The Development and Evolution of Best Practice Strategies for Using Drought Monitoring Tools in Colorado

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Introduction

Colorado has been actively involved in comprehensive multiagency drought monitoring, assessment and response dating back to the initial Colorado Drought Response Plan of 1981. Even before that, the extreme winter drought of 1976-77 brought several state, federal and university groups together to improve communications among the various groups involved in monitoring the various aspects of the hydrologic cycle. This led to a commitment to improved comprehensive drought monitoring in Colorado that resulted in several efforts to develop and utilize drought indices to combine complex hydroclimatic information into numerical indicators. These indices aid decision makers, who may not be climate and water experts, to properly assess drought severity.

With Colorado's aggressive early involvement in enhanced drought monitoring, the Surface Water Supply index (SWSI) was developed in the early 1980's. Then in the mid 1980's the Palmer Drought Severity Index which had become nationally popular in the 1970's was specifically adapted to the diverse and inhomogeneous climatic regions of Colorado. Finally, in the 1990's the Colorado Climate Center developed the Standardized Precipitation Index (SPI) as an easily computed index specifically aimed at addressing the many time scales of drought and their various impacts (short term agricultural drought, long term hydrologic drought, etc.). Recently, improvements have been made to these indices. The SWSI has been improved for Colorado by changing the formulation to make use of water supply forecasts and by dividing the 7 large drainage basins in the state into smaller hydrologic units in order to provide more useful information on a finer spatial scale. The Colorado Climate Center also did a complete update of input data and processing for both the SPI and the Colorado Modified Palmer Drought Severity Index (CMPDSI) to update the "normal period" to the most recent 30 year period, 1980 – 2009.

Through nearly 30 years of frequent meetings of Colorado's Water Availability Task Force (WATF), these various indices have been presented, discussed and compared. When combined with basic precipitation, snowpack, streamflow, reservoir levels, ground water and other hydrologic information a quantitative assessment of water supplies emerges. This experience has shown that no single index or indicator adequately defines and describes drought severity, extent or duration. But through experience, and the benefits of different perspectives from experts in various water-impacted fields, we have learned that depending on the application (agriculture, municipal water supplies, recreation, etc), the time of year and the area of the state, that different indicators or combinations of indicators most effectively represent current and anticipated drought severity and impacts. For example, the SWSI is relatively meaningless in the early autumn but is a confident and robust drought indicator in early summer. The 12-month SPI is often of limited value for agricultural applications but may relate well to surface water supplies. The 3-month SPI in autumn and late spring is a useful indicator of dryland agricultural production but is of limited use for municipal water supplies. The 48-month SPI is a poor indicator of current and emerging drought but is often the best retrospective index for determining the periods of greatest overall impact since it is the combination of severity, duration and areal extent that defines cumulative impacts.

Over the past decade the introduction of yet another "index", the U.S. Drought Monitor (USDM) with drought categories D0 (abnormally dry) to D4 (extreme drought), has provided a federally coordinated mechanism for assembling all the data, indices and indicators into an expert system (partially automated and partially a team of human experts) that combines the information from the various sources and weighs the seasonal significance and impacts. With the help of the National Integrated Drought Information System (NIDIS) Upper Colorado River Basin Pilot Project, the Colorado Climate Center has become fully engaged in this process during the past year. The Colorado Climate Center, in combination with other state and federal partners, produces and/or tracks a variety of complimentary data sources, indicators and drought indices to inform this process.

<u>Development of Best Practices in Colorado Drought Monitoring</u>

The use of drought indices for drought documentation, prediction, early warning and public dissemination is a complex and iterative process. Trigger levels of indices can be set to initiate drought related activities, but there is no guarantee that any one trigger level will be appropriate in all instances. In fact, it is a certainty that there is no universal index to work in all instances. For example, a short term drought in the late summer season (such as was experienced in 2010) may not reach trigger levels on a 6 month or even 3 month Standardized Precipitation Index (SPI) value, however the area can become dry enough quickly enough (less than 3 months) to trigger significant agricultural impacts related to wheat planting, germination or range conditions. Relatively short periods of very dry weather (again, such as was seen in late summer/early autumn 2010) can contribute to large wildfires because of a rapid drying in the presence of an abundant source of fuel from a wet spring. Because of the complexities in dealing with time scales, a diverse set of potential impacts (one person's drought is another's fine weather) and a variety of indices to choose from, drought monitoring should be an on-going and iterative exercise

While Colorado has traditionally convened meetings of climate and water experts on a quarterly, bi-monthly or monthly basis, we have seen (e.g. 2002) that there can be considerable advantage in more frequent assessments. Each week climate and water resource experts from across the U.S. feed information to the USDM author. Inputs may include but are not limited to: SPI over various time scales, Palmer Drought Severity Index, Surface Water Supply Index, Vegetative Health Index, soil moisture products, reservoir levels, streamflow, precipitation and temperature anomalies over varied time scales, etc. Looking at a variety of products allows one to understand the current situation and provide data and experience-derived recommendations that are updated weekly. The weekly timescale for drought monitoring is demanding, but is preferable to the monthly or longer time scales of former drought monitoring processes. This is true year round but is especially true during certain times of the year (especially spring and summer) and in those parts of the country where water demand is high and where conditions can deteriorate or improve rapidly.

The Colorado Drought Plan currently calls for monitoring the following indices for drought assessment in Colorado: 6 Month Standardized Precipitation Index (SPI), Colorado Modified Palmer Drought Severity Index (CMPDSI), USDM and Surface Water Supply Index (SWSI). Because several of these products are only updated monthly, they are not ideal for decision makers who may need more up to date information on the status of drought across the state. Because of this fact, the Colorado Climate Center is dedicated through our central mission of climate monitoring, to feed information to the USDM on a weekly basis and to coordinate input from other water experts in the state as resources permit. This approach marks a fundamental change from the traditional monthly update cycle. It is motivated from the experiences made possible through the NIDIS Upper Colorado River Basin Pilot Project and assessments and user surveys conducted in 2009 and 2010. There remains a need for periodic face to face meetings of water information experts and users, but this is only practical periodically (once per month or less often as needed). Improved data access, data analysis and communications technology are now making a weekly update cycle much more feasible than in the past. This will ensure the depiction of Colorado on the USDM is consistent with Colorado monitoring efforts and provide a better depiction of drought conditions across the state as it emerges and changes. This should allow state decision makers to access the USDM each week, trust the product more so than in the past, and make drought related plans and actions accordingly.

Summary of Colorado Drought Indices and Use

Standardized Precipitation Index

Although the Drought Response Plan indicates that the 6 month SPI will be evaluated for drought related actions, several additional time scales will also be evaluated including: 3, 9, 12, 24 and 48 month SPI values. The evaluation of these additional temporal scales is due to the fact that drought conditions across the state will vary with seasonality and duration of drought. In the early spring, shorter temporal scales will indicate how agricultural conditions are shaping up for planting season. During the winter months, longer time scales are used to evaluate winter snowpack conditions in the mountains, antecedent moisture conditions and how that will relate to spring snowmelt. These indices are currently updated monthly with plans to update weekly in the future.

Colorado Modified Palmer Drought Severity Index

The CMPDSI uses a water balance approach to indicate drought conditions. This index has a relatively long memory (on the scale of months to years) and is generally suited for range and agricultural conditions. This index does not respond quickly to dry conditions, SPI is more suited for shorter temporal scales. The CMPDSI has shown promising results for prediction of winter wheat harvest as well as streamflow across various areas of the state. This predictive power can indicate a bad agricultural or runoff year as early as May in certain areas/basins of the state. Because this index does not respond quickly to dryness, it is not ideal for short term evaluations. This index is currently updated monthly but the Colorado Climate Center is planning to update this to a weekly basis when resources allow for this work to be accomplished.

Surface Water Supply Index

The SWSI is an indication of the amount of surface water available in both reservoirs and streams for the basins of the state. This index is best suited for understanding how much water is available for storage and use in any given basin of the state. It does not give an indication of precipitation deficits unless those are translated into reservoir or streamflow draw downs. This index is best suited for use by water users, providers and managers and provides more information than streamflow and reservoir levels alone. This index is currently updated monthly and was recently updated by the Natural Resources Conservation Service to provide more spatial detail west of the Continental Divide in Colorado. The update is also supposed to remove inconsistencies from the older SWSI stemming from a change of weighting factors in the model with seasonality.

United States Drought Monitor

The USDM is a national level drought product that is driven by local input coordinated nationally. The USDM indicates not only drought severity, but also delineates dominant impacts to hydrology or agriculture. The depiction of any given area on the USDM is a function of the amount of local input and expertise given to the drought authors each week. The Colorado Climate Center has begun coordinating local experts (NWS, USGS, Dept. of Agriculture) to provide information to the USDM each week in order to have an accurate representation of drought in our state. This product is currently updated weekly and is an ideal product for rapidly changing drought conditions across the state. It is ideal for decision makers and public dissemination because it integrates all of the more complex indices into one easy to use product. This product is also ideal for early warning because it is updated on a weekly basis.

Index Behavior

In order to illustrate the behavior exhibited by the various indices utilized for drought monitoring, figures 2 – 4 below show a time series from 1996 – 2005 for three regions of the state: the South Plains of the Kansas drainage encompassing a region of both dryland and irrigated agriculture in east central Colorado (no SWSI), the Northern Front Range in the South Platte drainage and the Upper Valley of the Colorado Drainage (Figure 1). The time period 1996 – 2005 was selected because it spans an exceptionally wet period in the late 1990s, the onset of the extreme drought of 2000-2002 followed by a period of variable and erratic recovery. For each graphic the Palmer, SWSI, and SPI (3, 6, 9, 12, 24 and 48 months) are shown together. While this graphical presentation may seem a bit chaotic; this is a useful way to compare and assess index behavior. Keep in mind that the expected ranges of these indices differ. The SWSI is limited by design to the range of -4.2 to + 4.2. The Palmer normally spans this same range but can, in extreme conditions, go as far as +/- 6 or even more. The SPI's by definition and design, rarely exceed +/-3 and only infrequently go outside the range of +/- 2.5 These different inherent scales must be factored in when viewing and interpreting results.

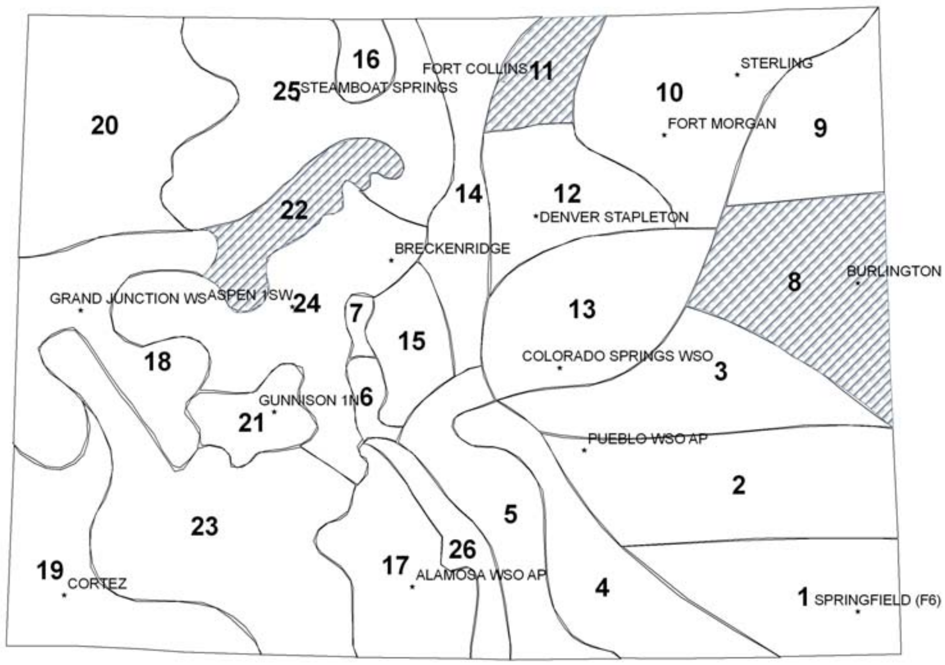

Figure 1: Selected Palmer Regions for Index Analysis.

In the Kansas drainage (Figure 2), a downward trend in a majority of the indices can be seen starting in early 2000 with the shorter term indicators (3 and 6 month SPI) leading the way.   The Palmer and long term 48-month SPI show a downward response but with several months of lag time. The SPI values of -2 and lower during the spring and summer of 2002 are indicative of extreme drought with short-term indices bottoming out in July and August 2002. Rapid improvement is seen in the 3-month SPI during the fall of 2002 and all indices trend quickly upward in the spring of 2003 only to tumble back down later in 2003. Even the slow reacting Palmer index went above zero briefly but quickly went negative again in July 2003. All indices then continued to show negative numbers through late 2004 consistent with harsh agricultural drought impact reports from that area. By late 2004 improvement in all the short term indicators is evident while the long-term indicators remain negative. The 48-month SPI dropped to below -2 by the fall of 2003 and remained near -2 through 2005 even as the shorter term indicators improved. This simply pointed retrospectively to the severity of the 2000-2004 drought period in this region even though recovery was underway in 2005.

This graphic is very illustrative of the information contained in the various drought monitoring tools and how they collectively describe the progression through the early 2000s drought. Combining the information from several indices is much more instructive than looking at indices individually.

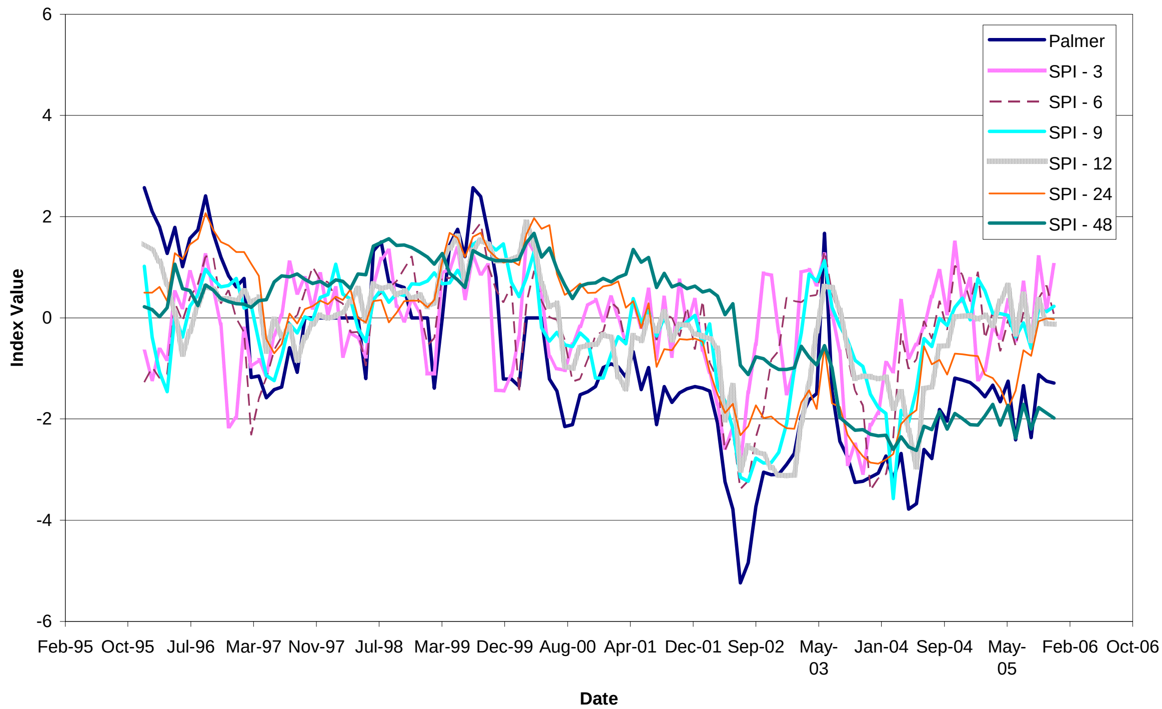

Figure 2: Region 8 Kansas Drainage Drought Indices Time Series 1996 - 2005

In the Northern Front Range (Figure 3), the progression is somewhat different. SWSI values for the South Platte drainage are also included on this graphic to compare the behavior in relation to the other indices. This region shows exceptional wetness in 1999 followed by a downward trend beginning already in October 1999. Note that it is not only the magnitude of the various indices that are significant but also their respective rates of change. The Palmer index shows a dramatic plunge into severe drought conditions already in August 2000 which set the stage for the 2002 drought. There is some recovery seen in the Palmer between the 2000 and 2002, however the SPI values stayed negative (with the exception of shorter time scales) through mid-2004. In addition to this, the SWSI values in this region trace the other indices well, but exhibits more short term variability. The 48 month SPI in this region clearly shows the evolution of the 2002 drought with a downward trend starting in early 2000 continuing through early 2004 where it finally began a positive trend.

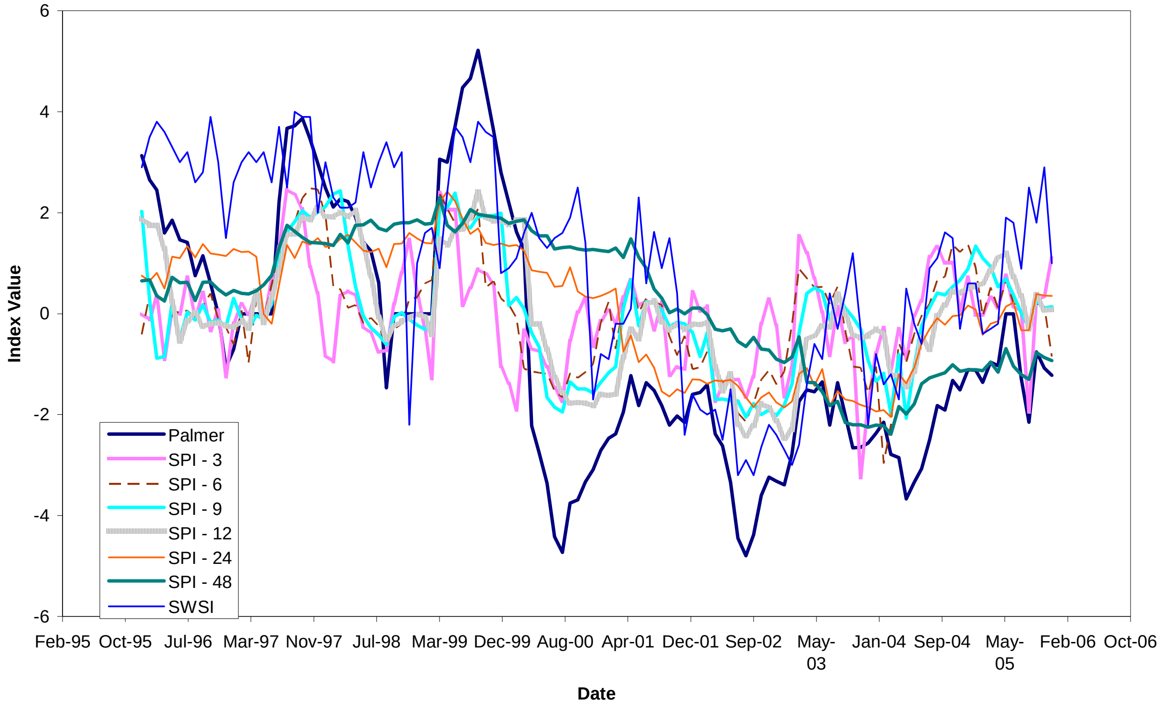

Figure 3: Region 11 Northern Front Range Drought Indices Time Series 1996 - 2005.

In Region 22 the Upper Valley of the Colorado drainage (Figure 4), it is evident that the SWSI index behaves differently than the other indices in this region. Although it follows a general trend, it shows much more inherent variability than the other indices. The SPI indices and Palmer begin a negative trend in mid-1999 which continued through mid-2002 when nearly all indices (especially shorter time scale SPI indices) began an upward trend to improving drought conditions. There is also a secondary drought in 2004 that is evident from the indices in this region which has a relatively quick recovery.

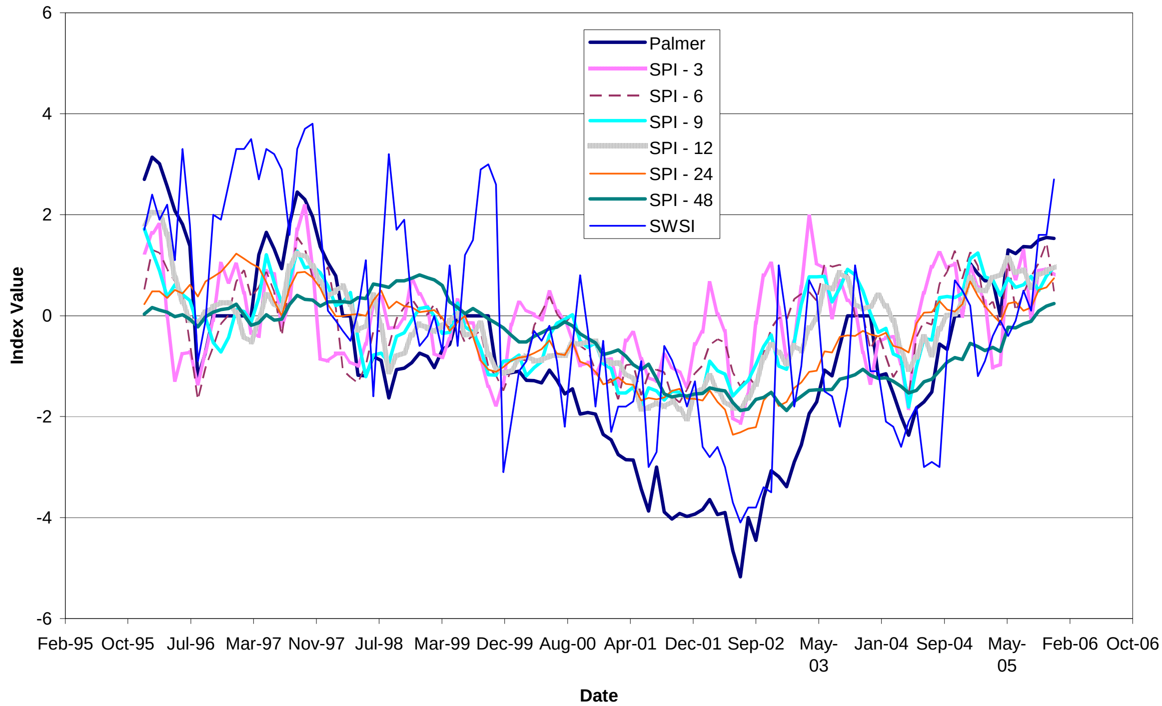

Figure 4: Region 22 Upper Valley of the Colorado Drainage Drought Indices Time Series 1996 - 2005.

These time series show how the various indices react to changing drought conditions. It is evident that by looking back at the 2002 drought, the 48 month SPI and Palmer are the best retrospective indicators of start and end of drought periods because of their long memory and smoother behavior.. Shorter time scales lead to faster reaction of these indices to wetter conditions in the short term and provide the best lead time for drought onset. Based on this study, we have concluded that producing and watching the evolution of these indices on the same regional graphics will now be an ongoing exercise for assessing drought conditions in Colorado. The production and routine updating of these graphics will begin in the fall of 2010.

Recommendations

While it is important for decision makers and the public to know about drought conditions across the state, some of the above indices require background knowledge to understand limitations and inconsistencies in the values. It is the recommendation that we begin to transition to using the USDM as a drought impact assessment and early warning product because it is an integration of several indices and products as well as the weekly updating frequency. Now that local experts are more fully engaged in the USDM process due to the NIDIS Upper Colorado Basin pilot, one can be more confident in the drought conditions represented by this product for Colorado. SPI, CMPDSI and SWSI should still be presented at the Water Availability Task Force meetings for water providers and experts, but the straightforward drought categories (D0, D1, D2, etc.) of the USDM relate directly to actions to be considered in Table 1.1 of the State Drought Response Plan. For example, Table 1 of the State Drought Plan lists several actions to be triggered at a D1 level on the USDM.

Through the addition of new data sources, such as CoCoRaHS, CoAgMet, NOAA's CRN and HCN-M, BLM/USFS RAWS (Remote Automated Weather Stations) and remotely sensed precipitation from radar, one can strive to provide enough observational detail to accurately assess drought onset and severity at a sub-county scale. The sub-county scale is desirable because cases arise where a county can be extremely dry in one area and not the rest which should be accurately represented by the U.S. Drought Monitor. Drought is not confined to political boundaries and should be represented with as much spatial detail as possible.

A single map depiction will never totally capture the full range of drought conditions and impacts that are possible in a state where reservoirs and diversions provide enhancements to water supply for some areas during certain parts of the year. This is a unique situation in Colorado which warrants the combination of several indices to accurately assess drought conditions across the state, and if the USDM is created in an informed manner one can have more confidence in its use for drought monitoring and early warning.

The successful implementation of these recommendations is contingent upon maintaining adequate funding within the Colorado Climate Center at Colorado State University and the other contributing partner organizations so that weekly monitoring activities can be maintained particularly during the critical late winter through mid summer period.