 4.4% of the time and an extreme drought 2.3% of the time (Wu et al. 2007). The SPI can also be calculated on any time scale, making it the ideal index to be used operationally. Thus, this index can be valuable to

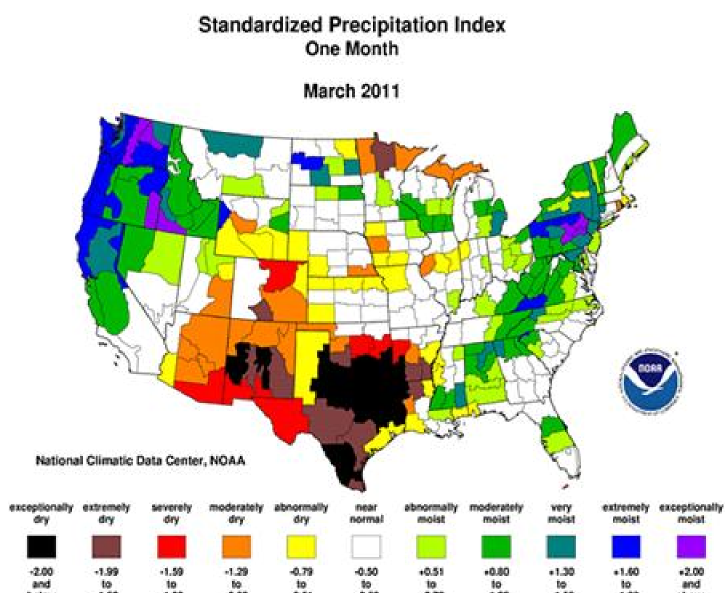

Figure 3: Map showing the one month SPI for March 2011.

irrigation managers who need short term drought information (one to three months) and agencies like the Army Corps of Engineers who need drought information on longer time scales (12 months or greater). One of the drawbacks to the SPI is that a location must have at least 30 years of data for the SPI calculation. Additionally, the SPI can also be based on preliminary data. Finally, in the western United States coverage is limited because differences in terrain increase the spatial variability of climatic variables (Hayes et al. 1999).

The USDM was developed in 1999 to display the severity and spatial extent of drought across the United States in a comprehensive easy to understand way (Svoboda, pers. com.). The USDM has also been used as to help trigger federal drought relief (Svoboda et al. 2002). The USDM is produced on a weekly basis using multiple indicators such as the PDSI, the SPI, Daily Streamflow Percentiles, CPC Soil Moisture, Percent of Normal Precipitation and remotely sensed Satellite Vegetation Health Index (Svoboda et al. 2002). In addition, local experts from around the country provide qualitative information on local conditions which is incorporated into the final weekly product (Svoboda et al. 2002). Unlike the previous indicators, the USDM classifies drought into one of five categories and does not indicate periods of abnormal wetness (Figure 4). In comparison with the other

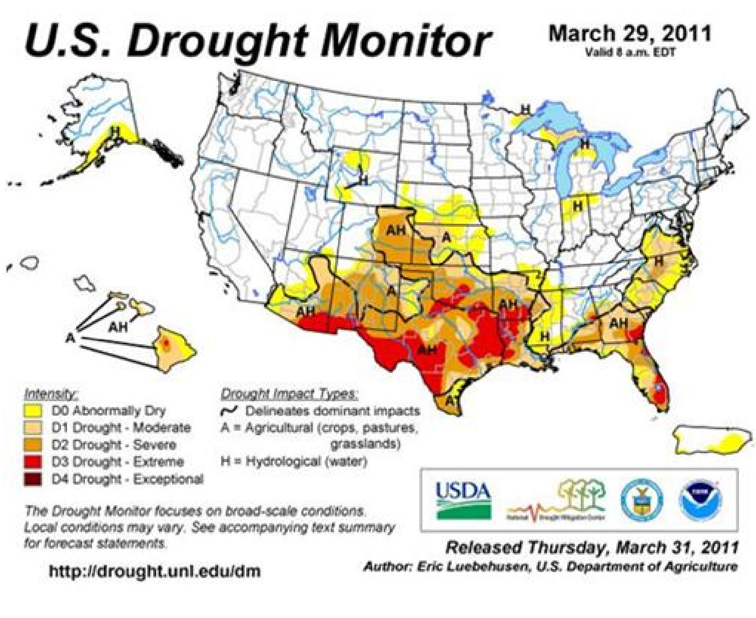

Figure 4: Map showing the USDM from March 29, 2011.

indicators, the USDM shows a slightly different depiction of drought conditions (Figures 1-4).

Similar to the SPI, the USDM is standardized. However, the USDM is standardized for the time of the year as opposed to for all times of the year at once (Svoboda et al. 2002). This standardization means that locations experiencing their regular dry season will not be indicated as experiencing drought during this time unless it is abnormally dry. The USDM also indicates different types of drought such as agricultural and hydrological. One drawback of the USDM is that it may not always capture local conditions (Steinemann et al. 2005). The UDSM also attempts to show drought at several temporal scales on one map (Heim, 2002).

Data and Methodology

To accomplish this project, each of the 44 currently available state drought plans was examined to identify the drought indices used in each plan. This information was organized into a Microsoft® Access database (Table 1). The indices used in each state's plan were then categorized as either an indicator or a trigger. Because states do not typically state whether an index is being used as an indicator or trigger, it was necessary to make this judgment by reading the description of the index in the plan. For example, if the plan described the index as being used to determine if a drought is occurring but did not include any specific actions associated with a given value, the index was classified as a trigger. However, if the plan included a specific action at a certain level, such as imposing water use restrictions, then the index was classified as a trigger. In addition, the spatial scale of the index was also entered into the database. Some options for this include county level, basin level, or climatic divisions. The temporal scale was also included to determine how often the index was assessed during a drought. Some indices can be assessed weekly such as the USDM while others are assessed on a monthly scale or longer. Finally, the total number of indicators and triggers used in each state's plan was calculated.

Table 1: Microsoft® Access state drought plan database categories.

Category
Index Classification
Index spatial scale
Index temporal scale
Number of triggers used in a state's plan
Number of indicators used in a state's plan
Total number of triggers or indicators used in a state's plan.

After the database was completed, it was merged with ArcGIS® 9.3 software to conduct a spatial analysis of the triggers and indicators. First, ArcMap™, an ArcGIS® application, was used to create a map template. Next, maps were created to show the total number of triggers and/or indicators used in each drought plan. Finally, maps were made to show which states were using each index and whether it was being used as an indicator or trigger.

Results

The analysis of the 44 state drought plans showed that a total of 20 indicators are being used by states (Table 2). Figures 5-12 show the spatial distribution of the total number of indicators and triggers used by each state, the four drought indices investigated in this study, and their classification as an indicator or trigger. This analysis shows that the number of triggers and indicators used by states varies from state to state (Figure 5-8). However, out of the 44 state plans analyzed only three (Illinois, Michigan, and North Dakota) do not formally use any indicators or triggers in their drought plans (Figure 5). Texas uses the most with a total of twelve.

Comparison of Figures 5 and 6 shows that approximately half of all states have elected to use drought indices as triggers, meaning that a given index value triggers a response. Of these, Texas uses the most triggers with a total of nine.

Table 2: Indicators used in the 44 state drought plans analyzed for this study.

Indicator
Standardized Precipitation Index (SPI)
U.S. Drought Monitor (USDM)
Palmer Drought Severity Index (PDSI)
Crop Moisture Index (CMI)
Keetch-Byram Drought Index (KBDI)
Surface Water Supply Index (SWSI)
United States Department of Agriculture (USDA) Declarations
Reclamation Drought Index (RDI)
Percent Normal
Streamflow
Reservoir Levels
Livestock Sales
Soil Moisture
Lawn and Garden Index
Groundwater levels
Pasture Conditions
Fire Danger
Generic Water Supply
Remote Sensing
Crop Conditions

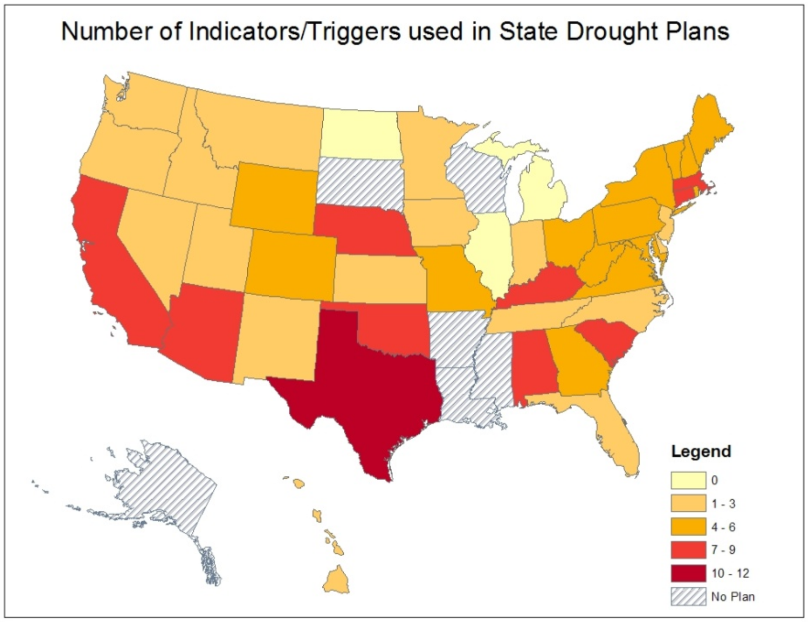

Figure 2: Map showing the number of indicators or triggers used by each state. The yellow represents no indicators of triggers used. The darker the orange and red represents more indicators and triggers being used.

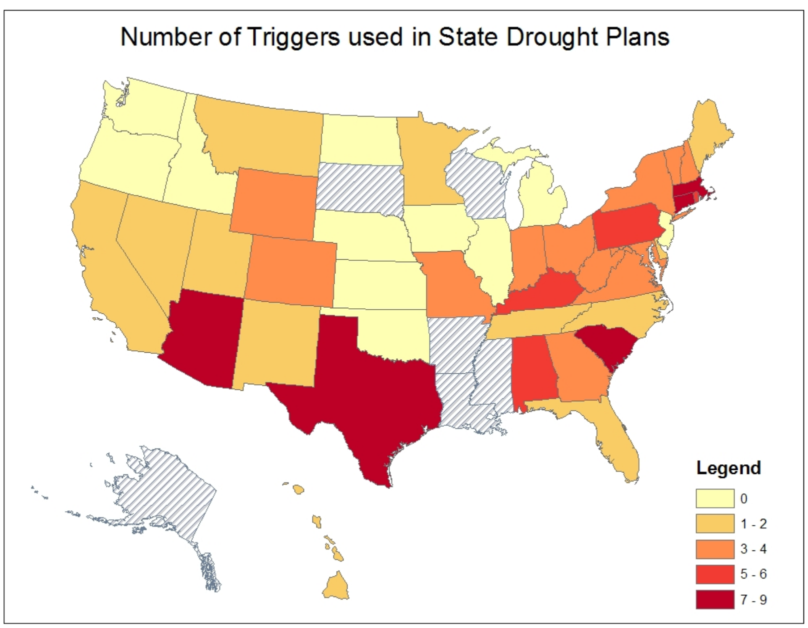

Figure 3: Map of the Number of triggers being used by each state.

To determine a possible explanation for the difference in the number of triggers and indicators among the states, the year of the plan adoption orlast update was plotted against the number of triggers and indicators used in each plan (Figure 7). This graph shows that the correlation between the number of indicators and triggers and the age of the plan is very small. Qualitatively, the graph shows that older plans (those prior to 2000) tended to use fewer indicators and triggers than more recent plans. During the 1980s and 1990s only three out of 12 states (25%) had plans containing 3 or more indicators or triggers. Since the year 2000, 21 out of 29 states (~72%) have plans containing 3 or more indicators or triggers (Figure 7). The numbers of triggers used in state plans have also increases since the year 2000. Two out of 12 states (1.7%) used 3 or more indicators as triggers prior to 2000, while 16 out of 29 (~55%) did so after 2000 (Figure 8).

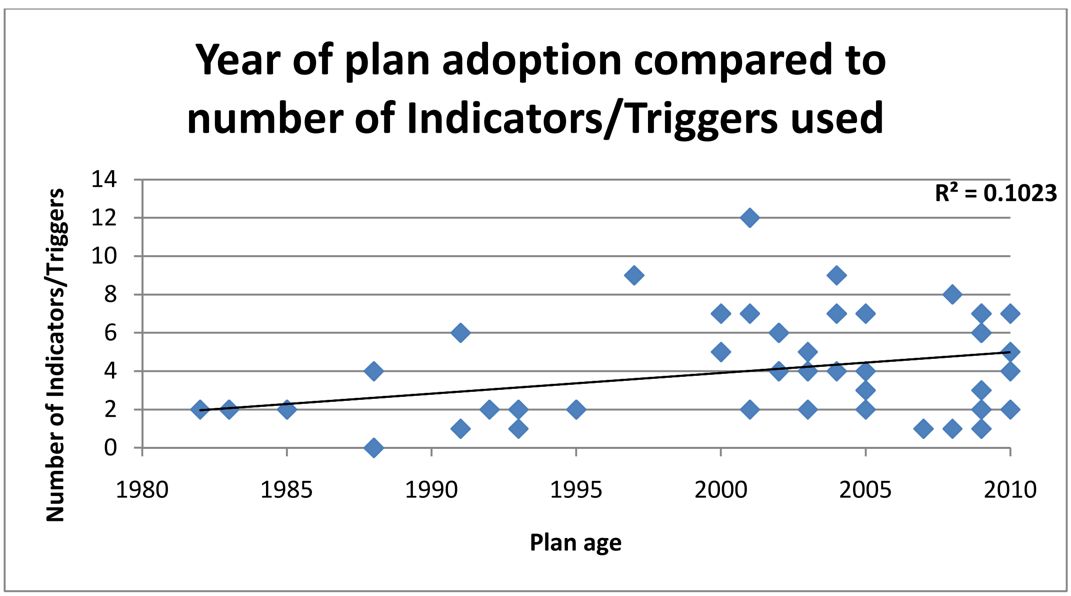

Figure 4: Year of plan adoption compared to number of Indicators or Triggers used.

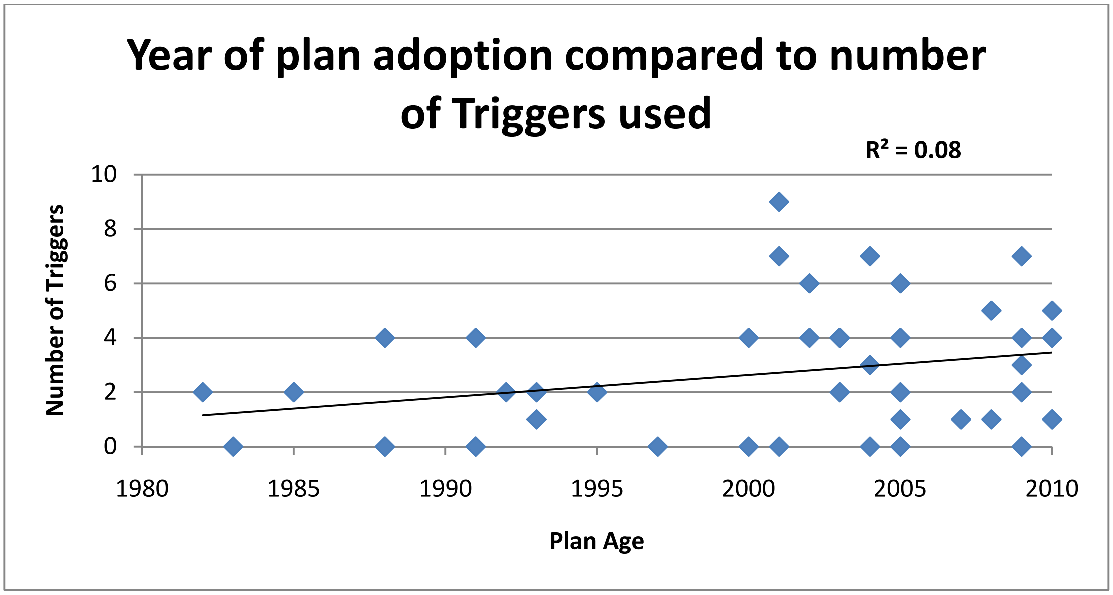

Figure 5: Year of plan adoption compared to number of triggers used.

Figures 9-12 show the spatial distribution of triggers and indicators for four drought indices: the PDSI, SWSI, SPI, and the USDM. The PDSI is used by 20 states as a trigger and eights states use it as an indicator (Figure 9). Several broad regional patterns are apparent. The PDSI is widely used in the west with seven states using it as trigger and two using it solely as an indicator. In addition, it is also used by a majority of states in the Northeast. It is also used as an indicator by four states in the central part of the U.S.

Given the nature of the SWSI, it is used only in the West (Figure 10). It is used by five states as a trigger and in three states as an indicator. Since this index was developed for the for snow and water supply assessment, it is not surprising that it is used in the West. However, it is important to note that the SWSI can be applied globally.

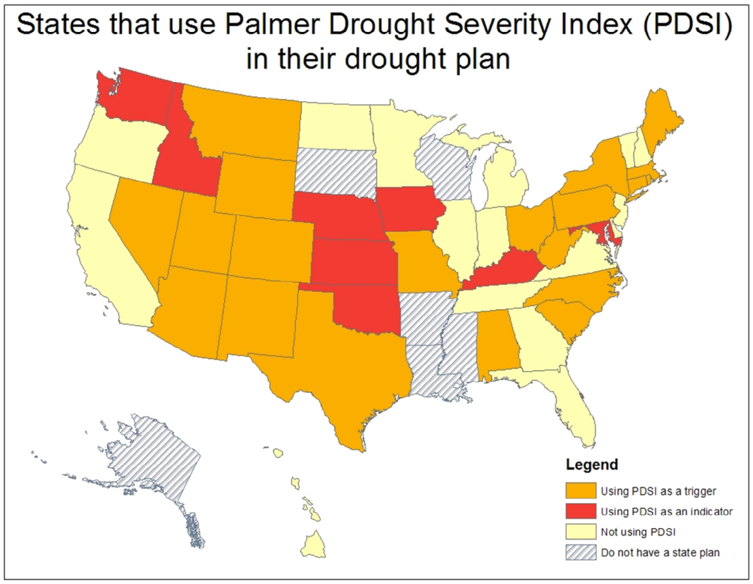

Figure 9: Map of states using the PDSI. If a state has indicated that it uses a certain index as a trigger it appears orange on the map. If the state uses an index as an indicator it appears red. If a state does not use that index in the drought plan it is yellow on the map. Any state that does not have a drought plan is indicated by gray hatching.

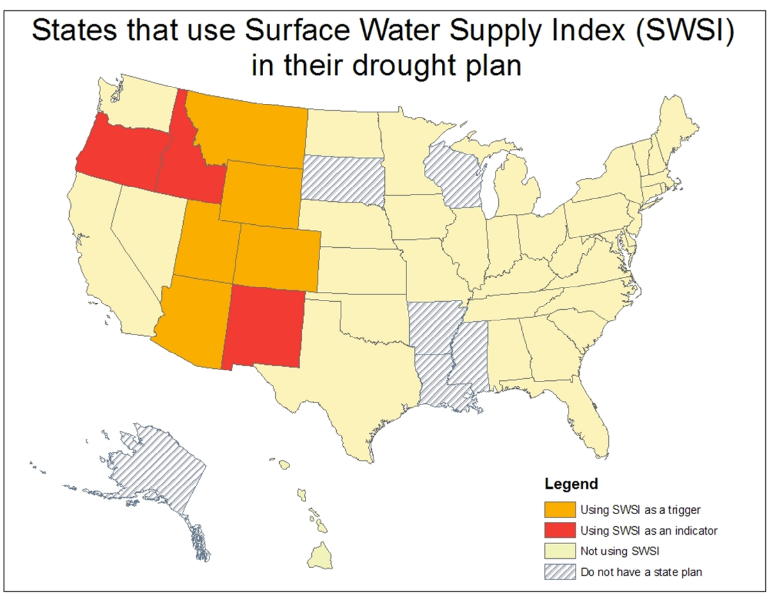

Figure 10: Map of states using the SWSI. The color scheme is the same as Figure 9.

The SPI is less widely used than the PDSI. It is used by four states solely as an indicator and ten states as a trigger (Figure 11). As with the PDSI, it is used by Arizona, Wyoming, Colorado, New Mexico, and Texas as a trigger and by Nebraska and Oklahoma as an indicator. The SPI is not widely used in the Midwest and the Northeast.

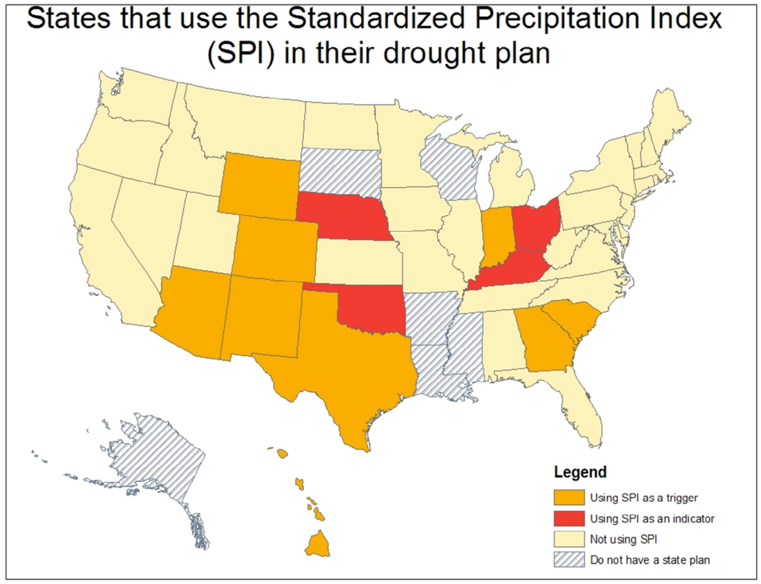

Figure 11: Map of states using the SPI. The color scheme is the same as Figure 9.

Only six states are formally using the USDM in their drought plan as an indicator or trigger (Figure 12). Colorado, Minnesota, Indiana, Kentucky and North Carolina all use it as a trigger, while Tennessee uses it as indicator. Because so few states are formally using the USDM, it is difficult to identify apparent patterns.

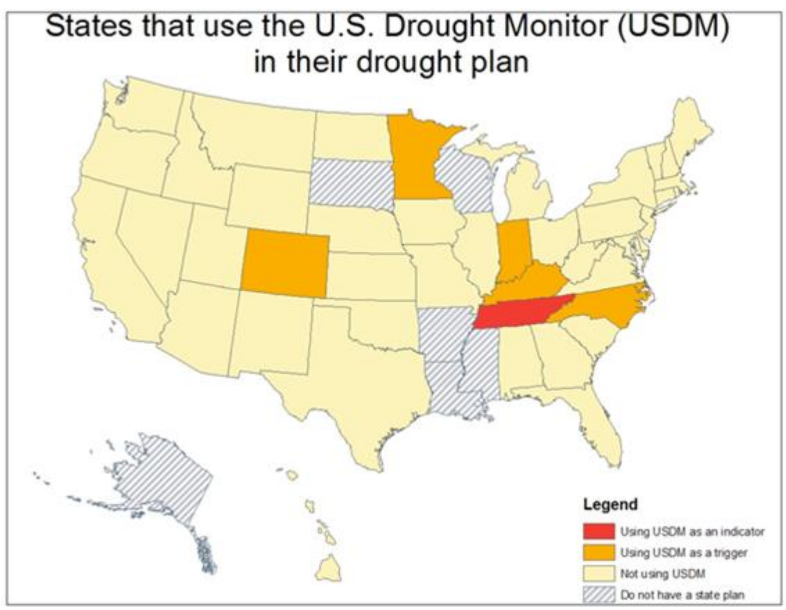

Figure 12: Map of states using the USDM.

Discussion

When looking at the number of indicators and triggers used in drought plans, it appears that the year the plan was adopted (or last updated) has an effect on the number of indicators or triggers used. This could be, in part, due to the fact that more triggers and indicators have been developed since the early 1990s. For example, the SPI was introduced in 1993 and the USDM was introduced in 1999. Another potential reason for this could be the occurrence of several significant drought events and the subsequent adoption of drought policy. For example, the National Drought Policy Act was passed in 1998. The Western Governors' Association has also been very involved with influencing drought policy since the year 2000, most notably in the pushing and eventual passage of NIDIS into Public Law (NIDIS, 2006).

The results of this research show that the PDSI is still used by many states (Figure 9). This may be due, in part, to the fact that it was the first comprehensive drought index available. The PDSI has been used for decades to monitor drought making it familiar to professionals in the drought community (Guttman 1998). The use in western and northeastern states is interesting due to the fact that the PDSI was developed based on a study of Kansas and Iowa (Alley 1984). Research has shown that PDSI does not capture the magnitude or onset of drought as quickly in the west (Hayes 1999). Hayes (2002) also states that the PDSI does not perform well in regions where there are extremes in variability or rainfall or runoff.

The SWSI, as discussed earlier, was developed specifically for use in Colorado. Since it incorporates snowpack, reservoir storage, streamflow, and precipitation at high elevations, this index has been modified and adopted by several other states in the west (Heim 2002). The results of this study are consistent with the intent of this index in that its use is limited to the western United States (Figure 10). States using the SWSI as a trigger share a river basin with one another. Colorado, Montana, and Wyoming share the Missouri River Basin. Arizona, Colorado, New Mexico, Wyoming and Utah share the Colorado River Basin (Figure 13). In the Columbia River Basin only Idaho and Oregon use the SWSI.

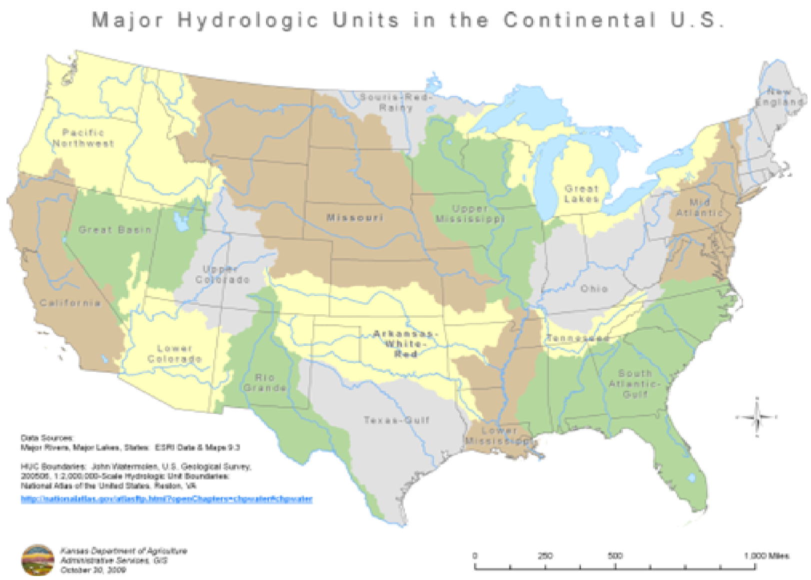

Figure 13: Map of the Major River basins in the United States.

Like the SWSI, the SPI was developed for Colorado. In the west it is being used by states that share river basins with Colorado (Figures 11 and 13). Arizona, Colorado, New Mexico, and Wyoming all share the Colorado River Basin; while Colorado, New Mexico, and Texas all share the Rio Grande River Basin. Both the Colorado and Rio Grande River are highly stressed basins and the states using the SPI in those basins are using it to initiate a drought response or action. Nebraska and Oklahoma also share basins with Colorado but these two states are only using the SPI to detect or indicate drought. Other basins where the SPI is used include the Ohio River and the South Atlantic-Gulf. The SPI only uses precipitation data when being calculated, so it theoretically can be used anywhere (Hayes 2002). However, the index will not be accurate if the precipitation record is not long enough or if it has poor data quality. In addition, the short term SPI may have problems detecting seasonal variations in precipitation that can occur in areas where it is being used (Hayes et al. 1999). For example, Arizona and New Mexico are very dry during the late spring and the summer (until the onset of the monsoon) and Nebraska normally does not receive a large amount of precipitation during the winter. Thus, the SPI alone may not detect drought onset as quickly in drier months.

The USDM is the newest of the indices, so one reason that it is not widely used may be because states have not updated their drought plan. However, it should be noted that the six states in this studyare not the only states that use the USDM (Svoboda, per. com.) Instead, these are the states that have officially adopted the USDM to be used as an indicator or trigger in their drought plan. The research is limited to what is listed in the state drought plan so while some state may be using the USDM unofficially, they are not included because it is not listed in the drought plan.

Conclusions

The purpose of this study was to determine if any regional patterns existed in indicators and triggers used in state drought plans. There are some general patterns that exist with three of the four triggers examined. The USDM does not have a pattern which may be because it is a relatively new index. A significant finding is that the PDSI is widely used in the West, an area for which research has shown this index to be less reliable (Alley 1984; Heim 2002; Heddinghaus and Sabol 1991). This could be in part, due to the fact that it was the original index used to determine which areas received federal drought relief. This index has been around the longest making it the most familiar index to many drought and water management professionals.

Even though some general patterns exist in the use of the PDSI, SWSI, and SPI, wide variability exist in the total number of indicators and triggers used. Qualitatively the data suggest that the more recently the plan was updated the more indicators and triggers they are likely to have. Finally, this study shows that indicators are more likely to be used in the Plains and in the Northwest while triggers are also more likely to be used to the east of the Mississippi and in the Southwest. The more indicators and triggers used by states in their drought plans will allow for better preparedness and responses when states are faced with drought (Steinemann 2006).

Acknowledgements

A special thanks to Dr. Mike Hayes for providing funding for this research, Dr. Deborah Bathke for advising during the research, and Mr. Mark Svoboda for serving as my reader. In addition, I would like to acknowledge the assistance provided by Crystal Bergman, Jeff Nothwehr, Nicole Wall, and Tonya Bernadt. I must also thank my parents Wayne and Kathy Robine for helping support me throughout the last four years.

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