IMPROVING DROUGHT DETECTION IN THE CAROLINAS: EVALUATION OF LOCAL, STATE, AND FEDERAL DROUGHT INDICATORS

by

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ABSTRACT

Persistent drought and increased water demand require that comprehensive drought planning, based on accurate drought indicators, guide future water resource management. Yet, drought indicators are often the weakest components of drought plans because drought affects different sectors at different time scales, making it difficult to define and measure. This research evaluates the spatial and temporal distribution of drought intensity and frequency as detected by South Carolina's state drought indicators and the recently defined Federal Energy Regulatory Commission's Low Inflow Protocol indicators for the Catawba-Wateree and Yadkin-Pee Dee River Basins. The dissertation connects indicators based on scientific justification with operational relevancy by evaluating water systems' and power company's vulnerability to drought, their understanding of drought indicators, and their identification of indicator characteristics that provide the most effective drought response.

Indicator discrepancies were identified and several major recommendations emerge from the research. First, statistical inconsistencies exist between the drought classes defined by the S.C. Drought Response Act regulations; these can be resolved by transforming the indicators from raw values to percentiles. Second, discrepancies in drought detection based on the LIP indicators were most acute during the drought recovery phase and for the Catawba-Wateree River Basin LIP, which is dependent on a recovery of all indicators to initiate a stage downgrade. Recommendations include

shortening the streamflow average and replacing the U.S. Drought Monitor with the Standardized Precipitation Index. The addition of a recovery condition based on storage recovery should also be considered.

The research identified that water systems and power companies value both local and state drought indicators, however, they have higher expectations and depend more heavily on their local indicators. Drought indicator(s) need to be multi-dimensional as indicator effectiveness is based on drought detection and indicator accessibility. The study implements the National Integrated Drought Information System initiative that calls for integrated drought research at relevant spatial scales to facilitate proactive decisions. The research results can be used to improve planning and coordination within and between levels of government and water users to help reduce society's vulnerabilities to drought and ensure sustainable water to meet growing demands.

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CHAPTER 1 INTRODUCTION

Over the last decade, as South Carolina endured two record multi-year droughts, it became clear that the sustainability of the state's water resources could no longer be taken for granted. These extreme events were a necessary "springboard" to elevate the public's awareness and capture decision makers' attention to the challenges associated with managing South Carolina's water resources. Well-publicized, major natural hazard events usually stimulate stakeholder interest and increase the public's acceptance of policy changes. The droughts brought about changes in how the state's water resources are managed and reinforced the need for improved coordination and planning within and between levels of government and water users.

As the drought response program evolved since the late 1970s, South Carolina experienced many of the institutional, political and budgetary constraints common to the drought planning process. The State's shift to more integrated drought planning and response occurred after twenty years of successes and failures in drought planning and policy implementation. A common, positive thread in the program is the State Drought Response Committee, which is composed of local and state representatives who must evaluate drought indicators and triggers to determine if action beyond the scope of local response is needed. One of the major shifts to improve the state's drought management has been the analysis of drought indicators, the development of drought triggers, and the corresponding management responses at both the state and local level.

At the local level, water users, such as water systems, industries, and power generation facilities, are responsible for maintaining drought management plans and response policies that are integrated between connected systems and the state's plan. The foundation of local drought management plans and policies relies on system-specific drought indicators, identification of alternative water supplies, and public education. Each plan designates drought indicators specific to the system that can be used separate from, or in conjunction with, state-level drought triggers. System-specific drought indicators include information such as reservoir levels, streamflow, number of days of supply remaining, and average daily use. The state uses more traditional indices such as the Palmer Drought Severity Index (PDSI) (Palmer, 1965) and Standardized Precipitation Index (SPI) (McKee et al., 1993) for state level declarations.

Beyond South Carolina's push for improved drought indicators and triggers there are examples of this trend at the federal and national levels. Many of the nation's hydropower dams are undergoing relicensing by the Federal Energy Regulatory Commission (FERC). In order to meet FERC's requirements, the hydropower companies must develop Low Inflow Protocols (LIP) as a part of their new license. Many of the current licenses have been in place since the 1950s and the inclusion of drought indicators and LIPs is a major milestone for future drought mitigation given the 30- to 50- year duration of each license. The LIP provides procedures for how the hydro-projects will be operated by the licensee and how other water users should respond during periods when insufficient water flows into the project reservoirs to meet normal needs (Catawba-Wateree Project, Comprehensive Relicensing Agreement, October 2006; Yadkin Hydroelectric Project, February 2007).

Designating indicators to detect drought conditions and triggers to activate the appropriate response is the backbone for improved drought mitigation to reduce drought impacts (Hrezo et al., 1986; Fisher and Palmer, 1997; Steinemann et al., 2005; Palmer et al., 2002). However, the complexity of drought makes determining the drought indicators and triggers difficult. Droughts may be characterized in many different ways (Wilhite and Glantz, 1985) and no single indicator serves as an adequate national standard to characterize the damage potential of drought the way the Saffir-Simpson Scale measures hurricane intensity, or the Fujita scale relates to tornado destruction. Instead, decision makers typically rely on multiple triggers from a long list of indicators. While multiple drought indicators improve detection, many stakeholders (e.g., water resource managers) do not know which indicators and trigger values to use. Decision makers often consider using multiple indicators without realizing their spatial and temporal inconsistencies (Steinemann et al., 2005; Karl et al., 1987; Guttman et al., 1992). Decision makers may use indicators that lack a consistent long-term record or one that can be reconstructed and be reliably generated in the future (Steinemann et al., 2005, Keyantash and Dracup, 2002). While South Carolina's drought response program is proactive in having state and local level drought indicators, many of the indicators are being developed without scientific justification.

The purpose of this research is to determine which drought indicators are most effective in enhancing South Carolina's state and local drought mitigation policies. The study will demonstrate the importance of developing and testing drought indicators. It will also assess the effectiveness of using an integrated planning approach by evaluating the spatial and temporal distribution of drought intensity and frequency as indicated by federal, state, and local indicators. This will be accomplished through four research objectives.

1. Determine the statistical consistency among state indicators and drought categories.

The first objective evaluates the correlation between state-level drought indicators (Table 3.1) used by the S.C. Drought Response Committee for official drought stage determination. The frequency of occurrence within each threshold trigger level will reveal any inconsistencies between indicators and serve to better understand the duration and probability of drought occurrence.

2. Identify inconsistencies between multiple indicators used in local drought plans.

Frequency distributions were computed to determine probabilities of drought occurrence for local drought indicators used in the Catawba-Wateree and Yadkin-Pee Dee LIP (Table 4.11 and 4.12). The importance of indicator consistency among local water systems within each basin was demonstrated by analyzing indicators for the City of Rock Hill, South Carolina.

3. Evaluate use of indicator percentiles comparison as a method to improve drought detection.

The research will test whether transforming indicators to percentiles and then combining the multiple indices using blends or weights to create a new, blended drought index is an efficient and alternative approach for improving drought detection. Specifically, the research will determine whether drought detection in the Catawba-Wateree river basin can be improved by using a single or blended drought index to replace the U.S. Drought Monitor. Subjective criteria based on communication with Duke Energy and the Catawba-Wateree Drought Management Advisory Group is used to evaluate indicator performance.

4. Determine what state and local indicator characteristics make an effective drought indicator for water system and power generation management needs.

A survey, as well as extensive interactions with water managers and stakeholders during the 1998-2002 and 2007-2008 droughts, was used to evaluate the effectiveness of state and local drought indicators. The emphasis of the previous objectives focused on the scientific justification of drought indicators. Objective 4 provides the link between the scientific justification and operational relevancy of the indicators. The survey also provides a manager's reconstruction of the historic sequence of the 1998-2002 drought to better understand their ability to tolerate drought. The survey results and correspondence with water users and decision makers were used to verify which indicator(s) meet the user's needs and more closely detect the drought impacts on their operations.

The research will provide scientific and operational information to consider in evaluating whether changes should be made to the drought indicators listed in the South Carolina Drought Response Act regulations, and those recently implemented in the FERC Low Inflow Protocols (LIP) for the Catawba-Wateree and Yadkin-Pee Dee river basins. Indicator research, such as that conducted for this study, is listed as a primary agenda item for evaluation by the FERC LIP Drought Management Groups that meet annually. The research results will also be useful as South Carolina Electric and Gas Company begins relicensing and LIP development for their hydropower dam in the Saluda basin. The research implements key components of the National Integrated Drought Information System federal initiative that calls for integrated drought research and information at relevant spatial scales to facilitate proactive decisions. Finally, the research will serve as a reference tool showing how indicators can be integrated between water systems, power generating facilities, and state level plans to improve drought response.

The research background, methodology, results, and conclusions are presented in six chapters. The first chapter serves as an introduction to the research questions focused on developing effective drought indicators that enhance state and local drought mitigation policies. Chapter 2 reviews existing literature on the advantages and limitations of the different drought indicators and the evolution of state and federal drought management. Chapter 3 examines the statistical consistency between the seven state drought indicators and stages. Chapter 4 investigates the diagnostic accuracy of the multiple indicators specified in the local FERC LIPs for the Catawba-Wateree and Yadkin Pee Dee river basins. This chapter also evaluates other potential local indicators, or blends of indicators, and stresses the importance of indicator consistency between the FERC licensee and local water systems in the basins. Chapter 5 provides the link between the scientific justification and operational relevancy of the indicators, summarizing the water system and power company survey results. The survey reveals those characteristic(s) that make an effective drought indicator(s) by meeting the user's management needs. Chapter 6 summarizes the research by providing implications and recommendations for improving drought management in South Carolina.

CHAPTER 2 LITERATURE REVIEW

2.1 Drought Indicators

Drought affects a wide variety of sectors across divergent time scales, making it difficult to define and measure. Various quantitative measures of drought have been developed to respond to the needs of different disciplines and regions. The terms "measure" or "indicator" are often used to describe those variables that characterize drought. Drought triggers are the thresholds of the measures or indicators used to activate the several levels of response. Typical indicators are based on meteorological and hydrological variables such as precipitation, temperature, evaporation, soil moisture, streamflow, reservoir storage, and groundwater levels. In many cases, several variables have been combined to form a drought index such as the computation of the Palmer Drought Severity Index that includes rainfall, temperature, evapotranspiration, and soil moisture (Palmer, 1965). As the list of indicators grows, so does the confusion over which indicator or combination of indicators should be used by decision makers. A new product is available from the Climate Prediction Center that blends or weights several indices for short and long-term intervals at climate divisions in the U.S. (Svoboda et al., 2002). This blended drought index is used by the U.S. Drought Monitor authors, but there is minimal literature available on the blended index or its creation.

Recent advancements have been made in the implementation of more sophisticated models that better represent the complex hydrologic cycle designed for large-scale applications. For example, there is growing interest in the operational use of the Variable Infiltration Capacity (VIC) macroscale hydrologic model that has been tested across multiple basins in the United States and globally (Cherkauer, K.A, et al., 2003). Such process-oriented approaches for detecting drought are used less commonly in local, state and federal drought plans because of their computational complexity and input data requirements. Models such as VIC are not currently used in S.C. state and local drought plans.

The most common drought indices include the Palmer Drought Severity Index (PDSI), the Palmer Hydrologic Index (PHDI), the Palmer Z-Index (Z index), the Crop Moisture Index (CMI), the Standardized Precipitation Index (SPI), the Keetch-Byram Drought Index (KBDI), Surface Water Supply Index (SWSI), Percent of Normal Rainfall, and the U.S. Drought Monitor. Drought indices derived from streamflow data as well as reservoir storage and groundwater levels also serve as useful indicators of water shortages. Additional local indicators often used by water systems include days of supply remaining and use greater than certain benchmarks. The indices and indicators evaluated as part of this research are discussed in more detail in the sections below.

2.11 Palmer Drought Severity Index

Of the variety of definitions and drought measures developed, the Palmer Drought Severity Index (PDSI) has been the most widely used and heavily relied on in the United States (Alley, 1984; Karl et al., 1987; Guttman et al., 1992). For example, the PDSI was used as the sole trigger for South Carolina's drought legislation (South Carolina Drought Response Act, 1985) and related triggered response from its inception in 1985 until its amendment in 2000 (South Carolina Drought Response Act, 2000). Amendments in the revised South Carolina Drought Response Act of 2000, however, list the Palmer Drought Severity Index as well as the Crop Moisture Index, Standardized Precipitation Index, U.S Drought Monitor, streamflow and aquifer levels as quantified indices that may be used for drought stage evaluation.

The PDSI is calculated based on precipitation and temperature data, as well as the local available water content of the soil. Despite many of the referenced limitations (assumptions used in water balance calculations and the empirical nature of some of the standardizing coefficients) of the PDSI it generally proved to be sufficient in detecting drought in South Carolina from the mid-1980s until early 2000 when additional indicators became more widely available resulting in amendments to the S.C. Drought Response Act. The PDSI's primary drawback is inability detecting agricultural droughts that often occur in South Carolina with one to two month rainfall deficits during the growing season. Some literature references the PDSI's skill in indicating the physical severity of drought on the soil (Gutmann, 1998) making it useful for monitoring agricultural impacts (Hayes et al., 1999) yet the index's long-term memory has proved to be insufficient for detecting short-term severe droughts that can devastate South Carolina crops.

South Carolina decision makers have also experienced the PDSI's limitations in detecting hydrologic drought (Karl, 1986; Alley, 1984). Since the PDSI is a meteorological drought index, as the weather changes from dry or wet to near normal, the PDSI will transition back to normal despite the fact that lakes, rivers, and reservoirs may still be quite low. For example, during the record drought of 1998-2002, the PDSI value was below –3 for South Carolina climate division 3 for nine consecutive months with a value of –3.81 in September 2002. Heavy rains during September and October forced a recovery of the PDSI to near normal, 0.34, for October. The near normal PDSI classification obscured the hydrologic drought that continued for the area. Ironically, according to Karl et al. (1987), the preferred time for ending severe drought as indicated by the PDSI in South Carolina from one month of rainfall is early fall.

The spatial inconsistency of the index referenced in the literature (e.g., Wells et al., 2004; Guttman et al., 1992; Alley, 1984) is less of a problem for South Carolina since the humid, subtropical climate pattern dominates statewide from the mountains to the coast. Concerns in the literature over the spatial comparability occur more when analysis is made across different climate regimes such as semiarid compared to sub-humid and humid (Guttman et al., 1992). Efforts have been made to overcome the limitations of the original PDSI by adjusting the calculations (Wells et. al., 2004; NCDC, 1994; Heim, 2005). Fewer studies have been conducted on intrastate spatial inconsistency of the PDSI. This study will provide a detailed examination of the spatial consistency of the different severity levels for all the commonly-used drought indices in the region.

2.12 Palmer Hydrologic Index and Z index

The Palmer Hydrologic Index (PHDI) and the Z index have been used less frequently by decision-makers in the Carolinas, but the PHDI is one indicator being considered for inclusion in the FERC LIP for the Catawba-Wateree and Yadkin-Pee Dee river basins. The PHDI is used to assess longer-term moisture anomalies that affect streamflow, groundwater, and reservoir storage. The PHDI responds more slowly to changing conditions than the PDSI. Several articles outline the differences between the PHDI and PDSI (Karl, 1987; Karl, 1986; Alley, 1984). Another index introduced by

Palmer is the Z index (Palmer, 1965). The Palmer Z index is a measure of an individual month's wetness and dryness. The value of Z is regarded as the "moisture anomaly index" (Karl, 1986). The Z index can be used to show how wet or dry it was during a single month without regard to recent precipitation trends.

2.13 Crop Moisture Index

The Crop Moisture Index (CMI) measures short-term drought on a weekly scale to quantify drought's impacts on agriculture during the growing season. It was developed by Palmer (1968) from procedures within the calculation of the PDSI. The CMI responds more rapidly than the Palmer Index and can change considerably from week to week, so it is more effective in calculating short-term abnormal dryness or wetness affecting agriculture. The CMI has been extensively used by the South Carolina Drought Response Committee and is listed as a drought indicator in the South Carolina drought act regulations. It's rapid week-to-week changes, however, can be confusing for agriculture decision-makers. The CMI responds drastically from heavy rainfall events such as the change in 1998 from –4.01, or extreme drought, to –0.84, incipient drought, in one week due to tropical rains across South Carolina from tropical system Earl. While the storm's five inches of rain quickly alleviated the extreme drought conditions, according to the CMI, the true agricultural drought disaster was not relieved. Most of the rainfall ran off and the federal government classified the entire growing season as an agricultural disaster (U.S. Agriculture Secretary Disaster Declaration, 1998).

Agricultural decision makers consistently face challenges using precipitation or index data at the climate division level. Their requests to the federal government for disaster declarations are based at the county level and require climate and drought data at a similar or smaller resolution. The rainfall and drought index data often must be supplemented with radar-estimated rainfall deficits that provide the higher resolution spatial coverage (Eubanks, personal communication, 2005).

2.14 Standardized Precipitation Index

McKee et al. (1993) designed the Standardized Precipitation Index (SPI) to quantify precipitation deficits for multiple time scales (1 month SPI, 3 month SPI, etc.), realizing that droughts of different duration impact different sectors. For example, soil moisture conditions respond to precipitation anomalies on a much shorter time scale than groundwater or streamflow (Hayes et al., 1999) and therefore require different indicators, or, as is the case with the SPI, an indicator for multiple time scales. The SPI is based on precipitation alone and is basically the number of standard deviations that the observed value would deviate from the long-term mean for a normally distributed, random variable.

Several articles compare the PDSI and SPI (Gutman, 1998; Hayes et al., 1999). The SPI's multiple timescale depiction of drought is considered a primary advantage over other drought indicators. Another primary advantage of the SPI compared to the PDSI is the SPI's normal distribution. The frequency of the extreme and severe drought classifications for any location and any timescale is spatially consistent (Hayes et al., 1999; Gutman, 1998). However, this means that the SPI cannot be used as a tool to identify areas that are more prone to drought.

Steinemann et al. (2005) also illustrate that equal categorical intervals have differing probabilities of occurrence. For example, the probability difference between –1.0 and –1.5 (9.1 percent) is not the same as the probability difference between –1.5 and

–2.0 (4.4 percent). Another recent article by Wu et al. (2005) cautions that discrepancies may occur between SPI values using different historical time periods (1931-1960, 1971-2000, 1894-2000) if the gamma distributions of precipitation are different. The SPI is listed as a drought indicator in the South Carolina Drought Response Act regulations; however, the regulations do not specify which SPI time interval should be used. Traditionally, the 3-month, 6-month and 9-month SPI is presented at the South Carolina Drought Response Committee meetings.

2.15 Keetch Byram Drought Index

Keetch and Byram (1968) designed a drought index specifically for fire potential assessment. The Keetch Byram Drought Index (KBDI) is calculated based on mean annual precipitation, maximum temperature, and the last 24 hours of rainfall. The KBDI assumes soil saturation with eight inches of precipitation. At any point along the scale, 0 to 800, the index number indicates the amount of net rainfall that is required to reduce the index to zero, or saturation. Reduction in drought occurs only when rainfall exceeds 0.20 inch (Janis et al., 2002). There is a limited amount of literature discussing the advantages and disadvantages of the KBDI. Haines et al. (1976) state a primary advantage is the ease of computation that provides a continuous record that is updated daily. A disadvantage outlined by Haines et al. (1976) is that wind and humidity are major factors contributing to fire danger, but these are not included in the KBDI computation. These factors are significant in South Carolina and other parts of the Southeast.

2.16 U.S Drought Monitor

One of the newest drought monitoring tools is the U.S. Drought Monitor (DM). The DM is produced weekly by agencies within the National Oceanic and Atmospheric

Administration, the U.S. Department of Agriculture, and the National Drought Mitigation Center. Rather than an index with a set calculation, the DM is a product that incorporates quantitative indicators or weather data with input from local, state, regional, and federal experts (Svoboda et al., 2002). Svoboda et al. (2002) explain that the DM was intended to be the "Fujita" or "Saffir-Simpson" type classification system for drought. Drought magnitude is classified into five levels: D0 (abnormally dry) to D4 (exceptional drought). The DM also attempts to depict drought impact types by giving a label A, W, or F for Agriculture, Water/Hydrologic, and Fire respectively. The DM uses a percentile approach in determining the thresholds for each severity level, all data are considered with reference to their historical frequency of occurrence. While percentiles guide the product development, subjective adjustments based on local impacts are considered**.** The local adjustments are generally considered a benefit to the process; however, since the DM is not a straightforward calculation historical values can not be regenerated because the local input is not available. Only available since 1999, the DM is a rather new tool and cannot be extended back in time to make comparisons with more traditional drought indicators and to recreate values during significant historical droughts. Many leaders in drought mitigation and monitoring emphasize that decision makers should use an indicator that has a consistent long-term record or one that can be reconstructed and generated reliably in the future (Steineman et al., 2005; Keyantash and Dracup, 2002). The literature stresses the importance of testing the statistical consistency among indicators (Steinemann et al., 2005).

The DM has gained popularity among the media and state and local officials. It should be evaluated for spatial and temporal consistency before it is used as an official indicator. The short historical period (1999-2008) limits performance of these comparisons. Currently, the DM is listed as one of three triggers in the relicensing LIP for the Catawba-Wateree and Yadkin Pee Dee river basins. One goal of this research is to assist the licensee for these basins with the spatial and temporal evaluation of their proposed license-specific drought indicators and other potential drought indicators, or blends of indicators.

2.17 Streamflow, Reservoir, Groundwater Levels

Hydrologic indicators of drought are typically reservoir storage, streamflow levels, and groundwater supply. Reservoir storage elevations are generally easy to measure, but operating curves may complicate assessment of drought conditions (Wilhite et al., 2005). Another drawback in using reservoir levels is lack of data and shorter records. A mechanism to quantify reservoir storage, however, is a typical indicator for local-level drought planning and is the primary indicator for the hydroelectric LIPs for the Catawba-Wateree and Yadkin-Pee Dee river basins.

Streamflow is also often used as a drought indicator. Dracup et al. (1980) suggest streamflow can be related to the total moisture of a basin since it is a function of soil moisture, groundwater levels, runoff, and precipitation. Streamflow measurements, however, have various limitations. Base flow or mean flow over some period (e.g., 14-day, monthly) should be used to average out runoff crests (Dracup et al., 1980; Heim, 2002). Small streams may respond more quickly to short periods of dryness or heavy downpours, large streams may react more slowly to the onset of drought, and streamflow can be strongly influenced by basin characteristics and manmade development.

The U.S. Geological Survey, in cooperation with other agencies, operates and maintains a network of stream gages across each state. In addition to the challenges of using weather station point data for spatial interpolation, further limitations arise in using streamflow data from a point location to represent the entire drainage basin. The point data from two different streams cannot be extrapolated like weather station data across counties because of the variation in basin characteristics. It is common practice, however, to assume the point data can represent drought conditions upstream from the station. The major assumption is that the runoff measured at the streamflow-gaging station is the result of basin-wide conditions.

Groundwater is particularly important for some public water supply systems in the Coastal Plain. The City of Sumter is the largest public water system in South Carolina that relies solely on groundwater (*South Carolina State Water Plan, 2004*). The South Carolina Drought Response Act supporting regulations list streamflow and aquifer levels as drought indicators (Table 3.1). Aquifer elevation or groundwater drawdown can be a useful drought indicator, but is usually limited by a poor understanding of the aquifer stratigraphy, recharge rates, and other factors that may influence the levels, such as agricultural, municipal, and industrial pumping. Static water levels in wells are a primary drought indicator by public water systems that depend on groundwater. There has been significant opposition to the use of groundwater as a drought indicator across South Carolina although it is important to individual systems. The argument is that the decline in water levels in confined aquifers can be a result of pumping and long-term groundwater withdrawals, rather than drought, making this a potentially misleading indicator in some locations.

Groundwater levels are usually the slowest to respond to drought, generally following soil moisture and streams decline. Groundwater levels are also the slowest to recover from drought. Deep groundwater is recharged from the shallow aquifers, which act as reservoirs from which groundwater can percolate slowly downward. As a result, they are buffered from short-term droughts and only show an effect during extended dry periods. During the record drought of 1998-2002 and again in 2007-2008, groundwater levels in shallow and deep aquifers across the Carolinas dropped to record lows. Pumps in municipal and domestic wells had to be lowered, wells had to be deepened, and in some instances, new wells had to be drilled. Gellici et al. (2004) documents the historical decline in streamflow to new record lows during late summer 2002. Downstream flows also measured lower than upstream flows, the reverse of what normally occurs in these streams. Without interference from water withdrawers, this phenomenon can be only interpreted that the streams were losing flow to the lower groundwater table (Badr, A.W., personal communication, 2008). The impact of the 1998-2002 drought on groundwater levels alleviated some of the opposition in South Carolina to using groundwater as a drought indicator. Duke Energy has listed groundwater levels as indicators for recovery out of their FERC LIP drought stages on the Catawba-Wateree river basin.

2.2 Evolution of State and Federal Drought Management

Interest in drought planning has increased over the past 30 years. Like many states, the evolution of South Carolina's drought planning has occurred through trial and error in response to increasing drought impacts. The incorporation of drought planning in the Federal Energy Regulatory Commission's hydropower relicensing over the past decade has resulted in additional improvements to the State's drought response.

2.21 History of S.C. Drought and the Progression of S.C. Drought Management

Historically, droughts have had severe, adverse impacts on the people and economy of South Carolina. Drought impacts are diverse, causing a ripple effect through the economy (Wilhite, 1993). Periods of dry weather have occurred in each decade since 1818 (National Water Summary 1988-1989 Hydrologic Events and Floods and Droughts, 1991). The earliest records of drought indicate that some streams in South Carolina went dry in 1818, and fish in smaller streams died from lack of water in 1848. The most damaging droughts in recent history occurred in 1954[1], 1986[1], 1998-2002[2], and 2007-2008[3] (National Water Summary 1988-1989 Hydrologic Events and Floods and Droughts, 1991[1]; Gellici et al., 2004[2]; South Carolina Department of Natural Resources On-line Archived Drought Status, 2008[3]). Less severe droughts were reported in 1988[1], 1990[2], 1993[2], and 1995[2] (National Water Summary 1988-1989 Hydrologic Events and Floods and Droughts, 1991[1]; South Carolina Climate, 2003[2]).

Adverse impacts to the people and economy were made especially clear during the droughts of 1998-2002 and 2007-2008 that affected agriculture, forestry, tourism, power generation, public water supply, and fisheries. The economic costs associated with these droughts will likely surpass any other drought in South Carolina's history (de Kozlowski, S., personal communication, 2008). During the past 50 years, droughts have caused South Carolina's third highest economic loss resulting from a natural hazard, surpassed only by Hurricane Hugo and flooding (*South Carolina State Hazard Mitigation Plan, 2004*).

The state began to examine drought impacts and occurrences in 1978 while most of the United States was experiencing severe drought conditions (Rouse et al., 1985).

Several plans and laws have been considered and/or established to monitor, manage, and conserve the state's water resources during drought periods in the best interest of all South Carolinians. South Carolina recognized the need to formalize a drought plan by passing the South Carolina Drought Response Act in 1985. South Carolina is unique in dealing with drought management through legislation and its associated regulations (Knutson and Hayes, 2001).

South Carolina's drought response differs from that of other southeastern states, owing primarily to the creation and existence of the Drought Response Act. Like many other states, South Carolina has a Drought Response Plan and a State Water Plan. While the plans consist of detailed actions and responses, they are only recommendations and not actual, enforceable laws. Through experience, South Carolina's decision makers learned that when dealing with an issue as controversial as restricting water use, it is necessary to have legislation with mandated actions.

In 1985, South Carolina's first drought law was adopted. This act was amended in 2000 to implement guidelines set forth in the 1998 State Water Plan. These guidelines included using multiple indicators to trigger drought response, adjusting drought management areas to correspond with the State's four major river basins, restructuring local drought committees, and clarifying existing procedures to identify and address water shortages. Since the record drought of 1998-2002 the S.C. Department of Natural Resources (SCDNR) revised the *State Water Plan* (2004), publishing a second edition that reflects the lessons learned during the drought. The Drought Response Act has yet to be amended and brought in line with recommendations in the revised State Water Plan. Other possible amendments may address policy shortfalls witnessed during the 1998-

2002 and 2007-2008 drought. One of the act's major shortfalls is the lack of regulation requiring private water systems, power generating facilities, and industries to develop drought plans. The current regulation requires the development and implementation of drought ordinances and plans by public water systems only.

South Carolina's drought law addresses a limited set of possible actions. During the original creation of the law and the amendment process, organizations and agencies lobbied against sections of the act restricting to their operations. For instance, agriculture-related groups believe that agriculture should be considered an essential water user and, therefore, should not be subject to water-use curtailment. Their argument is based on people's need for food to survive, thus making agriculture essential. The legislature agreed in 2000 that agriculture could not be excluded from the jurisdiction of the drought law, however, due to increased pressure from the agriculture community the law was revised in 2005. This amendment was opposed by representatives of water systems based on the argument that every sector could argue that it is an essential user of water - such as the need for power generation facilities. The surprising, unanimous vote from the S.C. General Assembly in favor of less stringent requirements on agriculture is some indication of the consistent political power of the agricultural community despite the limited number of farmers and acres under cultivation in the state. In other states, such as Georgia, the agriculture industry has successfully lobbied for programs that pay farmers not to irrigate during drought and that establish stronger incentives for private investment in water conservation.

The S.C. Department of Health and Environmental Control (SCDHEC), S.C. Chapter of the American Water Works Association (SCAWWA), and industrial representatives opposed several amendments that were included in the 2000 S.C. Drought Response Act, but a comprise was finally reached. SCDHEC is responsible for enforcing federal and state environmental laws and regulations, and for issuing permits, licenses, and certifications for activities that may affect the environment. Their primary concern was the possible conflict between their Groundwater Use and Reporting Act and the Drought Response Act. They wanted to exclude the use of declining water levels in confined aquifers as an indicator of drought because such declines can result from pumping and long-term groundwater withdrawals, not drought. SCAWWA represents public water supply systems in the state. Their concern was with the overall authority of the original Drought Response Act. Businesses may lose revenue when a drought declaration is made by the state on a regional basis, placing mandatory water restrictions on users and water system operators who have stored water for such shortfalls.

The S.C. General Assembly, like other policy makers, faces the challenge of managing natural resources for multiple benefits. This challenge includes considering the implications of their decisions on several economic sectors. In trying to reduce risk and arrive at optimal decisions, policy makers often depend on science to shape and support the policy. During the 2000 amendment process, the SCDNR was able to answer the questions and concerns of the S.C. General Assembly and other interested groups by justifying the amendments to the drought policy with scientific documentation.

The documentation was based on multidisciplinary research by a team consisting of climatologists, hydrologists, and soil scientists. Science incorporating different disciplines usually provides diverse forms of data and perspectives (Mizzell and Lakshmi, 2004). An integration of the diverse information into products that explicitly considered the factors relevant to the drought policy and that were discernible by the General Assembly guided the process. It also required cooperation and open communication between the scientists and the policy makers. The S.C. General Assembly would not have approved the amendments to the Drought Act (owing to the controversial nature of droughts and water rights) without the provided scientific documentation coupled with the state's ongoing severe drought. Stakeholders, policy-makers, and state government will face these challenges again as more changes to the Drought Act are needed.

2.22 Local Drought Response Ordinances and Plans

The passage of the South Carolina Drought Response Act of 2000 provided the opportunity to implement a new model drought mitigation plan and response ordinance for public water systems. The Act requires that all municipalities, counties, public service districts, special purpose districts, and commissions of public works engaged in the business or activity of supplying water for any purpose, develop, and implement drought response ordinances or plans. The ordinances and plans must be consistent with the State Drought Response Plan.

The State Drought Response Plan includes a model water system ordinance and plan. In order to support implementation, the models were developed by the SCDNR, SCDHEC, and the S.C. Water Utility Council (SCWUC). SCWUC is composed of the state's most proactive water systems. These groups worked together to ensure that the model not only represented the best interests of the state, but also was applicable for water system management. Regulatory policies that are developed without the input of the primary stakeholder lead to distrust and opposition to the overall process. Including the SCWUC made it easier to convince the water systems that developing the drought plan and response ordinance was a legitimate and necessary task and not just another policy imposed by bureaucrats who have no experience in operating a water system.

The model consists of a section devoted to drought planning and a section outlining the ordinance requirements. The Drought Management Plan requires the designation of a water system drought response representative; description of the water system layout, water sources, capacities, and yields; identification of water system - specific drought or water shortage indicators; documentation of cooperative agreements and alternative water supply sources; description of pre-drought planning efforts; and a description of capital planning and investment for system reliability and demand forecasting. The Drought Response Ordinance outlines the actions to be taken at each level of drought (moderate, severe, and extreme), the requirements for rationing, the enforcement of restrictions, and the process of requesting a variance.

2.23 Federal Drought Response

In 1998, the U.S. Congress passed the National Drought Policy Act, recommending that the nation would benefit from a national drought policy based on preparedness and mitigation to reduce the need for emergency relief (Motha, 2000). The National Drought Preparedness Act of 2003 was introduced in both the U.S. House and Senate to develop a comprehensive national drought policy that statutorily authorizes a lead federal agency for drought and delineates the roles and responsibilities for coordinating and integrating federal assistance for droughts. In 2006, the National Integrated Drought Information System Act (NIDIS) (Western Governors' Association, 2004) was introduced by the U.S. Congress and signed by the President. A goal of

NIDIS is to foster and support coordination to ensure the most effective drought research efforts to benefit decision makers and NIDIS users. This project implements the federal initiatives calling for cohesive and collaborative interactions at national, regional, and local levels.

2.24 Federal Energy Regulatory Commission Licenses

The Federal Power Act gives the Federal Energy Regulatory Commission (FERC) the exclusive authority to issue licenses to construct, operate, and maintain certain non-federal hydropower projects. The FERC regulates hydroelectric power projects under other statutes including the Public Utility Regulatory Policies Act, Electric Consumers Protection Act of 1986, and the Energy Policy Act of 1992. The FERC licenses more than 1,700 non-federal public dams used for hydroelectric power generation with dams located in 44 states and in Puerto Rico. Twenty-five percent of the licenses are up for renewal before 2020 (http://www.ferc.gov/industries/hydropower/gen-info/licensing.asp).

The license process has changed over the past 50 years with emphasis shifting away from a license focused solely on generating electricity from hydropower to a balance between producing electricity and its impact on the environment. The relicensing process addresses not only the generation of electricity, but also the natural resources that may be affected by a project's operation. With 200 dams or projects up for renewal over the next 15 years, four in South Carolina alone (Catawba-Wateree, Yadkin-Pee Dee, Saluda, and Keowee), resource agencies and conservation groups have a once-in-a-lifetime opportunity to work with hydropower operators to slow shoreline development, improve fish habitat, enhance river recreation, and enhance management plans that will shape the river management for the next 30 to 50 years.

During the height of the 1998-2002 drought, FERC initiated drought management workshops to exchange information on drought and discuss FERC hydropower responses to drought conditions. In 2002, the first workshop was held in Atlanta, Georgia and targeted licensee and stakeholders in the Southeast who were suffering from the multi-year, severe drought. The goals of the workshops were to gain a better understanding of drought indicators that may be useful to implement earlier responses to drought conditions involving FERC hydropower projects and to identify ways to improve and maintain coordination and cooperation among licensees, agencies, stakeholders, and FERC during drought events. The workshop was an important step toward the recognition of drought mitigation during this federal-mandated process. This is another example of the shift in the license process that began in the early 1980s to better balance relicensing hydropower to produce electricity with environmental interests.

The evolution of the drought plans, or LIPs, in the Yadkin-Pee Dee and Catawba-Wateree river basins demonstrates the need to create an LIP that has "diagnostic accuracy of the trigger points and the effectiveness with which the licensee and the water users work together to implement their required actions." Duke Energy, the licensee in the Catawba-Wateree river basin, and the state resource agencies realized the indicators and trigger points must be determined scientifically and evaluated historically. Duke Energy provided funding to the State Climate Offices of South Carolina and North Carolina to assist in the identification of appropriate triggers through development of an online Dynamic Drought Index Tool (DDIT) (Carbone et al., 2008) and research components from this research that evaluate the indicators and methodology used to create a higher resolution drought indicator database based on percentiles rather than raw index values.

In order to ensure continuous improvement regarding the LIP and its implementation throughout the term of the new license, the Catawba-Wateree Drought Management Advisory Group (CWDMAG) will conduct periodic re-evaluations and modifications. The DMAG will use research findings and experience with the 2006-2008 drought to determine whether adjustments to the drought indicators currently listed in the license are needed. The re-evaluations provide some flexibility for changes during the 30- to 50- year duration of the license.

In summary, the process of planning for drought has evolved at all levels over the past few decades. Increasing drought impacts and concerns for future water availability presents new challenges for stakeholders and policy-makers. In South Carolina, amendments to the S.C. Drought Response Act in 2000, increase in local drought planning, and the relicensing of several hydro-power projects has resulted in significant improvements to the State's drought response. Despite this, detecting drought and its impacts continues to present a daunting task. Single indicators often prove to be inadequate in detecting the onset, duration and recovery from drought especially for diverse sectors. Additional challenges occur when users combine multiple indicators in drought management plans without understanding the spatial and temporal consistency and the direct relevance of the indicators in meeting their needs.

CHAPTER 3 EVALUATION OF STATE DROUGHT INDICATORS

While South Carolina's drought response program is proactive in having state and local level drought indicators, many are being developed without scientific justification. One of this dissertation's goals is to determine whether statistical inconsistencies exist among state-defined drought indicators and categories. The S.C. Drought Response Committee relies primarily on seven drought indicators defined in the S.C. Drought Response Act's supporting regulations (Table 3.1) to declare four levels of drought: incipient, moderate, severe, and extreme. South Carolina uses seven indicators because droughts can be characterized in many different ways (Wilhite and Glantz, 1985) and no single indicator serves as an adequate national standard to characterize drought. The seven indicators were selected to detect drought severity at varying time scales and to characterize drought for different sectors. The Crop Moisture Index, for example, is used to detect short-term drought periods that impact soil moisture for agriculture. The Crop Moisture Index would not be a useful indicator for detecting hydrologic droughts, which usually occur on a longer time-scale.

Inconsistencies in the frequency of drought occurrence as determined by each indicator cause confusion for the S.C. Drought Response Committee and all water users. This analysis will compare the frequencies of drought events that fall into each drought level for each indicator in Table 3.1. If the indicators are consistent they should have similar frequencies. This evaluation will compare statistical properties of probability distributions using the two-way chi-square test.

Table 3.1 State level indicators designated by regulation.

Drought Indicator	Incipient	Moderate	Severe	Extreme
PDSI[1]	-0.50 to -1.49	-1.50 to -2.99	-3.00 to –3.99	< -4.00
SPI[2]	0.00 to -0.99	-1.00 to -1.49	-1.50 to –1.99	< -2.00
DM[3]	DO	D1	D2	D3
CMI[4]	0.00 to -1.49	-1.50 to -2.99	-3.00 to –3.99	< -4.00
KBDI[5]	300 to 399	400 to 499	500 to 699	> 700
Streamflow	Average daily streamflow 111%-120% of the 5% monthly flow for 2 consecutive weeks	Average daily streamflow 101%-110% of the 5% monthly flow for 2 consecutive weeks	Average daily streamflow is between 5% monthly flow and 90% of the 5% monthly flow for 2 consecutive weeks	Average daily streamflow less than 90% of the 5% monthly flow for 2 consecutive weeks
Groundwater	Groundwater levels from the surface are between the 80% to 90% range	Groundwater levels from the surface are between the 90% to 95% range	Groundwater levels from the surface are between the 95% to 98% range	Groundwater levels from the surface are between the 98% to 100% range

[1]PDSI =Palmer Drought Severity Index, [2]SPI=Standard Precipitation Index,
[3]DM=U.S. Drought Monitor, [4]CMI=Crop Moisture Index,
[5]KBDI=Keetch Byram Drought Index.

3.1 Data and Methodology

The data source for this analysis is the Carolinas Dynamic Drought Index Tool (DDIT) (Carbone et al., 2008; Rhee, 2007). This drought monitoring tool was developed to improve drought monitoring in the Carolinas by providing a single application to access drought indicators at a higher resolution. Users may select raw indicator values or percentile occurrence. Using the percentiles, the user may also weight multiple indices to create a blended index. The DDIT computes monthly Palmer Drought Severity Index (PDSI), Palmer Hydrologic Index (PHDI), Palmer Z index (Z Index), Standardized Precipitation Index (SPI 1-, 3-, 6-, 9-, 12-month) and precipitation totals (1-, 3, 6-, 12-, 24-, 60-month) for over 200 weather stations in the Carolinas. The Crop Moisture Index data are computed weekly and the Keetch-Byram Forest Fire Drought Index is computed daily. The DDIT also provides streamflow averages (7-day,14-day, 1-month, 3-month, 6-month, 24-month) at U.S Geological Society (USGS) gage locations in the region. Only stations and gages with over 30 years of data and less than 20 percent missing data were included. The data are interpolated to a 4-kilometer grid using inverse distance weighting at a 4-kilometer resolution for the period 1950-2008. Since the indices are computed for point locations and then interpolated to a grid, the index values can be spatially aggregated based on the user specifications, such as by county or hydrologic units. The DDIT also gives the user the ability to transform all indicators to a scale based on percentiles, which will be evaluated in Chapter 4. The interpolated database of raw indicator values and percentiles can be retrieved through a graphical user interface.

For the state indicator analysis, the DDIT application was used to extract drought indicator data at the county and basin scale for the period 1951-2008. The application will also be used to evaluate indicators expressed as percentiles. Other data sources, such as indicator data received from Duke Power, Alcoa Yadkin and Progress Energy, and the City of Rock Hill, are described specifically within methodologies in Chapter 4.

Percent frequency distributions of each state drought indicator used by the S.C. Drought Response Committee (Table 3.1) were calculated using data retrieved from the

DDIT and U.S Drought Monitor (http://www.drought.unl.edu/dm/about.html). The S.C. Drought Response Act's supporting regulations do not define corresponding levels of wetness; however, equivalent thresholds for wet periods are defined elsewhere and are provided for some indicators in order to show the full distribution of the data. For example, extreme droughts are defined by the PDSI when values are less than –4. Extreme wet periods for the PDSI were defined when values were greater than +4. Frequency distributions for the "wet periods" were not defined for the KBDI, streamflow, and groundwater.

The data were analyzed for 660 months included in the period 1951-2005 for the PDSI, 1-month SPI, 3-month SPI, 6-month SPI, 9-month SPI, and 12- month SPI. Evaluation also included the 2,860 weekly data values for the period 1951-2005 for the CMI and the 20,089 daily values of the KBDI. The highest DM drought level for each county was extracted from a database provided by the National Drought Mitigation Center for 312 weekly values for the period 2000 – 2005.

The interpolated indicator data were spatially averaged by county for all variables, excluding streamflow and groundwater. Streamflow- and groundwater- drought levels are based on percent frequency of occurrence and therefore are consistent spatially. Three counties, Oconee, Florence, and Charleston, were selected for analysis to represent different geographic regions in South Carolina. The S.C. Drought Response Committee does not use the groundwater declaration thresholds defined by the S.C. Drought Response Act's supporting regulations. The regulations define groundwater threshold based on static water levels in the aquifer compared to the predevelopment level of an aquifer for two consecutive months. The Committee uses general USGS groundwater duration plots and data. The groundwater ranges for each drought level, defined in Table 3.1 are also based on percent frequency of occurrence and are consistent between spatial units.

The chi-square test was selected for the statistical analysis since it is a nonparametric test commonly used to examine differences between categorical variables. For this analysis, the chi-square test is used to estimate the independence of the drought indicators categorized by drought occurrence (extreme/severe, moderate, incipient, and normal). Chi-square must be calculated on actual count data, not substituting percentages, so frequency of occurrence was analyzed. The test is not valid for small samples (general rule is fewer than five), so the extreme and severe categories were combined. Adjustments were made to the weekly CMI values and daily KBDI values to express them as monthly equivalent values. The DM frequency of occurrence for 2000 – 2005 was extrapolated to represent drought frequencies for the period from 1951-2008. However, the values are not representative of drought conditions throughout the period of record since severe drought was common from 2000-2005. The null hypothesis for the chi-square test is that no difference exists between the indicators. The degrees of freedom are df=(# of rows - 1)(# of columns - 1) or df= (4-1)(2-1)= 3. Based on the confidence level 0.05, the critical value is 7.82. These results must be considered within the independence assumption of the chi-square test. While each drought index is calculated uniquely, several rely on similar underlying data.

3.2 State Indicator Results

The percent frequencies for state drought indicators in Oconee County are displayed in Table 3.2. Figures 3.1 a-e displays the frequency plots of the indicators showing inconsistencies between the occurrence frequency for most stages of drought. The occurrences of drought based on the SPI indicators (3-month, 6- month, 9-month and 12- month) are generally consistent as expected based on the standardized computation that is normalized with respect to location and in time (Mckee et al., 1993). The inconsistencies between most indicators are greatest from the moderate drought level to the moderate wet level and less for severe and extreme drought and wet categories, except for the CMI and streamflow. The CMI and streamflow are most inconsistent with the other indicators at the severe and extreme levels.

The DM will be discussed separately from all other indicators due to its significant inconsistencies for all drought levels. These inconsistencies may be attributed to the shorter duration of analysis from 2000-2005 when most of South Carolina experienced some level of drought for extended periods of time.

The frequency of occurrence in extreme drought is consistent between all indicators (0.76 percent to 2 percent) except the CMI (0 percent), KBDI (0.05 percent), and streamflow (4.49 percent). Based on the range of levels defined in the S.C. Drought Response Act’s supporting regulations for streamflow, extreme drought will occur more often than severe, moderate, or incipient droughts. For example, extreme drought occurs anytime the flows are 90 percent of the 5 percent monthly flow or less which would be a 4.49 percent occurrence. Severe drought occurs anytime the flows are between the 5 percent monthly flow and 90 percent of the 5 percent monthly flow, which would only be a 0.45 percent occurrence. For all other indicators, extreme drought occurs the least often, as expected based on the highest severity level and defined ranges. The frequency of severe droughts (2.27 percent to 5.15 percent) is consistent among all indicators except for CMI and streamflow (0.17 percent and 0.45 percent). The frequency of moderate droughts is consistent between the SPI indicators (7.58 percent to 10.78 percent) and KBDI (7.28 percent). The frequency of moderate droughts based on the PDSI is much higher with a 19.24 percent occurrence. Moderate droughts occur less often based on the KBDI (5 percent), CMI (2 percent), and streamflow (0.45 percent). Incipient drought occurrence is consistent between the CMI (11.82 percent), KBDI (11.06 percent), and groundwater (10 percent). The SPI indicators are relatively consistent among each other (33.03 percent to 37.42 percent), however, incipient droughts occur 4.39 percent more often using the 1-month SPI than the 12-month SPI. This is equivalent to 29 more months in incipient drought. Based on the PDSI, incipient drought occurs 16.97 percent while based on streamflow only 0.45 percent.

The DM is generally not consistent with other indicators for each level of drought; however, it has only been in existence since 2000. It was in the early stages of development in late 1999 so these data were not incorporated. For the period analyzed, 2000-2005, South Carolina experienced extended periods of severe and extreme droughts. The DM frequency analysis indicates the highest occurrence of extreme droughts for all indicators (13.78 percent). Severe and moderate droughts each occurred 17.95 percent. Incipient droughts occurred 7.05 percent.

Table 3.2 Percent frequencies for state drought indicators in Oconee County, SC.

Drought Level	DM[1] 313 Weekly Values %	KBDI[2] 20,089 Daily Values %	Streamflow (Based on predefined percentiles %)	Groundwater (Based on predefined percentiles %)
Extreme Drought	13.78	0.05	4.49	2.00
Severe Drought	17.95	3.90	0.45	3.00
Moderate Drought	17.95	7.28	0.45	5.00
Incipient Drought	7.05	11.06	0.45	10.00
No Drought	43.27	77.70	94.16	80.00

Drought Level	PDSI[3]	SPI1[4]	SPI3[4]	SPI6[4]	SPI9[4]	SPI12[4]	CMI[5]
	660 Monthly Values %						2,860 Weekly Values %
Extreme Drought	0.76	1.21	1.06	1.67	1.52	0.76	0.00
Severe Drought	5.15	3.64	3.18	2.27	3.48	4.70	0.17
Moderate Drought	19.24	7.58	9.85	10.76	9.39	8.33	2.06
Incipient Drought	16.97	37.42	36.67	35.45	33.03	33.64	11.82
Normal	18.48	0.00	0.00	0.00	0.00	0.00	0.00
Incipient Wet	20.15	36.67	35.00	35.76	39.09	39.24	41.67
Moderate Wet	16.36	9.24	8.94	10.00	9.70	9.39	29.90
Severe Wet	2.73	3.18	4.85	3.94	3.03	3.33	8.67
Extreme Wet	0.15	1.06	0.45	0.15	0.76	0.61	5.70

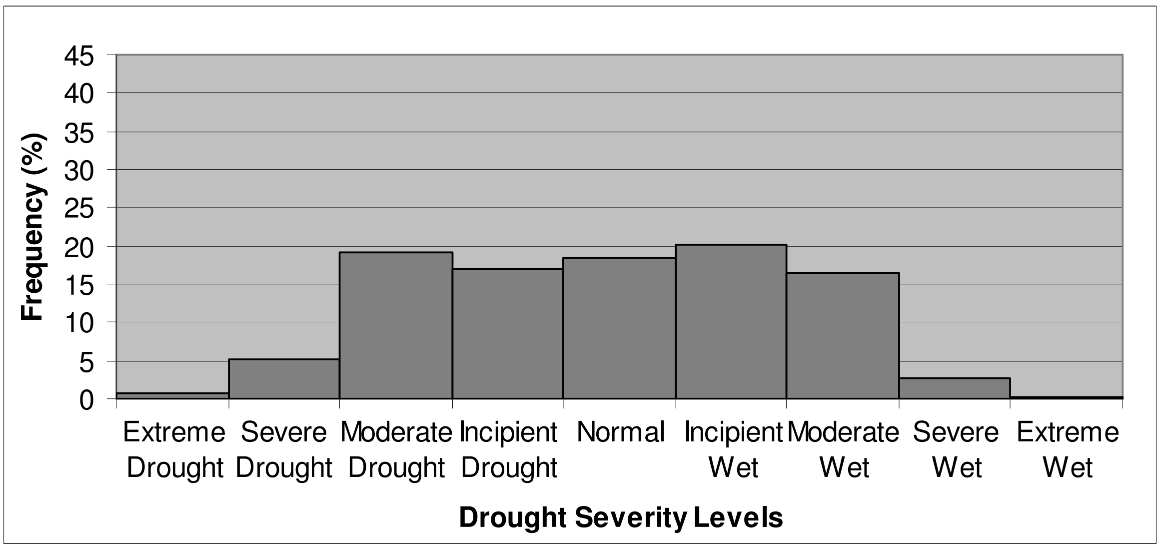
[1]DM=U.S. Drought Monitor
[2]KBDI=Keetch Byram Drought Index
[3]PDSI =Palmer Drought Severity Index
[4]SPI=Standard Precipitation Index (1-, 3-, 6-, 9-, 12-month)
[5]CMI=Crop Moisture Index

Figures 3.1 a-e graphically display the frequency distribution based on the defined ranges for each indicator in the S.C. Drought Response Act regulations. The graphs show the variable distributions. For SPI, CMI and streamflow, the variation is in part due to the range of drought categories specified in the regulations. However, for variables such as the PDSI, literature demonstrates that the time series distribution is skewed (Wells et al., 2004). The SPI time-series indicators should be normally distributed because of calculation.

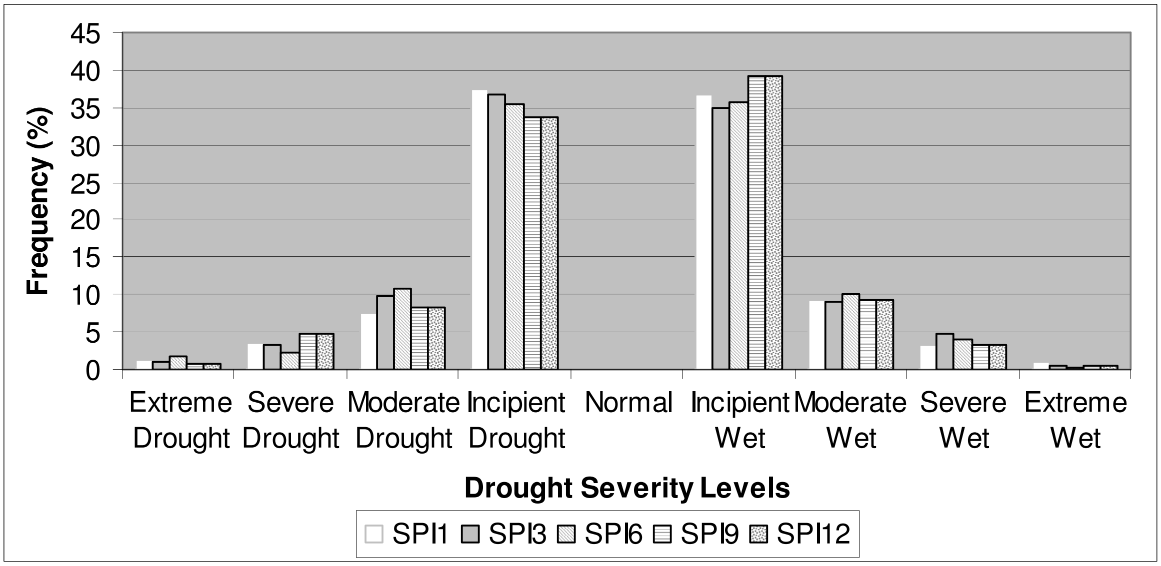
Figure 3.1a shows the frequency distribution of the PDSI. The distribution of the data ranges from 16 percent to 20 percent for moderate droughts, incipient drought, normal, incipient wet periods, and moderate wet periods. Severe and extreme drought and wet periods occur less than 5 percent. Figure 3.1b provides the frequency distribution of the 1-month SPI, 3-month SPI, 6-month SPI, 9-month SPI, and 12-month SPI. The SPI indicators are relatively consistent for all drought levels, with the largest difference, 4.39 percent, between SPI-1month and SPI-12 month during incipient droughts. Since the SC Drought Response Act designates that incipient drought begins at 0.00 for the SPI and CMI, there is no range for normal conditions assuming the same range of values is implied for wet periods. Figure 3.1c displays the Crop Moisture Index frequency distribution, which has the second lowest occurrence of drought, 14.06 percent, of all indicators. This is due to the index computation, which is focused on detecting drought severity during the growing season months and automatically returns to normal conditions during the winter months with or without rainfall. Streamflow has the lowest occurrence of all drought levels combined, 5.84 percent, due to the specified ranges in the S.C. Drought Response Act regulations (Figure 3.1d). Figure 3.1d also displays the frequency distribution of the KBDI and groundwater. The occurrence of all levels of drought based on groundwater is 20 percent. The KBDI indicates drought 22.3

percent of the time. The DM frequency distribution (Figure 3.1e) shows some level of drought, 56.73 percent, with the highest occurrence of extreme and severe droughts, 13.78 percent and 17.95 percent, respectively.

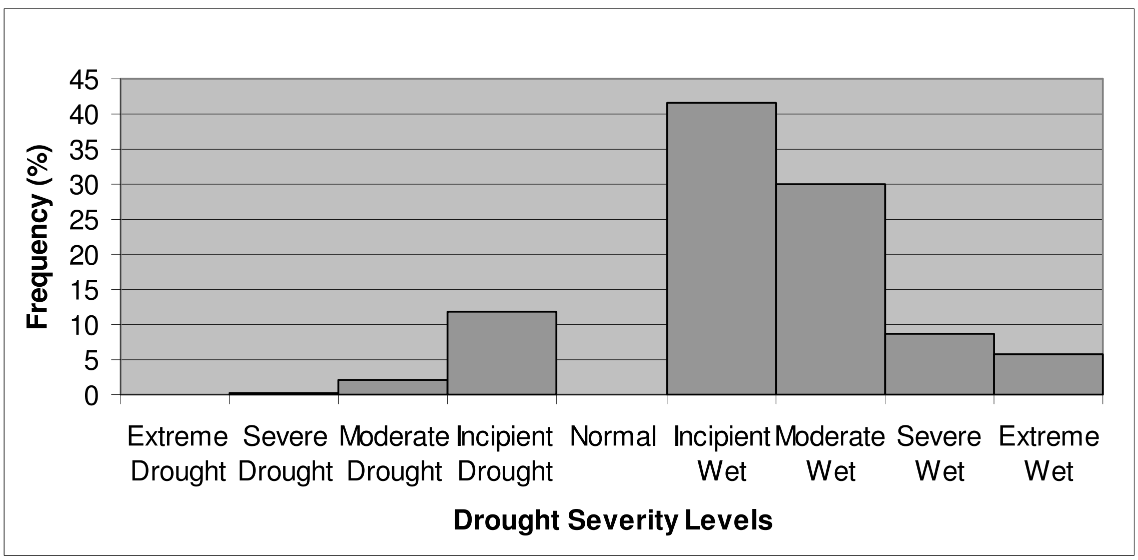
Figures 3.1 Percent frequencies for drought and wet severity levels (a) Palmer Drought Severity Index, (b) Standardized Precipitation Index (1-, 3-, 6-, 9-, 12-month), (c) Crop Moisture Index, (d) streamflow, groundwater, Keetch Byram Drought Index, (e) U.S. Drought Monitor.



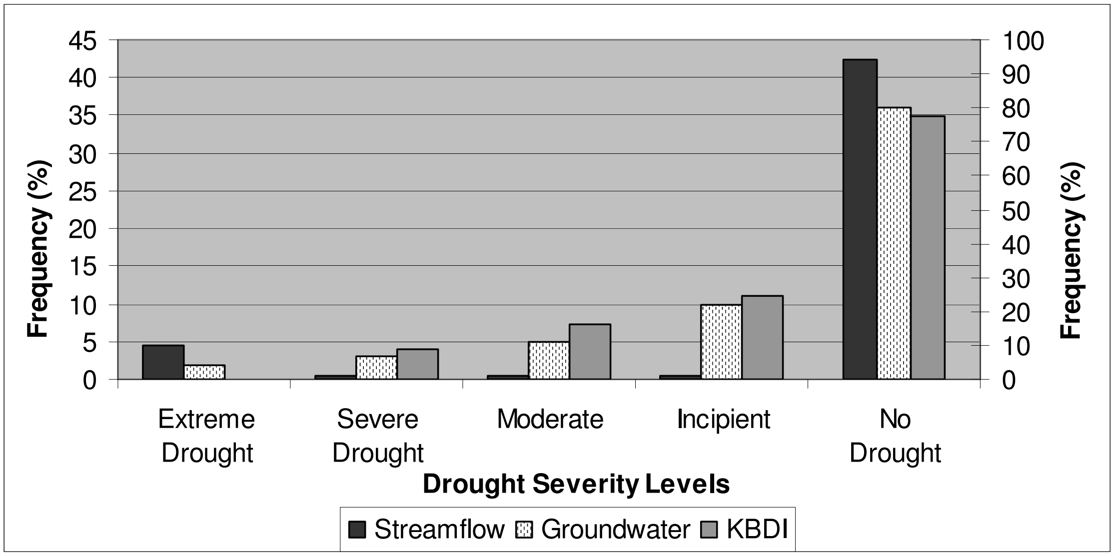
(a) Palmer Drought Severity Index



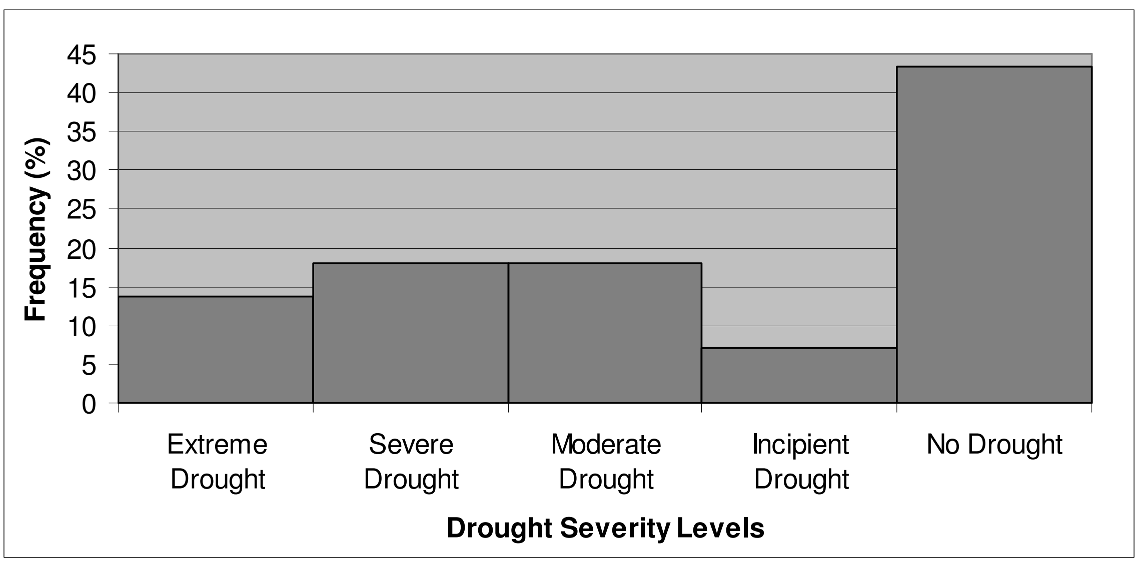
(b) Standardized Precipitation Index (1-, 3-, 6-, 9-, 12-month)



(c) Crop Moisture Index



(d) Streamflow, Groundwater (secondary y-axis),
Keetch Byram Drought Index (secondary y-axis)



(e) U.S. Drought Monitor

The comparison of the drought level occurrence data for Charleston (Table 3.3) and Florence (Table 3.4) illustrates that the county indicator differences were not unique to Oconee County. For example, the DM has the largest percent frequency of extreme drought of all indicators (13.78 percent for Oconee, 12.46 percent for Florence, 9.9 percent for Charleston), which is inconsistent with all other indicators reaching extreme drought less than 2 percent of the time. Streamflow has the second highest percent frequency of extreme drought, 4.49 percent. The Crop Moisture Index never reached extreme drought. The SPI indicators continued to show consistency among each other.

The primary goal of the county comparison was to ensure that indicator comparison results were not unique to one county or geographic region in the State. This was confirmed, but the analysis also revealed significant differences when comparing the same indicator for each county. Table 3.5 shows results from the chi-square test of the relationship between the three counties for each indicator. Since the chi-square test cannot be computed on percent data, actual frequencies of occurrence were compared. Adjustments were made to the weekly and daily data and the shorter DM data (discussed above). The statistically significant differences occurred primarily between the indicators for Charleston and Florence compared to Oconee. The differences between the PDSI, SPI-9, SPI-12, DM, and KBDI were all statistically significant when comparing Charleston to Oconee and Florence to Oconee. The differences between the indicators comparing Charleston to Florence were not statistically significant except for the CMI. The indicator data for streamflow and groundwater were equal due to the range, as based on percentiles defined in the S.C. Drought Response Act's regulations.

While the comparison was limited to three counties it does support the need for additional research to better understand the spatial variation of drought across the State. Most importantly, it demonstrates that the same indicator can vary spatially resulting in additional challenges for decision-makers. An indicator may provide different detection of drought for different regions of the State.

Table 3.3 Percent frequencies for state drought indicators in Charleston County, SC.

Drought Level	DM[1]	KBDI[2]	Streamflow	Groundwater
	313 Weekly Values	20,089 Daily Values	Based on predefined percentiles	
Extreme Drought	9.90	0.00	4.49	2.00
Severe Drought	7.35	1.95	0.45	3.00
Moderate Drought	8.95	7.78	0.45	5.00
Incipient Drought	24.92	16.70	0.45	10.00
No Drought	48.88	73.58	94.16	80.00

Drought Level	PDSI[3]	SPI1[4]	SPI3[4]	SPI6[4]	SPI9[4]	SPI12[4]	CMI[5]
	660 Monthly Values						2,860 Weekly Values
Extreme Drought	0.45	0.76	0.91	0.76	1.52	1.36	0.00
Severe Drought	3.48	2.88	3.48	3.33	3.18	3.18	0.14
Moderate Drought	22.12	9.09	8.64	8.03	5.61	5.91	2.48
Incipient Drought	22.73	37.73	36.67	40.91	43.44	43.33	19.69
Normal	16.52	0.00	0.00	0.00	0.00	0.00	0.00
Incipient Wet	16.21	36.97	38.18	35.30	33.64	33.33	52.41
Moderate Wet	13.94	7.73	7.88	7.12	8.79	7.58	19.41
Severe Wet	3.33	3.94	3.48	3.79	3.48	5.15	3.88
Extreme Wet	1.21	0.91	0.76	0.76	0.45	0.15	1.99

[1]DM=U.S. Drought Monitor
[2]KBDI=Keetch Byram Drought Index
[3]PDSI =Palmer Drought Severity Index
[4]SPI=Standard Precipitation Index (1-, 3-, 6-, 9-, 12-month)
[5]CMI=Crop Moisture Index

Table 3.4 Percent frequencies for state drought indicators in Florence County, SC.

Drought Level	USDM[1] 313 Weekly Values	KBDI[2] 20,089 Daily Values	Streamflow	Groundwater
			Based on predefined percentiles	
Extreme Drought	12.46	0.00	4.49	2.00
Severe Drought	4.49	3.39	0.45	3.00
Moderate Drought	9.57	8.62	0.45	5.00
Incipient Drought	28.75	17.11	0.45	10.00
No Drought	44.73	70.87	94.16	80.00

Drought Level	PDSI[3]	SPI1[4]	SPI3[4]	SPI6[4]	SPI9[4]	SPI12[4]	CMI[5]
	660 Monthly Values						2,860 Weekly Values
Extreme Drought	1.06	1.06	0.76	0.80	1.06	0.76	0.00
Severe Drought	1.97	2.42	3.33	3.20	3.18	2.42	0.35
Moderate Drought	18.48	10.00	9.70	8.15	5.76	7.33	2.52
Incipient Drought	23.03	36.97	37.33	40.70	41.95	41.61	18.71
Normal	16.06	0.00	0.00	0.00	0.00	0.00	0.00
Incipient Wet	18.18	35.91	34.39	33.23	34.97	34.99	56.40
Moderate Wet	17.88	9.39	11.21	9.40	7.52	7.62	18.25
Severe Wet	2.12	3.18	1.92	3.88	4.60	4.19	2.73
Extreme Wet	1.21	1.06	1.36	0.61	0.45	0.61	1.05

[1]DM=U.S. Drought Monitor
[2]KBDI=Keetch Byram Drought Index
[3]PDSI =Palmer Drought Severity Index
[4]SPI=Standard Precipitation Index (1-, 3-, 6-, 9-, 12-month)
[5]CMI=Crop Moisture Index

Table 3.5 Chi-square statistic and (p-values) for the indicator frequency distribution (extreme/severe, moderate, incipient, no drought) comparison between counties (p ≤ 0.05).

		Charleston	Oconee	Florence
C	PDSI		12.12 (0.007)	4.05 (0.255)
H	SPI1		2.08 (0.550)	0.35 (0.949)
A	SPI3		0.62 (0.893)	0.70 (0.873)
R	SPI6		5.76 (0.123)	0.19 (0.990)
L	SPI9		18.12 (0.000)	0.31 (0.959)
E	SPI12		14.04 (0.003)	2.65 (0.448)
S	CMI		12.39 (0.006)	10.32 (0.016)
T	DM		116.00 (0.000)	3.04 (0.385)
O	KBDI		13.28 (0.004)	2.66 (0.448)
N	Streamflow		0 (1)	0 (1)
	Groundwater		0 (1)	0 (1)
F	PDSI	4.05 (0.255)	12.62 (0.006)	
L	SPI1	0.35 (0.949)	3.72 (0.293)	
0	SPI3	0.70 (0.873)	0.12 (0.990)	
R	SPI6	0.19 (0.990)	5.33 (0.149)	
E	SPI9	0.31 (0.959)	14.00 (0.003)	
N	SPI12	2.65 (0.448)	11.61 (0.009)	
C	CMI	10.32 (0.016)	1.07 (0.790)	
E	DM	3.04 (0.385)	132.00 (0.000)	
	KBDI	2.66 (0.448)	11.77 (0.008)	
	Streamflow	0 (1.000)	0 (1.000)	
	Groundwater	0 (1.000)	0 (1.000)	
O	PDSI	12.12 (0.007)		12.62 (0.006)
C	SPI1	2.08 (0.550)		3.72 (0.293)
O	SPI3	0.62 (0.893)		0.12 (0.990)
N	SPI6	5.76 (0.123)		5.33 (0.149)
E	SPI9	18.12 (0.000)		14.00 (0.003)
E	SPI12	14.04 (0.003)		11.61 (0.009)
	CMI	12.39 (0.006)		1.07 (0.790)
	DM	116.00 (0.000)		132.00 (0.000)
	KBDI	13.28 (0.004)		11.77 (0.008)
	Streamflow	0 (1.000)		0 (1.000)
	Groundwater	0 (1.000)		0 (1.000)

STATISTICALLY DIFFERENT (shaded cells)

A chi-square test was used to estimate the independence of the drought indicators categorized by drought occurrence (extreme/severe, moderate, incipient, and normal). Table 3.6 displays the chi-square statistic and p-value for the comparison between indicators for Oconee County. The null hypothesis was rejected for most of the indicator comparisons, which indicates statistically significant differences exist between indicators. This test is interpreted to mean the frequency of drought based on the four levels (extreme/severe, moderate, incipient, no drought) depends on the indicator. The difference between the SPI-1, SPI-3, SPI-6, SPI-9, and SPI-12 data were not statistically different ($p>0.05$) as expected by the indicator computation (McKee, 1993). The difference between the KBDI and groundwater indices was not statistically significant (chi-square statistic 4.28, $p=0.243$); however, there is no relationship in the indicator computation. The KBDI was developed to detect forest-fire potential. Groundwater is a trigger used to detect longer-term hydrologic droughts.

Table 3.6 Chi-square statistic and (p-values) for the frequency distribution (extreme/severe, moderate, incipient, no drought) comparison between indicators for Oconee County (p≤0.05).

Indicator	PDSI	SPI1	SPI3	SPI6	SPI9	SPI12
PDSI		88.60 (0.00)	74.16 (0.00)	65.41 (0.00)	58.58 (0.00)	66.51 (0.00)
SPI 1	88.60 (0.00)		2.32 (0.57)	4.63 (0.20)	3.49 (0.32)	2.18 (0.54)
SPI3	74.16 (0.00)	2.32 (0.57)		0.50 (0.92)	2.45 (0.48)	3.42 (0.33)
SPI6	65.41 (0.00)	4.63 (0.20)	0.50 (0.92)		2.48 (0.498)	4.44 (0.22)
SPI9	58.58 (0.00)	3.49 (0.32)	2.45 (0.48)	2.48 (0.48)		0.59 (0.90)
SPI12	66.51 (0.00)	2.18 (0.54)	3.42 (0.33)	4.44 (0.228)	0.59 (0.90)	
CMI	168.81(0.00)	199.22 (0.00)	207.77 (0.00)	202.59 (0.00)	179.60 (0.00)	179.54 (0.00)
KBDI	65.66(0.00)	134.4 (0.00)	135.48 (0.00)	129.09 (0.00)	106.91 (0.00)	109.38 (0.00)
Streamflow	279.04(0.00)	368.3 (0.00)	328.7 (0.00)	378.22 (0.00)	340.27 (0.00)	337.47 (0.00)
Groundwater	91.04 (0.00)	153.34 (0.00)	159.74 (0.00)	155.00 (0.00)	127.65 (0.00)	127.57 (0.00)
USDM	158.05 (0.00)	298.4 (0.00)	289.09 (0.00)	283.03 (0.00)	263.09 (0.00)	266.34 (0.00)

Indicator	CMI	KBDI	Streamflow	Groundwater	USDM
PDSI	168.81(0.00)	65.66(0.00)	279.04(0.00)	91.04 (0.00)	158.05 (0.00)
SPI 1	199.22 (0.00)	134.4 (0.00)	368.3 (0.00)	153.34 (0.00)	298.40 (0.00)
SPI3	207.77 (0.00)	135.48 (0.00)	328.7 (0.00)	159.74 (0.00)	289.09 (0.00)
SPI6	202.59 (0.00)	129.09 (0.00)	378.22 (0.00)	155.00 (0.00)	283.03 (0.00)
SPI9	179.60 (0.00)	106.91 (0.00)	340.27 (0.00)	127.65 (0.00)	263.09 (0.00)
SPI12	179.54 (0.00)	109.38 (0.00)	337.47 (0.00)	127.57 (0.00)	266.34 (0.00)
CMI		44.66 (0.00)	109.13 (0.00)	40.19 (0.00)	390.17 (0.00)
KBDI	44.66 (0.00)		115.29 (0.00)	4.18 (0.24)	243.77 (0.00)
Streamflow	109.13 (0.00)	115.29 (0.00)		90.00 (0.00)	401.67 (0.00)
Groundwater	40.19 (0.00)	4.18 (0.24)	90.00 (0.00)		252.72 (0.00)
USDM	390.17 (0.00)	243.77 (0.00)	401.67 (0.00)	252.72 (0.00)	

Statistically Significant

The inconsistencies among many of the indicators can primarily be attributed to the inconsistencies in the drought level ranges defined by the S.C. Drought Response Act's regulations. Based on the ranges defined for the SPI and CMI, normal conditions never occur because incipient conditions begin at 0 to –0.99 for the SPI and 0 to –1.49 for the CMI. This is different and inconsistent with ranges of drought and normal periods defined by the Climate Prediction Center, the National Climatic Data Center, and the

National Drought Mitigation Center. Since there is no documentation explaining the selection of ranges defined in the S.C. Drought Response Act's regulations, it may be inferred that normal conditions or no drought conditions begin at zero through the positive values of the indicators. For the PDSI, normal or no drought conditions begin at –0.5 and higher. The normal range for the other indicators (streamflow, DM, KBDI, and groundwater) can not be compared to the PDSI, SPI, and CMI. This is because there is no range for wet conditions so all other non-drought periods are defined as no drought. The frequency range for all non-drought events for the KBDI and groundwater is consistent with each other with normal conditions occurring 77.71% to 80% respectively. Normal conditions based on streamflow occur the majority of the time or 94.16%.

The consistencies that do occur between certain indicators, such as the KBDI and groundwater, are not based on similarities in calculation nor should these indicators be used interchangeably for detection of drought. The KBDI was developed specifically for fire potential assessment, assuming eight inches of precipitation means saturated fuel moisture conditions. Since groundwater and streamflow are based on percentiles, comparisons could be made if the percentile ranges were equal or similar. Streamflow is considered to be in drought six percent of the time compared to 20 percent based on groundwater.

The results clearly demonstrate the inconsistency in drought frequency using the ranges defined in the S.C. Drought Response Act's regulations. The S.C Drought Response Committee should redefine the ranges for each indicator or use indicator percentiles. A possible solution for using multiple and often statistically inconsistent indicators is to transform all indicators to percentiles (Steinemann et al., 2005). This will be examined in more detail in Chapter 4.

CHAPTER 4 EVALUATION OF LOCAL DROUGHT INDICATORS

4.1 Local Drought Indicator Case Studies: Data and Methodology

The evolution and implementation of the drought plans or Low Inflow Protocols (LIPs) in the Yadkin-Pee Dee and Catawba-Wateree FERC licenses demonstrated the need for additional research on drought indicator validation. The LIPs were new to the relicensing process for the two basins and the identification of drought indicators and trigger points presented challenges to the licensee (Duke Energy, Alcoa-Yadkin, and Progress Energy) and the stakeholders. As stated in both LIPs, the success of the LIP depends on the diagnostic accuracy of the trigger points and the effectiveness with which the licensee and the water users work together to implement their required actions (Catawba-Wateree Project, Comprehensive Relicensing Agreement, October 2006; Yadkin Hydroelectric Project, February 2007). The 2007-2008 severe drought brought to the forefront additional challenges in determining drought indicators that effectively detect drought onset and recovery. The second objective of this research involves specific case study evaluations of local drought indicators used by Duke Energy and Alcoa-Yadkin/Progress Energy in their LIPs (Table 4.11, Table 4.12). The research identifies scientific and operational inconsistencies between the LIP indicators.

Table 4.11 Local-level drought indicators for Duke Energy.

System Name	Source	Stage 0[1]	Stage 1[1]	Stage 2[1]	Stage 3[1]	Stage 4[1]
Duke Energy	11 Catawba-Wateree Lakes	Storage index (SI) based on combined storage in all lakes. Ratio of Remaining Useable Storage to Total Usable Storage (TSI).				
		90%<SI <100% TSI	75%TSI<SI <=90% TSI	57% TSI < SI<=75% TSI	42% TSI< SI<=57%TSI	SI<=42% TSI
		US Drought Monitor Three-Month Numeric Average				
		>=0	>=1	>=2	>=3	=4
		Streamflow 6-month averages expressed as percentages of long-term average.[2]				
		<= 85%	<= 78%	<= 65%	<= 55%	<= 40%
	Wells	**Groundwater Recovery Levels[1]**				
	Langtree Peninsula	18.21	22.21	23.61	24.91	Not Required b/c Only Used for Recovery
	Linville	2.04	2.11	2.19	2.74	
	Glen Alpine	7.69	8.32	9.03	10.01	

[1] Stage 0 is triggered when any two of the three indicators are reached. Stages 1- 4 are triggered when storage index reaches trigger and one of the other two are reached. Recovery from each stage occurs when all indicators have returned to a lower level. Specified groundwater levels must also return to lower level before a stage declaration can be lowered.

[2] Streamflow gages: South Fork Catawba River at Lowell; Catawba River near Pleasant Gardens; Johns River at Arneys Store; and Rocky Creek at Great Falls.

The mainstem river of the Catawba-Wateree Basin is regulated by a series of eleven hydroelectric dams (Figure 4.11). The reservoirs formed by these dams are commonly referred to as the Catawba-Wateree chain lakes. All dams are owned by Duke Energy and were created to generate electricity. Duke Energy's FERC license to operate the dams on the Catawba River expires in 2008. The original license was issued by the FERC in 1958 as Duke Energy was building the eleventh and largest reservoir on the

Catawba River, Lake Norman. While the new license officially goes into effect in 2008, Duke and the stakeholders have voluntarily operated under the new LIP since 2006 in response to a significant drought.

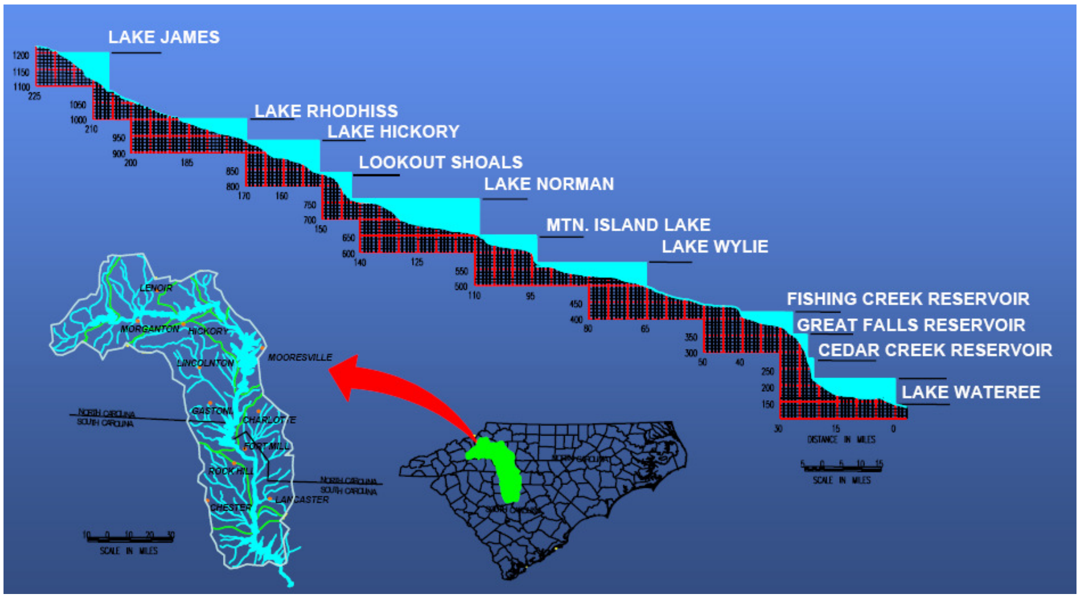


Figure 4.11 Catawba-Wateree Basin (Source: Duke Energy)

Alcoa-Yadkin (Alcoa) is relicensing its four hydroelectric stations on the Yadkin-Pee Dee River (Figure 4.12). The current license was granted in 1958 and expires in 2008. The four reservoirs are High Rock, Tuckertown, Narrows (Badin Lake), and Falls. Progress Energy Carolinas, Inc., also known as Carolina Power & Light, a subsidiary of Progress Energy, owns and operates the Yadkin-Pee Dee River Project, located on the Yadkin-Pee Dee River in North Carolina with dams at Tillery and Blewett Falls (Figure 4.12). Alcoa/ Progress Energy also have voluntarily followed guidance from the new LIP since 2006 in response to the drought.

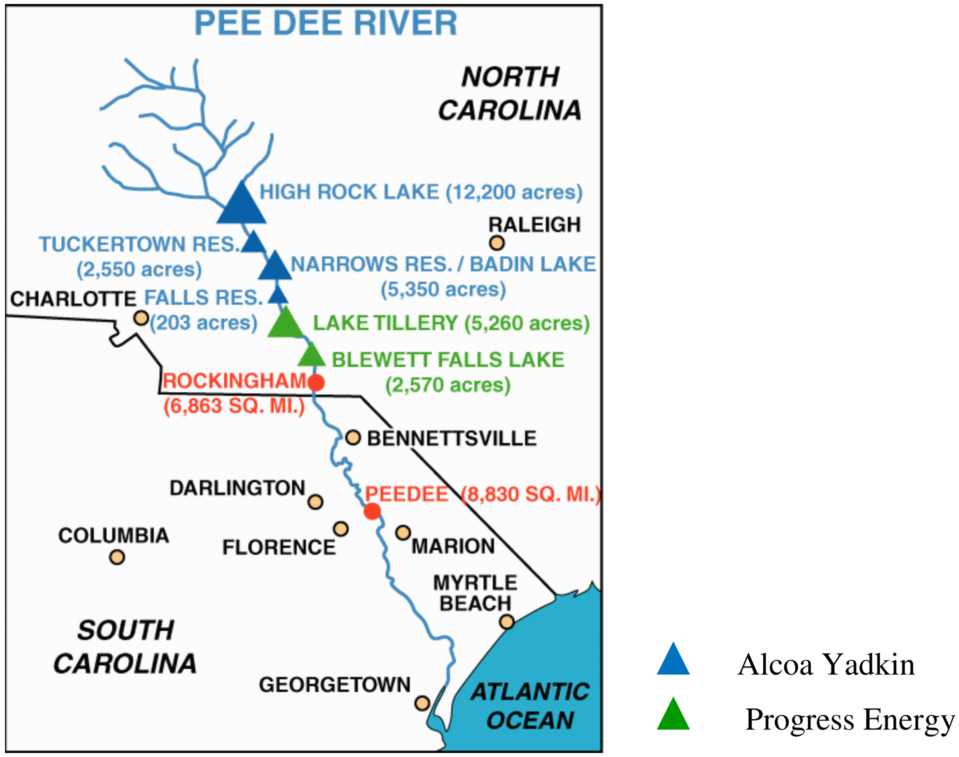


Figure 4.12 Yadkin-Pee Dee Basin (Source: S.C. Department of Natural Resources)

While the indicators and triggers for Duke Energy, Alcoa, and Progress Energy's LIPs are included in their new license, the LIP provides for revisions that must occur no less than every five years to ensure continuous improvement of the LIP and its implementation. Specifically mentioned is the substitution of a regional drought monitor for the U.S. Drought Monitor, which requires research focused on testing and improving drought indicators.

The indicators currently listed in the LIPs (Table 4.11, Table 4.12) are reservoir storage index, rolling streamflow averages (6-month averages for Duke, 3-month averages for Alcoa and Progress Energy), and the U.S. Drought Monitor. While both

LIPs use a lake storage indicator, streamflow, and the U.S. Drought Monitor they differ in their computations and triggers.

Table 4.12 Local-level drought indicators for Alcoa Yadkin and Progress Energy.

System Name	Source	Stage 0[1]	Stage 1[1]	Stage 2[1]	Stage 3[1]	Stage 4[1]
Alcoa/ Progress Energy	6 Yadkin-Pee Dee Lakes	Normal Minimum Elevation (NME) is the elevation of a reservoir (ft) that defines the bottom of the reservoir's Normal Operating Range				
		<NME minus 0.5ft Or <NME and either of the other two indicators have been reached	< NME minus 1 ft.	< NME minus 2 ft.	< NME minus 3 ft.	< ½ of (NME minus Critical Reservoir Water Elevation)
		US Drought Monitor Three-Month Numeric Average				
		>=0	>=1	>=2	>=3	=4
		Stream Gage Three-Month Rolling Average as a percent of the Historical Average [2]				
		< 48%	< 41%	< 35%	< 30%	< 30%

1 Stage 0 is triggered when High Rock Reservoir water elevation is below the NME minus 0.5 ft or High Rock Reservoir water elevation is below its NME and either of the two other indicators have reached Stage 0. Stage 1 – Stage 4 are triggered when High Rock Reservoir elevation reaches the trigger and one of the other two are reached.

[2] Streamflow gages: Yadkin River at Yadkin College, South Yadkin River near Mocksville, Abbotts Creek at Lexington, Rocky River near Norwood.

Duke's storage indicator is based on a ratio of the remaining useable storage to the total useable storage. These indicators are based on the project's total volume of water for all lakes in the system (Catawba-Wateree Project, Comprehensive Relicensing

Agreement, 2006). The streamflow indicator is computed by taking the sum of the actual rolling six-month average streamflow at four designated USGS gages as a percentage of the period of record rolling six-month average streamflows for that period. The period of record began in 1985 when all four gages were operational. The U.S. Drought Monitor designation ranges from D0 to D4 as of the last day of a month. The basin is assigned a numeric value for that month equal to the highest U.S. Drought Monitor designation (e.g. D0=0, D1=1, D2=2, D3=3 and D4=4) for any part of the Catawba-Wateree River Basin draining to Lake Wateree. Months with no drought designation are assigned a numeric value of negative one (-1). A rolling average of the numeric values of the current month and previous two months is calculated. Three groundwater wells were selected for the recovery phase. Two of the wells were from the USGS network and one from the North Carolina Department of Natural Resources (http://www.ncwater.org/Data_and_Modeling/Ground_Water_Databases/). The specific stage levels for each well are defined in the LIP. According to the LIP, Stage 3 equals the period of low record water level for each well, Stage 2 is the 10th percentile, Stage 1 is the 25th percentile, and Stage 0 is the 50th percentile.

The Alcoa/Progress Energy storage indicator is based on the normal minimum elevation (NME) for High Rock Lake, which is the elevation of the reservoir (ft.) that defines the bottom of the reservoir's normal operating range. In contrast to Duke, the Alcoa/Progress system has six lakes, but only High Rock elevation is used for the storage indicator. The streamflow LIP indicator uses daily flow for four designated USGS stream gages to calculate a monthly average flow for the period of record 1974 through 2003. The Abbotts Creek gage began in 1988; therefore, the historical average for this gage is based on the period 1988 through 2003. The current three-month average flow for the four gages is expressed as a percentage of the historic three-month rolling average flow for each month. Similar to Duke's LIP, the U.S. Drought Monitor designation ranges from D0 to D4 as of the last day of a month. The basin is assigned a numeric value for that month equal to the highest U.S. Drought Monitor designation (e.g. D0=0, D1=1, D2=2, D3=3, and D4=4) for any part of the Yadkin-Pee Dee River Basin draining to Blewett Falls development. Months with no drought designation are assigned a numeric value of negative one (-1). The drainage area to Blewett Fall does not include any of the South Carolina portion of the basin since all the reservoirs are in North Carolina. A rolling average of the numeric values of the current month and previous two months is calculated.

In summary, the primary differences between Duke's LIP and Alcoa/Progress Energy's LIP indicators are the use of only one lake, High Rock Lake, for the Alcoa/Progress Energy's storage indicator versus a storage indicator that considers the total remaining useable storage for all 11 lakes in Duke's project. Duke also uses a 6-month rolling streamflow calculation rather than the 3-month rolling average used by Alcoa/Progress Energy. There are also major differences in the streamflow levels that trigger each stage. Both use a similar computation for the DM, but since Duke's lakes span the entire basin from Lake James in North Carolina to Lake Wateree in South Carolina, Duke considers the highest value for the entire basin and Alcoa/Progress Energy considers the highest value for parts of basin draining to the Blewett Falls project since Blewett Falls is the last lake in the basin. The South Carolina Pee Dee portion of the basin contains no lakes. Duke also uses groundwater indicators in the recovery phase of the LIP and Alcoa/Progress does not.

Differences exist in how each stage is reached between the LIPs. Duke's Stage 0 is declared when any two of the three indicators are reached. However, Stages 1- 4 are triggered when the storage index reaches a trigger point and one of the other two indicators are reached. Duke's recovery from each stage occurs when all indicators have returned to a lower level. Specified groundwater levels must also return to a lesser drought level before a stage declaration can be lowered. In Alcoa/Progress Energy's LIP, Stage 0 is declared if the High Rock reservoir water elevation is below the normal minimum elevation minus 0.5 ft, or if the High Rock Reservoir water elevation is below its NME and either the DM three-month numeric average or the three-month rolling streamflow average has reached the Stage 0 trigger. Similar to Duke's LIP, Alcoa/Progress Energy's Stages 1- 4 are triggered when the storage index (High Rock Elevation) reaches the trigger and one of the other two are reached. The recovery triggers between Duke's LIP and Alcoa/Progress Energy also differ. Duke's designations cannot recover without a lowered stage by all three indicators plus a recovery by the groundwater gages. The Alcoa/Progress Energy recovery from the LIP is triggered by any of the three conditions.

Condition 1: All three triggers associated with a lower numbered LIP Stage are met.

Condition 2: High Rock Reservoir water elevations return to at or above the NME plus 2.5 ft.

Condition 3: High Rock Reservoir water elevations return to at or above the NME for two consecutive weeks.

According to Marshall Olson, Environmental and Natural Resources Manager, Alcoa Power Generating, Inc. (APGI), "When APGI considered how to best recover from the LIP they needed to consider a range of possible inflow conditions from a very rapid to a very slow recovery. Historically, the recovery from a drought is often a high precipitation event that fills High Rock Reservoir quickly. What APGI wanted to avoid in a recovery is to be in a drought stage that limits releases and then, within a short period of time, have to spill to avoid overtopping the dam. The recovery Condition 1 is for a slow recovery and may proceed one or more drought stages at a time. Recovery Conditions 2 and 3 will apply during a rapid recovery and the LIP is discontinued so that APGI can manage the higher inflows to avoid spilling as much a possible."

Questions have been raised as to the effectiveness of the proposed indicators in both LIPs due to conditions experienced in the most recent drought that began in 2007 and was ongoing in spring 2008. The original concerns expressed by resource agencies as the indicators were being developed in 2005-2006 focused on the use of the U.S. Drought Monitor. The concerns were that the DM was not intended for smaller scale drought detection at the basin or sub-basin level. Other concerns involved the subjectivity of the DM introduced by the different DM authors and local input into the weekly indicator. The 2007-2008 drought raised additional questions about the streamflow indicator, especially for the Catawba-Wateree Basin. Some resource agencies and water systems have expressed concern that the 6-month streamflow covers too long of an historical period. Duke Energy also lists groundwater level trigger points that must be attained before each recovery stage is reached. Three wells are currently listed with an adequate period of record. Additional concerns exist that groundwater should not be included as an indicator. Groundwater is not listed as an indicator in Alcoa/Progress Energy's LIP.

In order to evaluate the LIP indicators (Table 4.11, Table 4.12) frequency distributions were computed and analyzed. Duke Energy and Alcoa/Progress Energy make the stage declaration on the first day of each month using indicator data from the last day of the previous month or months in the case of streamflow and the DM. For example, the DM value for the end of March 2008 is averaged with the January and February 2008 DM to result in a three-month average value. This value ending in March 2008 is then considered for the April 1, 2008 declaration. For historical analysis, it is important to understand that the data ended in March, but the official declaration is entered for the next month's stage. The period analyzed for each indicator was:

- Duke's Storage Indicator: November 1985-April 2008 for 270 monthly values and April 2000- April 2008 for 97 values,
- Duke's Streamflow 6-Month Rolling Average: November 1985-April 2008 for 270 monthly values and April 2000-April 2008 for 97 values,
- Duke's U.S. Drought Monitor Three-Month Numeric Average: April 2000- April 2008 for 97 values,
- Duke's Groundwater gages: April 2001-April 2008 for 85 values,
- Alcoa/Progress Energy High Rock Elevation Storage Indicator: December 1996-April 2008 for 137 monthly values and April 2000-April 2008 for 97 values,

- Alcoa/Progress Energy Streamflow 3-Month Rolling Average: December 1996-April 2008 for 137 monthly values and April 2000-April 2008 for 97 values, and
- Alcoa/Progress Energy U.S. Drought Monitor Three-Month Numeric Average: April 2000-April 2008 for 97 values.

Data availability for the DM limited one study period from April 2000 to April 2008. Storage and streamflow were evaluated for longer periods based on available data for each basin. The frequency of occurrence within each threshold trigger level is analyzed to identify scientific inconsistencies among the indicators within each LIP, between the LIPs for both basins and between the State-level drought indicators discussed in Chapter 3. A chi-square statistical test was used to evaluate the statistical significance of the differences.

4.2 Duke Energy's Low Inflow Protocol Indicator Comparison

The percent frequency of drought occurrence for Duke's LIP indicators is displayed in Table 4.21. The percent frequency of occurrence for the storage indicator and streamflow was computed for the extended period from November 1985 – April 2008 and for the most recent period April 2000 – April 2008 (the period of record for the DM). Certain caveats should be associated with the data from April 2000 to July 2006. The LIP did not exist during that period, thus the releases and management of the lakes did not follow the LIP guidelines. Water conservation measures and downstream release requirements were not implemented, so the storage levels may be different than if the LIP were being followed.

Based on the storage indicator for the two time periods no major difference was found between the percent frequency of drought. The greatest difference was approximately four percent for stage 2 and stage 0. The storage in the lakes is highly dependent on Duke's releases from the hydropower dams. Duke hydropower operators confirmed that similar management strategies from 1985 until the new LIP was initiated in August 2006 explain the similarities in the storage drought stage frequency of occurrence between the two periods 1985 to 2008 and 2000 to 2008. Steamflow had larger differences in the percent frequency of occurrence between the two time periods with stage 4 occuring almost ten percent more often during the period April 2000 – April 2008. Stage 3, based on streamflow, occurred six percent more often during the recent period with normal conditions occurring only 40.21 percent versus 56.30 percent during November 1985 to April 2008. The increased percent frequency of Stage 3 and 4 and the decreased occurrence of normal periods is consistent given the extended drought conditions experienced in the basin over the past decade.

A comparison among the indicators for the period April 2000 – April 2008 shows inconsistencies in the percent frequency of occurrence between each indicator. The storage indicator never reached Stage 4 and only one percent of the time reached Stage 3. Whereas, streamflow reached Stage 4, 15.46 percent, and Stage 3, 19.58 percent. The DM reached Stage 4, 5.15 percent, and Stage 3, 14.43 percent of the time. The difference in percent occurrence between the indicators for Stage 1 is less. The 4.12 percent occurrence of Stage 0 drought by streamflow is inconsistent with the other indicators and can, in part, be attributed to the smaller range of possible values. Streamflow reaches a Stage 0 drought when the average flow is between 78.1 percent and 85 percent whereas Stage 1 is reached when the average flow is between 65.1 percent and 78 percent. Normal conditions occur 55 percent of the time based on the storage indicator, 40 percent based on streamflow and 32 percent based on the DM. The fewer occurrences of drought in general, and especially the lower occurrences of the higher drought levels by the storage indicator, is consistent with Duke's planning. According to their LIP, after Stage 0 the storage indicator must reach a higher level before the official stage is upgraded. Streamflow and the DM cannot trigger an upgrade beyond Stage 0 without confirmation by the storage indicator that the level of drought has increased. The higher frequencies of streamflow and DM, however, do impact the stages during recovery. This is examined more closely in Figures 4.21- 4.25, which display the indicator stages by month from April 2000 to April 2008.

Table 4.21 Percent frequency of drought for Duke LIP indicators.

Drought Level	Storage 11/85-4/08	Storage 4/00-4/08	Streamflow 11/85-4/08	Streamflow 4/00-4/08	DM 4/00-4/08
Stage 4	0.00	0.00	5.90	15.46	5.15
Stage 3	0.37	1.03	14.39	19.58	14.43
Stage 2	3.70	7.21	8.86	10.31	16.49
Stage 1	15.19	15.46	9.23	10.31	15.46
Stage 0	25.56	21.60	5.54	4.12	16.49
No Drought	55.19	54.63	56.09	40.12	31.96

Figures 4.21 to Figure 4.25 show the stages by month and give the overall LIP stage recreated for the dates April 2000 to July 2006. The overall Stage value (labeled Stage) was computed based on indicator criteria listed in the LIP. For example, if the LIP had been in existence in November 2000, the storage indicator was at Stage 1, streamflow at Stage 3,and the DM at Stage 2. Since the LIP is primarily driven by the storage indicator going into drought the official stage would have been Stage 1. Starting in August 2006, Duke began voluntarily following the LIP, so actual LIP values were used for this period, August 2006-April 2008. For the period April 2000 to July 2006, water

conservation measures and downstream release requirements based on the new LIP were not implemented; therefore, certain stage declarations based on storage may have been different than if the LIP were being followed.

Figure 4.21 shows the monthly indicator stages for April 2000 to December 2001. Streamflow and the DM were in some level of drought for all months. Groundwater values were not available until April 2001, but from April 2001 to December 2001 groundwater was also in some stage of drought. The storage indicator was in drought for all but six months. The official LIP stage would have been in Stage 1 starting in August 2000 through October 2001 even though in February 2001 the storage indicator returned to normal and stayed at normal until May 2001. While storage levels returned to normal, the official LIP remained in Stage 1 because streamflow, DM and groundwater had not returned to a lower level.

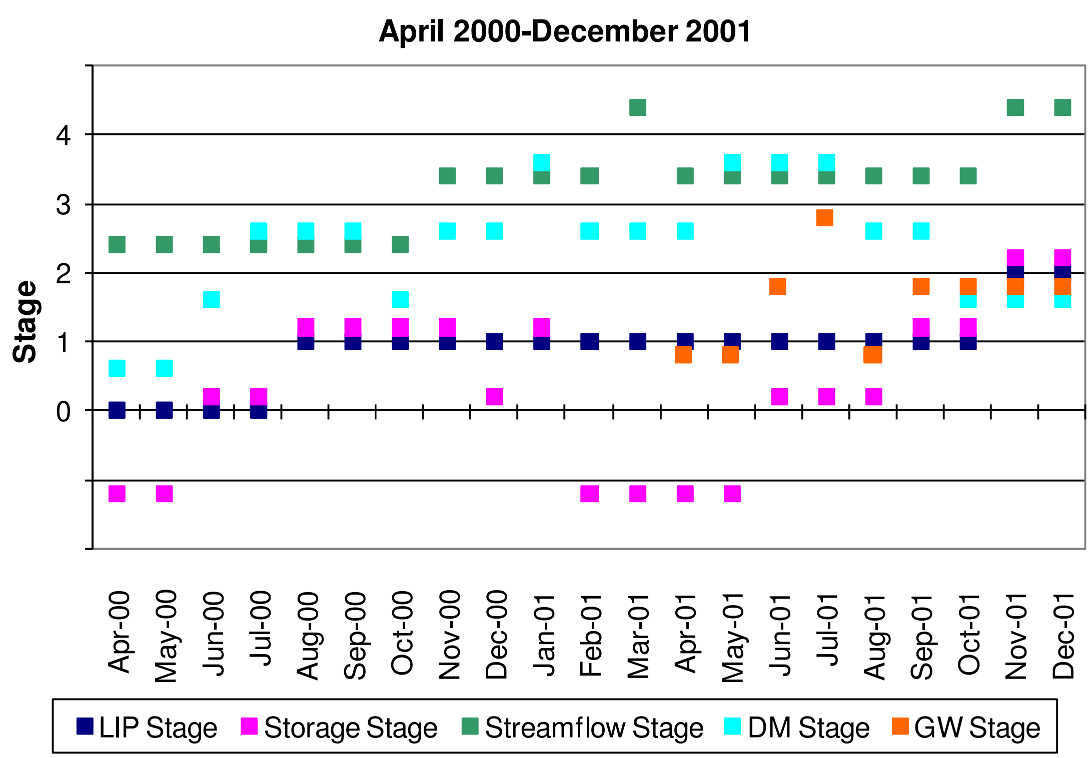


Figure 4.21 Duke's LIP indicators April 2000 – December 2001.

Figure 4.22 shows the indicator levels from January 2002-December 2003. The official LIP stage for this period would have been at Stage 2 from January 2002 through December 2002. The storage indicator returned to normal from February 2002 to June 2002, but streamflow, the DM, and groundwater remained at the higher stages. The storage index dropped to Stage 2 in September and returned to normal in December 2002. The other indicators were slower to respond to the above normal rainfall that was reported in the later months of 2002. The official stage would not have been downgraded to no drought until May 2003 (five months after the storage indicator returned to normal) when all other indicators recovered (groundwater and the DM were the last to recover).

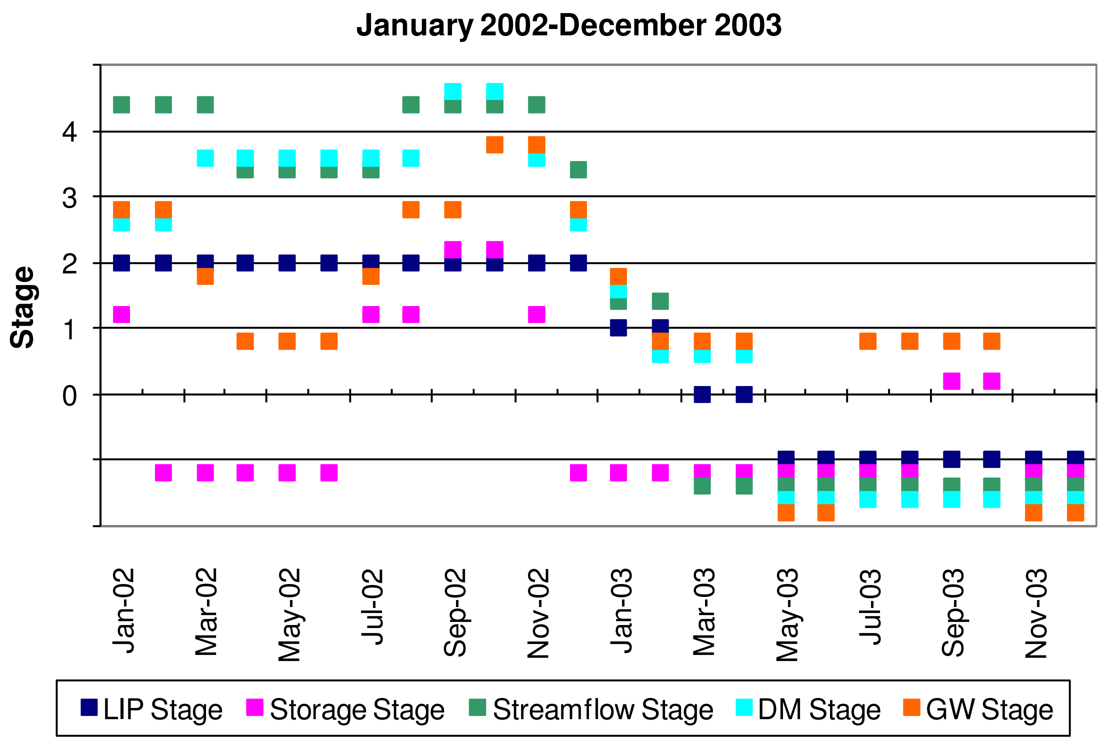


Figure 4.22 Duke's LIP indicators January 2002 – December 2003.

Figure 4.23 displays the indicators from January 2004 – December 2005. Starting in June 2004, the official stage was Stage 0 because of streamflow and groundwater while the storage indicator was still normal. Only at Stage 0 can the declaration occur without the storage indicator in combination with the other indicators. By September 2004, the storage indicator reached Stage 1, with no support from the other indicators so the stage remained at Stage 0. All indicators and the official stage returned to normal by December 2004. The storage indicator reached Stage 1 in October 2005, however, since streamflow and the DM remained at normal levels, the official stage remained at Stage 0. Storage quickly returned to normal by November 2005, proving the indicators worked as they should: complimenting each other and providing the user with guidance to avoid moving in and out of drought stages too frequently.

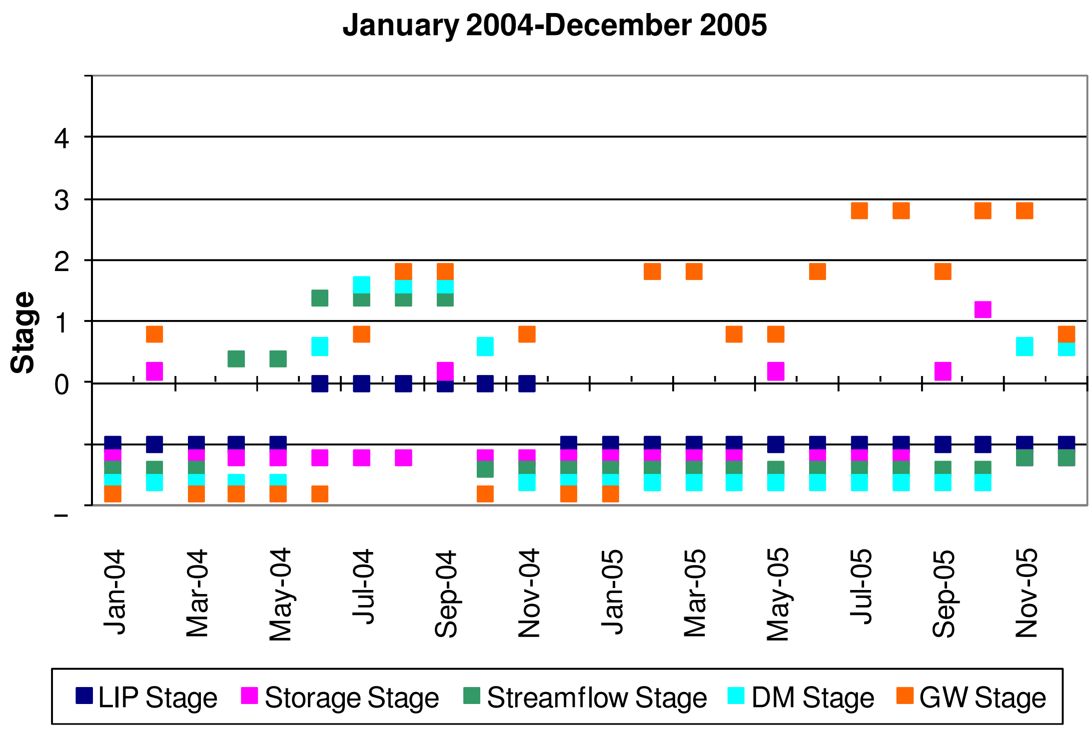


Figure 4.23 Duke's LIP indicators January 2004 – December 2005.

Figure 4.24 provides the indicators from January 2006 – April 2008. Beginning in August 2006, the indicator values are actual LIP stages (rather than estimated) under which Duke and its stakeholders managed water in the basin during the worst drought conditions on record. Table 4.22 highlights the indicator stage levels by month as the drought intensified from June 2007 through April 2008.

The official LIP stage entered Stage 0 in June 2007 due to the storage indicator and the DM. Streamflow reflected normal conditions primarily due to the 6-month streamflow averages that included above normal flows in early 2007 (Table 4.23). Streamflow reached D0 in July 2007. This one-month difference does not seem significant, however, conditions rapidly deteriorated in summer 2007. The official stage dropped almost one stage each month starting in July 2007 reaching Stage 3 by mid-October 2007. By August 2007, all indicators were reflecting Stage 1, and by September all indicators were at Stage 2. Streamflow increased to Stage 3 by October with the storage index and DM hovering in Stage 2. Storage reached Stage 3 by mid- October 2007 with the DM and streamflow at Stage 3. The official stage was upgraded for the first time to Stage 3 since the LIP implementation. The LIP calls for indicator evaluation and stage changes on the first day of the month, based on conditions at the end of the previous month, but due to the rapid intensification of the drought during fall 2007, Duke and the stakeholders agreed to make stage changes as needed based on indicator guidance.

Heavy rains in December 2007 started storage recovery, with the storage stage improving to Stage 2. However, the LIP requires that all indicators recover to lower levels before the official stage can be downgraded. Winter rains helped the storage indicator recover to normal levels by February 2008, but the DM and streamflow remained at Stage 4. Streamflow and the DM remained in Stage 4 in March 2008. By April 2008, streamflow and the DM kept the official declaration at Stage 3, even though the storage index returned to normal in February. Some stakeholders expressed concern during the LIP indicator development that groundwater would hold the stage at higher levels due to the lag in recovery, however, during late 2007-early 2008, both streamflow and DM were at an elevated stage. Groundwater was also at a higher stage compared to storage (only by one stage in April), but was not the only indicator holding the LIP from recovery to a lower stage as expected.

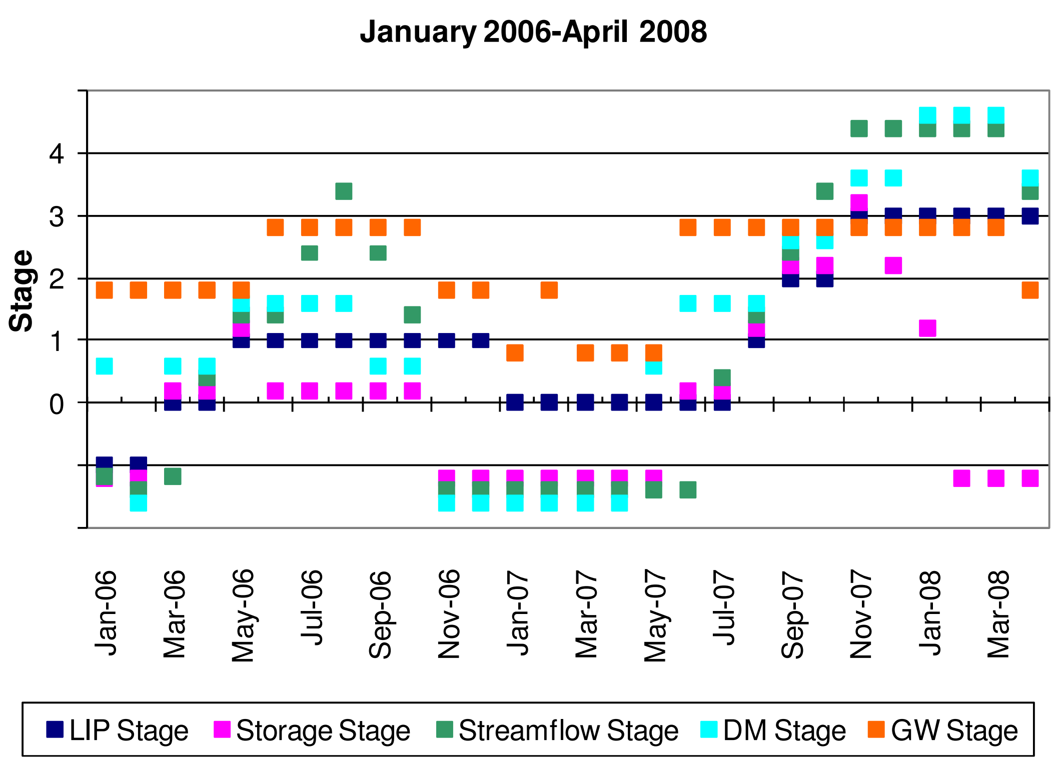


Figure 4.24 Duke's LIP indicators January 2006 – April 2008.

Table 4.22 Duke's LIP indicator drought stages, June 2007 – April 2008.

	Jun. 2007					Jul. 2007					Aug. 2007					Sept. 2007				
	Drought Stage					Drought Stage					Drought Stage					Drought Stage				
	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Storage	■					■						■						■		
DM		■					■					■						■		
Streamflow						■						■						■		
Groundwater																				

	Oct. 2007					Mid-Oct. 2007*					Dec. 2007					Jan. 2008				
	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Storage			■						■				■				■			
DM			■						■					■						■
Streamflow				■					■						■					■
Groundwater													■					■		

	Feb. 2008					Mar. 2008					Apr. 2008				
	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Storage															
DM					■					■				■	
Streamflow					■					■				■	
Groundwater			■					■				■			

* Due to the rapid intensification of the drought during fall 2007 Duke and the stakeholders agreed to make stage changes as needed based on indicator guidance.

Table 4.23 Streamflow 6-month averages and values expressed as percentages of long-term average, January 2007 – April 2008.

	Actual 6-month Rolling Streamflow Expressed as Percent of Long-term Average Rolling 6-Month Streamflow
January 2007	126
February 2007	118
March 2007	126
April 2007	103
May 2007	100
June 2007	89
July 2007	82
August 2007	67
September 2007	64
October 2007	46
November 2007	39
December 2007	34
January 2008	32
February 2008	30
March 2008	34
April 2008	41

In summary, the storage indicator was at a lower stage since December 2007, but, due to the streamflow and DM, the official LIP operated under a Stage 3 declaration. This caused significant concern by water systems in the basin since Stage 3 requires mandatory water restrictions. During the winter, the mandatory restrictions were not difficult to manage, however, as spring progressed more citizens and landscape companies pressured water systems to relax their mandatory restrictions. The water systems also experienced financial burdens due to the water restrictions on their customers and some water systems proposed water rate increases. The complaint was that as the lakes were at normal elevations, the Stage 3 water restrictions were difficult to justify. The indicator analysis shows that both 6-month streamflow and the DM (Figure

4.24 and Table 4.22) held the declaration at Stage 3. Through the entire period analyzed, April 2000 – April 2008, for 39 out of the 97 months (42 percent) the official LIP stage was higher than the storage indicator due to streamflow or DM higher stages. The official LIP stage was higher than the storage indicator due to groundwater only three times. Only six times out of 97 months was the storage indicator at a higher drought stage (Stage 0 and Stage 1) than the official stage, reaching Stage 1 only once (October 2005). Moving forward from April 2008, without consistent above normal streamflows, the 6-month rolling streamflow will be slow to recover (Table 4.23). Higher streamflow values are needed to cancel out the low flows from the late 2007 – early 2008 periods.

While the drought stage indicated by the storage index differs from streamflow, the DM, and groundwater 42 percent of the time, Duke personnel and stakeholders believe that multiple indicators provide better detection of drought onset and recovery. The strength of using multiple indicators, in spite of their inherent differences, is that they collectively improve detection and response. Results from the research show that the appropriate lead-time is met with the indicators, but the recovery time is probably insufficient. Duke and the stakeholders agreed to continue following the LIP despite concerns over the 2008 conditions, noting that changing course and revising the LIP during the drought may cause more confusion. Information from this study will be presented to the Catawba-Wateree Drought Management Group for their next LIP revision.

4.3 Duke Energy's Low Inflow Protocol Comparison with South Carolina's State Indicators

This section will compare the drought frequency based on State and LIP indicators. Table 4.31 provides the percent frequency of drought based on Duke's LIP indicators and selected state indicators for York County. York County was selected since its drought frequency among the State indicators was consistent with other counties in the South Carolina portion of the Catawba-Wateree basin. Table 4.31 displays results for Duke's Storage LIP, the State's SPI 9-month and SPI 12-month, Duke's LIP 6-month Streamflow, Duke's LIP 3-month DM, State Streamflow and State DM. The SPI-6 month (SPI6), SPI 9-month (SPI9), and SPI-12 month (SPI12) were selected for comparison since longer-term indicators spanning 6 to 12 months are often used for hydrologic drought depiction. The data were analyzed for the period April 2000 – April 2008. This shorter study period was selected based on the DM's period of record.

Direct comparisons between the LIP and State indicators are difficult since Duke's LIP has five levels of drought (Stage 0, 1, 2, 3, 4) and the State only has four (incipient, moderate, severe, and extreme). The S.C. Drought Response Committee compares the indicators by assuming incipient is closest to Stage 0, moderate to Stage 1, severe to Stage 2, extreme to Stage 3, or a combination of Stage 3 and Stage 4. Discrepancies between the LIP and State indicator drought designation can also be expected given the differences in the indicator estimating period and trigger level ranges.

The State analyzes streamflow over a 14-day period while the LIP averages over six months. According to the state-defined streamflow trigger, extreme drought conditions occur 4.49 percent of the time, with severe to incipient drought each occurring only 0.45 percent. Normal conditions would therefore occur 94.16 percent of the time. Based on the values estimated from April 2000 to April 2008, the 6-month streamflow LIP indicator was in a Stage 3 drought 15 percent more often than the streamflow reached extreme drought based on the state trigger. Combining LIP Stage 3 and Stage 4 percent drought occurrence, the 6-month streamflow indicator was in drought 31percent more often that the state-defined extreme level. The LIP 6-month streamflow reached Stage 1 and 2 almost 10 percent more often than it would have based on the State's definition. The LIP also indicates that normal conditions occurred 40 percent compared to the State designated 94 percent.

Despite the differences in the spatial and temporal averaging of the State and LIP DM, there was less than a 5 percent difference between their drought frequencies. The State uses the monthly DM values and the LIP computes a 3-month average DM at the end of each month. The LIP DM had a slightly higher frequency of occurrence for all levels except Stage 2 compared to the State severe level. Combining Stage 3 and Stage 4 of the LIP, resulted in less than a 2 percent difference with the frequency of extreme drought based on the State.

The attempt to relate the SPI 6-month, SPI 9-month and SPI 12-month to Duke's LIP Storage Indicator revealed that the SPI calculations were in all stages of drought more often as compared to the LIP storage indicator. The greatest difference between the storage frequencies and the SPI frequencies occurred at Stage 0 (incipient drought) and for months with no drought. The SPI values reached incipient (or Stage 0 based on LIP) 13 percent to 16 percent more often than the storage indicator. Based on the storage indicator, months with no drought designation occurred 55 percent of the time, whereas, months with no drought based on the SPI calculations occurred only 19 percent to 25 percent of the time. The frequency of months with no drought designation based on the SPI values for April 2000 – April 2008 is much less than for the extended period (1951-2005) due to prolonged drought over the past decade. The frequency of months with no drought designation from 1951-2005 occurred 48 percent to 55 percent of the time. One goal of the research is to evaluate which indicator could be used as an alternative to the DM in the LIP. A more detailed comparison of the SPI values and other indicators will be discussed in Section 4.4.

Table 4.31 Percent frequency of drought occurrence based on Duke's LIP indicators and selected state indicators, April 2000 – April 2008: a) Duke's LIP storage, State's SPI6, SPI9 and SPI12, b) Duke's LIP streamflow, Duke's LIP DM, State streamflow and State DM.

Duke LIP Stages	Storage 4/00-4/08	State Drought Stages	State SPI6[1]	State SPI9[1]	State SPI12[1]
			4/00-4/08		
Stage 4	0.00				
Stage 3	1.03	Extreme	2.06	4.12	6.19
Stage 2	7.22	Severe	11.34	16.49	13.40
Stage 1	15.46	Moderate	25.77	19.59	25.77
Stage 0	21.65	Incipient	35.05	38.14	35.05
No Drought	54.64	No Drought	25.77	21.65	19.59

[1]SPI=Standardardized Precipitation Index (6-, 9-, 12-month)

a) Duke's LIP Storage, State's SPI6, SPI9, and SPI12

Duke LIP Stages	Duke LIP Streamflow 4/00-4/08	Duke DM[2] 4/00-4/08	State Drought Stages	State Streamflow Based on Percentiles	State DM[2] 4/00-4/08
Stage 4	15.46	5.15			
Stage 3	19.59	14.43	Extreme	4.49	17.83
Stage 2	10.31	16.49	Severe	0.45	21.45
Stage 1	10.31	15.46	Moderate	0.45	12.53
Stage 0	4.12	16.49	Incipient	0.45	13.01
No Drought	40.21	31.96	No Drought	94.16	35.18

[2] U.S. Drought Monitor

b) Duke's LIP Streamflow, Duke's LIP DM, State Streamflow, and State DM.

The chi-square test was used to estimate the independence of the Duke LIP drought indicators categorized by drought occurrence (Stage 2-Stage 4, Stage 1, Stage 0, and No Drought). Stage 2, Stage 3 and Stage 4 were combined into one drought category. Table 4.32 displays the chi-square statistic and p-value for the comparison between Duke's LIP indicators (Storage Index, 6-month Streamflow, 3-month average DM). The null hypothesis was rejected between all the indicators indicating there are statistically significant differences between the storage index, streamflow, and the DM. The p-values were very low, providing strong evidence for rejecting the null hypothesis.

The chi-square test was also used to estimate the independence of Duke's LIP drought indicators and State indicators. Duke's LIP indicators were categorized by drought occurrence in four levels; Stage 2 to Stage 4, Stage 1, Stage 0, and No Drought. State indicators were categorized by Severe to Extreme, Moderate, Incipient, and No Drought. The levels were combined since the chi-square test is not valid for small samples (fewer than five). Frequency of occurrence rather than percentages was analyzed since the chi-square must be calculated on actual count data. Table 4.33 displays the chi-square statistic and p-values for the comparison between Duke's LIP indicators (Storage Index, 6-month Streamflow, 3-month Average DM) and the state indicators (SPI6-month, SPI9-month, SPI 12-month, State 14-day streamflow, and State DM). The null hypothesis that there was no difference between the indicators was rejected in most comparisons. The difference between Duke's LIP storage index and all the State indicators was statistically significant with very low p-values. The null hypothesis was accepted for the comparison of LIP streamflow to State DM and between the LIP DM and State DM, indicating no statistical difference. The statistical consistency between the LIP 3-month average DM and State's monthly DM may be attributed to the persistent drought during the study period, April 2000-April 2008, with minimal month-to-month changes in drought levels.

Table 4.32 Chi-square statistic and (p-values) for the comparison of the frequency distributions of drought levels (LIP Stage 2 to Stage 4, LIP Stage 1, Stage 0, No Drought) between indicators for Catawba-Wateree Basin (p≤0.05).

LIP Indicators	Storage	Streamflow	DM[1]
Storage		39.61 (0.00)	23.39 (0.00)
Streamflow	39.61 (0.00)		10.12 (0.00)
DM	23.39 (0.00)	10.12 (0.00)	

[1] U.S. Drought Monitor

Statistically Significant

Table 4.33 Chi-square statistic and (p-values) for the comparison of the frequency distributions of drought levels (LIP Stage 2 to Stage 4 and State Severe to Extreme, LIP Stage 1 and State Moderate, LIP Stage 0 and State Incipient, and No Drought) between indicators for Catawba-Wateree Basin and State indicators (p≤0.05).

	State SPI 6[1]	State SPI 9[1]	State SPI 12[1]	State Streamflow	State DM[2]
LIP Storage	16.81 (0.00)	23.87 (0.00)	22.76 (0.00)	44.44 (0.00)	25.93 (0.00)
LIP Streamflow	50.03 (0.00)	43.75 (0.00)	46.93 (0.00)	64.14 (0.00)	5.72 (0.13)
LIP DM	19.71 (0.00)	14.80 (0.00)	16.60 (0.00)	81.09 (0.00)	0.91 (0.82)

[1]SPI=Standard Precipitation Index (6-, 9-, 12-month)
[2] U.S. Drought Monitor

Statistically Significant

4.4 Alcoa Yadkin and Progress Energy's Low Inflow Protocol Indicator Comparison

The percent drought frequency for each of Alcoa/Progress Energy's LIP indicators is displayed in Table 4.41. The drought frequencies for the storage indicator and streamflow were computed for the extended period from December 1996 – April 2008 and for the most recent period April 2000 – April 2008 (the period of record for the

DM). Similar to Duke's LIP there are some caveats with Alcoa/Progress Energy's storage data before the LIP was implemented in 2006. Prior to 2006, Alcoa/Progress and other water withdrawers were not following the LIP guidelines so the releases and withdrawals from the system may have been different resulting in different drought stages.

A major difference between the storage indicator drought frequency for the two time periods did not occur. Streamflow had a larger difference in the frequency of drought between the two time periods, but primarily only for Stage 1 and no drought periods. Based on the LIP stage definitions, streamflow reaches Stage 3 and Stage 4 when the three-month average expressed as a percent of the long-term average is less than 30 percent. This means that the overall LIP Stage 4 declaration is driven by the storage and DM trigger levels. The overall increased percent frequency of drought is consistent given the extended drought conditions experienced in the region over the past decade.

The indicator comparison for the period April 2000 – April 2008 shows inconsistencies in the percent frequency of drought occurrence between each of Alcoa/Progress Energy's indicators. The DM was the least consistent indicator compared to streamflow and storage with a much higher frequency of drought occurrence for all stages except Stage 1. The percent frequency of months with no drought was 67 percent based on the storage indicator, 64 percent based on streamflow, but only 34 percent based on the DM.

Table 4.41 Percent frequency of drought for Alcoa/Progress Energy LIP indicators.

Drought Level	Storage 12/96-4/08	Storage 4/00-4/08	Streamflow 12/96-4/08	Streamflow 4/00-4/08	DM[1] 4/00-4/08
Stage 4	2.21	3.09			5.15
Stage 3	11.03	9.28	3.68	5.15	12.37
Stage 2	5.15	5.15	3.68	5.15	14.43
Stage 1	6.62	7.22	11.76	16.49	16.49
Stage 0	5.88	8.25	7.35	9.28	17.53
No Drought	69.12	67.01	73.53	63.92	34.02

[1] U.S. Drought Monitor

The chi-square test was used to analyze the actual occurrences of drought in each category of Alcoa/Progress Energy's LIP. Stage 3 and Stage 4 were combined since Stage 4 has no separate criteria based on streamflow. The chi-square statistic and p values indicate no difference in the occurrence of drought based on storage and streamflow (chi-square 6.53 and p-value 0.163). A statistically significant difference did occur between the storage indicator and the DM (chi-square 25.83 and p-value 0) and between the streamflow and DM (chi-square 30.45 and p-value 0). The indication that there is no statistical difference between the storage indicator and the streamflow indicator is based on frequency in each drought category; this does not guarantee consistency between stages each month. This will be explained following a comparison of drought occurrence based on Alcoa/Progress Energy's LIP indicators and Duke's LIP indicators.

4.41 Alcoa Yadkin and Progress Energy's Low Inflow Protocol indicators compared with Duke Energy's Low Inflow Protocol indicators.

Distinct differences are found between the frequency of drought based on Alcoa/Progress Energy's LIP indicators (Table 4.41) and Duke's LIP indicators (Table 4.31). The greatest differences are for streamflow and storage since each power company computes these indicators differently. Both use a 3-month average of the DM. Based solely on the DM for the study period, April 2000 – April 2008, droughts occurred somewhat more often in the Catawba-Wateree River Basin (29 percent occurrence of months with no drought designation compared to 34 percent in the Yadkin-Pee Dee River Basin).

The storage indicator from Alcoa/Progress Energy's LIP had a higher occurrence of Stages 3 and 4, but a lower occurrence of the earlier stages (Stage 0 to Stage 2). Stage 4 has never occurred based on Duke's storage indicator whereas Stage 4 occurred 3.09 percent based on Alcoa/Progress Energy's storage indicator. Stage 3 drought also occurred more often (8 percent) based on Alcoa/Progress Energy's storage indicator. However, Stage 1 and Stage 0 occurred 8 percent to 13 percent less often based on Alcoa/Progress Energy's LIP.

The detection of drought via streamflow had the greatest difference between the two LIP indicators. The 3-month streamflow triggered Stage 3 and Stage 4 thirty percent less often than Duke's 6-month streamflow indicator. This large difference may be attributed to the differences in the 6-month versus 3-month values, but also because Alcoa/Progress Energy does not have separate streamflow criteria for Stage 3 and Stage 4. For stages 2, 3, and 4, Alcoa/Progress Energy's 3-month streamflow triggered drought less often. Alcoa/Progress Energy's storage and streamflow indicators indicated a higher frequency of months with no drought compared to Duke's storage and streamflow indicators.

The analysis of the monthly drought stages according to each of Alcoa/Progress Energy's LIP indicators will be discussed below. The discussion focuses on two periods, May 2002 to May 2003 and August 2007 to April 2008. The period May 2002 – May

2003 was selected since the stage reached the highest level during that time, Stage 4. The period January 2007 to March 2008 is discussed since the LIP was followed according to the new license to deal with the serious drought.

Table 4.42 shows the monthly drought level and gives the overall LIP stage recreated for the dates May 2002 to May 2003. The official LIP quickly progressed from Stage 1 in May 2002 to Stage 4 by August 2002. Through the entire period, only one month, September 2002, showed the storage, streamflow, and DM depicting the same level of drought. The largest discrepancies between the indicator stages occurred during recovery from the drought. Leading up to the Stage 4 declaration in August 2002, either the DM or streamflow supported the storage indicator detection of a higher level. The LIP requires the storage indicator and only one of the other indicators in order to trigger the next level. During the recovery from drought, to lower the drought level all indicators must indicate a lower stage or High Rock storage has to return to the LIP-specified levels.

Streamflow and storage indicated a much faster recovery from the drought than the DM. The DM kept the official declaration at a higher stage than indicated by storage and streamflow from October 2002 through February 2003. Storage and streamflow indicated no drought by December 2002, but the DM kept the official LIP at Stage 2. By March 2003, the recovery criterion relating to the elevation of High Rock storage (2.5 feet above the normal minimum elevation) was reached and the LIP was discontinued even though the DM still indicated Stage 0. The DM did not recover to a no drought declaration until May 2003.

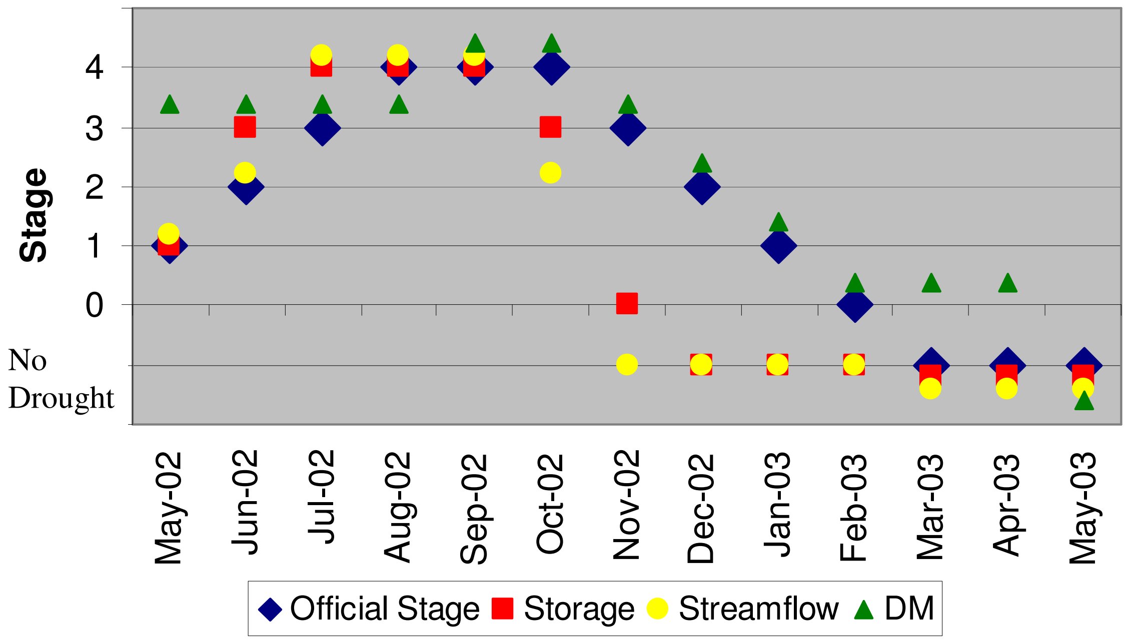


Figure 4.41 Alcoa/Progress Energy LIP indicator stage comparison, May 2002 – May 2003.

During the next study period, the power companies and water users followed the LIP. Figure 4.42 shows the stages by month and gives the overall LIP stage for August 2007 – April 2008. During no months did all the indicators consistently trigger the same drought level. The intensification and recovery from the drought, based on the storage indicator, were faster and not closely reflected by the DM or the streamflow levels. The official LIP declaration reached Stage 1 by October 2007. The intensity of the 2007-2008 drought was less severe in the Yadkin-Pee Dee River Basin as compared to the Catawba-Wateree River Basin where Duke's LIP reached Stage 3.

Once again, the largest discrepancies among Alcoa/Progress Energy's indicators occurred during the recovery. Storage improved to normal elevations or no drought by November 2007, but a downgrade was not supported by any of the recovery criteria. By

December 2007, the official stage was downgraded to no drought and the LIP discontinued because High Rock's elevation recovered to 2.5 feet above the normal minimum level. Streamflow and the DM continued to reflect Stage 1 or higher drought conditions. Streamflow primarily remained at Stage 1 through the end of the study period (April 2008); however, the DM remained in Stage 3 and Stage 4 drought. The High Rock storage indicator returned to normal in November 2007, while five months later, the DM and streamflow were still in drought. The DM is most inconsistent in comparison to the storage indicator with the DM showing a Stage 4 or Stage 3 while storage had recovered to normal elevations.

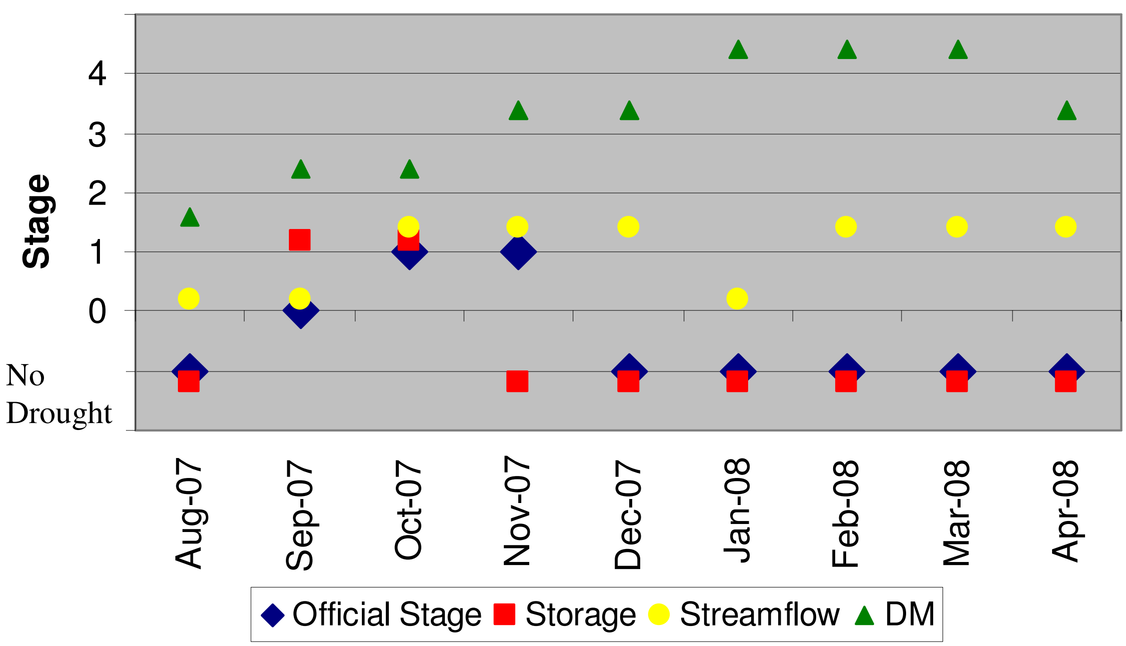


Figure 4.42 Alcoa/Progress Energy LIP indicator stage comparison, August 2007 – April 2008.

Duke and Alcoa/Progress Energy experienced similar inconsistencies between the indicators. Alcoa/Progress Energy has not faced the same challenges as Duke Energy because they have the recovery criteria that allow a downgrade if their storage recovers above the normal minimum elevation. The 3-month streamflow indicator for Alcoa/Progress Energy also proved to be more consistent with the storage indicator than the 6-month streamflow indicator for Duke. In the May 2002 to May 2003 period discussed, the Alcoa/Progress Energy's 3-month streamflow recovered to a no drought classification one month before Storage. During the August 2007 – April 2008, the 3-month streamflow was less consistent with storage, but was at a lower stage than the DM. Stakeholders and system operators in the Yadkin-Pee Dee Basin confirm that the two additional recovery criteria, based on storage in Alcoa/Progress Energy's LIP, have provided them with a more accurate representation of the drought's true impact on their system and compensated for the inconsistency in the indicators based on 3-month streamflow and the 3-month average DM.

4.5 City of Rock Hill's Drought Indicator Comparison

The City of Rock Hill pumps source water from Lake Wylie, one of the Catawba-Wateree chain of reservoirs, in the northeast portion of York County. The distribution system serves residential, commercial, and industrial public water customers inside the corporate city limits of Rock Hill and certain customers adjacent to, but outside, the corporate limits. Their wholesale customers include the Town of Fort Mill and York County. As of 2002, the City of Rock Hill served approximately 23,552 customers. Since the City of Rock Hill draws water from the Catawba-Wateree River Basin they are expected to follow guidelines set forth in Duke Energy's LIP.

The City of Rock Hill changed their local drought plan and related drought indicators in early 2008 to comply with response requirements and the drought indicators provided in the LIP for the Catawba-Wateree River Basin. The City of Rock Hill is one of over 20 water withdrawers that must comply with the LIP. All water withdrawers who signed the relicensing agreement or joined the Catawba-Wateree Water Management Group are expected to follow the LIP and other licensing requirements. This suggests that consistent drought indicators require integrating local drought plans with the LIPs. In turn, these indicators trigger uniform response strategies that can be jointly applied to mitigate drought impacts on water supply in the river basin.

The City of Rock Hill's previous ordinance had two indicators used for triggering three levels of drought (moderate or phase 1, severe or phase 2, and extreme, phase 3). The indicators included the water filter plant's average daily treatment capacity expressed as a percent of S.C. Department of Health and Environmental Control's permitted capacity and the elevation of Lake Wylie (Table 4.51). Their revised ordinance uses indicators listed in the LIP and meets the response requirements (i.e, water conservation goals) required by both the LIP and South Carolina's model local drought management plan and response ordinance.

Table 4.51 City of Rock Hill's previous ordinance drought indicators.

System Name	Source	Moderate	Severe	Extreme
City of Rock Hill	Lake Wylie	1. Avg. daily treatment capacity is 80% of permitted capacity.* 2. Lake Wylie elevation is 95 ft	1. Avg. daily treatment capacity is 85% of permitted capacity.* 2. Lake Wylie elevation is 90 ft	1. Avg. daily treatment capacity is 90% of permitted capacity.* 2. Lake Wylie elevation is 85 ft.

*The average daily treatment capacity indicator was not available for this analysis.

This analysis compares the frequency of drought severity based on the City of Rock Hill's lake elevation indicator in their former ordinance with the new indicators listed in the LIP (LIP Storage, 6-month streamflow and 3-month average DM). A more common practice in South Carolina is for water systems to use their individual lake elevation and an additional indicator such as daily use. However, even if the water system's intake is on one lake, the new LIP, especially in the Catawba-Wateree river basin, encourages them to use a storage indicator that reflects storage upstream or for the entire basin.

The percent frequency comparison displayed in Table 4.52 for the period April 2000 to April 2008 shows the large differences between the City of Rock Hill's previous Lake Wylie elevation indicator and the new LIP indicators. Based on the elevation indicator used in their old ordinance, extreme and severe drought did not occur during the study period. The percent frequency of moderate droughts was 10.64 percent. A side analysis of the period of record daily data for Lake Wylie, 1951-2008, indicates that the elevation has never dropped below the extreme defined level of 85 feet and only twice did the elevation drop to or below the 90 feet severe drought trigger. On January 7, 1958, the elevation dropped to 89.6 ft., and on April 8, 1957, the elevation dropped to 90 ft. These dates coincide with another lengthy and serious drought that plagued the state. The chi-square statistics comparing Lake Wylie elevations to the LIP indicators show that the differences are statistically significant with p values at or less than 0.00.

Table 4.52 compares the percent frequency of drought based on the City of Rock Hill's old ordinance indicators, the overall LIP stage, and the individual LIP indicators (storage, 6-month streamflow and LIP) for the period April 2000 – April 2008. Based on the old ordinance, the City of Rock Hill only experienced drought 11 percent of the time, whereas, based on the LIP, the river basin was in some level of drought 71 percent of the time. A comparison of Lake Wylie's elevation triggers compared to the LIP storage indicator shows major differences. The differences can be attributed to using one lake elevation compared to a combination of lake storage and to the triggers established for the indicators. Based on the City of Rock's Hill old ordinance, droughts would rarely be triggered. However, based on the new LIP indicators, the City of Rock Hill is in each stage of drought more often and for the first time reached severe and even extreme drought levels (Stage 3 of the LIP is equivalent to the extreme level based on State drought levels).

The City of Rock Hill's water system managers indicate that education is key to helping their customers understand the new drought criteria and the increased frequency of drought based on their new ordinance. As expected, the majority of their customers are most concerned with reaching Stage 3, which requires mandatory water conservation, and during 2007-2008, required a complete ban on outdoor watering. Most water system managers in the Catawba-Wateree River Basin emphasize the importance of a coordinated response and are members of the Catawba-Wateree Drought Management Advisory Group (CWDMAG), which helps facilitate the basin-wide response.

Table 4.52 Percent frequency of drought occurrence based on City of Rock Hill's old ordinance lake elevation indicator compared to Duke's LIP Indicators.

Rock Hill's Previous Drought Levels	Lake Wylie Elevation	Duke's LIP	LIP Overall Stage		Storage	Streamflow	DM
	4/00-4/08	Drought Levels	4/00-4/08		4/00-4/08		
		Stage 4	0		0.0	15.5	5.2
Extreme	0	Stage 3	6.2		1.0	19.6	14.4
Severe	0	Stage 2	16.5		7.2	10.3	15.5
Moderate	10.6	Stage 1	26.8		15.6	10.3	16.5
Incipient	Not defined	Stage 0	21.7		21.6	4.1	15.5
No Drought	89.4	No Drought	28.9		54.6	40.2	33.0

The majority of the water systems in the Catawba-Wateree River Basin brought their local drought plans in line with the LIP, and they were quickly tested during the 2007-2008 drought. Marilyn Lineberger, Duke Energy spokesperson, stated that "Working together and implementing the LIP helped protect drinking water, electricity, and water for jobs." as the drought persisted (Lineberger, personal communication, 2008). In other South Carolina basins with LIPs in place, less collaboration and integration of drought plans occurs. This one case study demonstrates the discrepancies in drought stage declarations and corresponding actions that can occur when indicators are inconsistent. These results can also be used by Duke Energy and SCE&G to illustrate the importance of indicator consistency as they develop LIPs for the Saluda and Keowee hydropower projects.

4.6 Evaluate use of indicator percentiles comparison as a method to improve drought detection.

The fourth objective of the study is to evaluate expressing indicators within a probabilistic framework by transforming indicators to percentiles and then combining the multiple indices using blends or weights to create a new blended drought index, a strategy used by the U.S. Drought Monitor authors (Svoboda et al., 2002) and of specific interest for LIPs. A possible solution for using multiple and often statistically inconsistent indicators is to transform all indicators to percentiles (Steinemann et al., 2005). This can be accomplished using an empirical cumulative distribution function. Drought plan triggers can then be based on percentiles rather than raw indicator values. The decision maker can relate triggers to the concept of return periods or probabilities of occurrence and the trigger values associated with each drought level would be statistically consistent. For example, an extreme drought could be equivalent to the 2nd percentile rather than –4.0 for the PDSI and –2.0 for the SPI.

Once all indicators are based on percentiles, they can be weighted and combined to create a blended index, a technique used by the U.S. Drought Monitor authors. Few references in the literature demonstrate or evaluate the effectiveness of this approach. This research evaluates a blend of various indicator percentiles for the Catawba-Wateree River Basin for the period April 2000 to April 2008. The study period is once again limited to one of shorter duration to coincide with the available data for the DM. The data from January 2008 to April 2008 are preliminary since the original weather station data and streamflow data have not undergone quality control by the National Climatic Data Center and the United States Geological Survey. The cumulative frequency distribution of the blends will be compared to the storage indicator, 6-month streamflow, and 3-month average DM indicators currently listed in Duke's LIP to determine if any blend or individual indicator is a feasible replacement index.

As discussed, questions have been raised as to the effectiveness of the proposed indicators in the LIP due to conditions experienced in the most recent drought that began in 2006 and is ongoing through June 2008. Stakeholders in the Catawba-Wateree River Basin have expressed concern with the inconsistencies between the LIP indicators. The storage indicator has been at a lower stage since December 2007, but due to the 6-month streamflow average and DM the official LIP is operating under a Stage 3 declaration. The Stage 3 mandatory water restrictions are causing financial difficulties for many water systems and landscape companies. The complaint has been that with the lakes at normal elevations or higher, it is difficult to explain the Stage 3 restrictions to water system customers. The indicator analysis shows that it is not just the 6-month streamflow holding the declaration at Stage 3, but also the DM.

The original concerns expressed by resource agencies as the indicators were being developed focused on the use of the DM. The DM was not intended for smaller scale drought detection at the basin or sub-basin level. Other concerns revolved around the subjectivity of the DM introduced by the different DM authors and local input into the weekly indicator.

This research reports the difference in drought stage declarations among Duke Energy's storage indicator, 6-month average streamflow, 3-month average DM, and four indicators retrieved from the DDIT application. These indicators include the SPI 6-month, SPI 9-month, and two blended indicators. The first blended index was based on the weights and indicators used by the DM authors. The blended index uses weights and blends that consist of 27 percent Palmer Hydrologic Index, 22 percent 24-month precipitation, 22 percent 12-month precipitation, 17 percent 6-month precipitation, and 12 percent 60-month precipitation (Blend 1). The long-term blended indicator used by the U.S. DM authors includes a Climate Prediction Center soil moisture value. This indicator is not available using the DDIT Application and is only available in real-time map format. The 10 percent weight for this index was distributed equally among the five other indicators (e.g. bringing 25 percent Palmer Hydrologic Index to 27 percent). The second blended indicator was 30 percent 6-month SPI, 40 percent 9-month SPI, and 30 percent 12-month precipitation (Blend 2). Blend 2 indicators were selected to capture the longer-term scale measurements needed for detecting hydrologic droughts. Several trial comparisons of different percentages were conducted.

Five stages of drought and no drought periods were defined to correspond with the five stages of drought in the LIP (Stage 4, Stage 3, Stage 2, Stage 1, and Stage 0). The percentile ranges correspond to the those used by the DM:

- 0 to 2 percentile = Stage 4
- 3 to 5 percentile = Stage 3
- 6 to 10 percentile = Stage 2
- 11 to 20 percentile = Stage 1
- 21 to 30 percentile = Stage 0

Since the Catawba-Wateree River Basin covers 12 counties and four USGS hydrologic units (HUCs) a pre-test was performed to determine how the indicator data should be spatially averaged to best represent the entire basin. The DDIT application provides the flexibility needed to spatially average the indicator data by numerous spatial units such as counties, 8-digit HUCs, climate divisions, or basin-wide averages. The application computes station indicator values and interpolates on a four km by four km grid. This gridded-data can then be spatially averaged by different units. A chi-square test was used to determine if the differences in the drought stages according to the SPI 6-month and SPI-9 month were statistically different computed by county, 8-digit HUCs or basin-wide data. The basin-wide data were compared to county data for York and Chester Counties and to averages for three HUCS (Upper Catawba, Lower Catawba, and Wateree). Table 4.61 shows the SPI-6 month spatial comparison between basin, county, and HUC. The chi-square and corresponding p values show no statistically significant difference when comparing the SPI 6-month and SPI 9-month by county, HUCs or basin-wide. Therefore, to best represent the conditions throughout the Catawba-Wateree River Basin the basin-wide averages were analyzed.

Table 4.61 SPI-6 month spatial comparison of monthly drought occurrence between basin, county and HUCs, April 2000-April 2008.

	Basin-Wide	York	Chester	Upper Catawba HUC	Lower Catawba HUC	Wateree HUC
Stage 4	0	0	1	0	2	1
Stage 3	1	5	3	1	3	3
Stage 2	9	7	6	8	7	3
Stage 1	17	23	22	18	20	16
Stage 0	16	10	12	11	11	15

The chi-square test for independence was used to analyze the basin-wide Catawba- Wateree River frequency of drought occurrence in four drought categories (Stage3 and Stage 4 combined, Stage 2, Stage 1, and Stage 0) and for months with no drought. The analysis compared Duke Energy's storage indicator, Duke Energy' 6-month streamflow indicator, and the SPI 6-month, SPI 9-month, Blend 1, and Blend 2. The null hypothesis is that there is no difference in the frequency of drought based on the five categories (including months with no drought).

The primary purpose of this objective is to determine whether the SPI 6-month, SPI 9-month, Blend 1, or Blend 2 is a viable indicator for replacing the DM in Duke's LIP. The analysis also investigated whether using multiple indicators weighted together to create a blended indicator improves drought detection over using a single indicator. The subjective criteria used to evaluate the performance of the indicators are based on communication with Duke Energy and the Catawba-Wateree Drought Management Advisory Group. The criteria include:

- The frequency of drought occurrence by stage is more closely related to the storage indicator.
- The lead-time entering drought and the recovery from drought are adequate and more closely in-line with the storage indicator.

4.61 Results

The results of the percent frequency of drought comparison between the SPI 6-Month, SPI 9-Month, Blend 1, Blend 2, and Dukes' LIP indicators are presented in Table 4.62. Based solely on percent frequency of Stage 2, Stage 3, and Stage 4 drought occurrence, the Blend 2 indicator is most closely related to the storage indicator. The frequency of drought for the other three indicators was more closely related to the storage indicator than the LIP 3-month DM. The DM is in Stage 3 or Stage 4 drought 28 percent more often than the storage indicator. A comparison of Stage 1 and Stage 0 drought occurrence reveals that the SPI 6-Month, SPI 9-Month, Blend 1, and Blend 2 all are in Stage 1 more often than the storage indicator, but the reverse is true for Stage 0. According to the storage indicator, 54.63 percent of months have no drought. The SPI 6-Month, SPI 9-Month, Blend 1, and Blend 2 were all similar to the Storage indicator with percent frequency of no drought ranging from 45 percent to 51 percent.

The chi-square test and corresponding p-value show that the null hypothesis could be rejected and there is a significant difference in the frequency of drought based on the different indicators. Statistical differences occurred between the SPI 6-Month, SPI 9-Month, Blend 1, and Blend 2 compared to the LIP 6-month average streamflow and LIP 3-month DM. Most importantly, the null hypothesis of no difference in drought frequency was accepted when comparing the SPI 6-Month, Blend 1, and Blend 2 to the storage indicator. The p-value for the comparisons to the storage indicator was 0.532 for the SPI 6-month, 0.268 for Blend 1, and 0.373 for Blend 2. The p-value for the comparison of the SPI-9 month drought frequency to the storage indicator was 0.055 which indicates a statistical difference. The chi-square is only testing a statistical relationship between the indicators based on the frequency of drought in the five categories and does not guarantee that drought levels occur during the same months.

Table 4.62 Percent frequency of drought occurrence, April 2000 – April 2008, for SPI 6-Month, SPI 9-Month, Blend 1, Blend 2, Dukes' Storage, Duke's 6-month streamflow, Duke's 3-month average DM.

Drought Level	Storage	Streamflow[1]	DM[2]	SPI6[3]	SPI9[3]	Blend 1[4]	Blend 2[5]
Stage 4	0.0	15.5	5.2	0.0	0.0	0.0	0.0
Stage 3	1.0	19.6	14.4	2.1	4.1	2.1	1.0
Stage 2	7.2	10.3	16.5	11.3	12.4	12.4	10.3
Stage 1	15.5	10.3	15.5	21.7	24.7	21.7	24.7
Stage 0	21.6	4.1	16.5	19.6	10.3	12.4	14.4
No Drought	54.6	40.2	32.0	45.4	48.5	51.6	49.5

[1]Streamflow = 6-month rolling streamflow expressed as percent of long-term average rolling 6-month streamflow
[2] U.S. Drought Monitor
[3]SPI=Standard Precipitation Index (6-, 9- month)
[4]Blend 1=27% Palmer Hydrologic Index, 22% 24-month precipitation, 22% 12-month precipitation, 17% 6-month precipitation, and 12% 60-month precipitation
[5]Blend 2=30% 6-month SPI, 40% 9-month SPI, and 30% 12-month precipitation

Table 4.63 and Table 4.64 provide the direct stage comparison by month for the indicators under evaluation for two serious drought periods: January 2002 to May 2003 and January 2007 to April 2008. The primary purpose is to determine whether the SPI 6-month, SPI 9-month, Blend 1, or Blend 2 are suitable and reliable replacements for the DM for use in Duke Energy's LIP. The overall LIP stage depends on storage in addition to either the 6-month streamflow or 3-month DM to advance from D0 to higher stages; for recovery, all indicators must show a lower stage, including groundwater. The LIP was not in place until 2006 so prior stages are estimated based on indicators. The discussion will focus on transition months between higher and lower stages. Since the official stage can't be upgraded from D0 to higher levels without a combination of storage and one other indicator, the replacement indicator should not be repeatedly lower than the storage, which would result in a delayed stage and corresponding response. Similarly, recovery requires an indication of a lowered stage by all indicators including groundwater. Groundwater stages were not included in the graphs since they are only considered during recovery. Inconsistent and delayed recovery designations also impact response, causing confusion for stakeholders and users in the basin.

Leading into the significant summer drought of 2002, the SPI 6-month, SPI 9-month, Blend 1, and Blend 2 were all higher than storage (Table 4.63). Similar to the DM and streamflow, these indicators were one to two drought levels higher than the stage based on storage for each month. During the recovery period from the drought that began in November 2002, the SPI 6-month, SPI 9-month, Blend 1, and Blend 2 all provided a more rapid response to the improving drought conditions. Under the current LIP, the official stage would have remained in Stage 2 until December 2002 due to the LIP streamflow and the LIP DM indicators. The SPI 6-month, SPI 9-month and Blend 2 recovered somewhat faster than storage, but were generally consistent with the storage stage by indicating no drought by December 2002. Blend 1 returned to normal in January 2003. The LIP streamflow did not return to normal until March 2003. The DM returned to normal in May 2003, five months later than the storage. Any of the evaluation indicators were more consistent with the LIP storage on recovery than the LIP streamflow and DM.

Table 4.63 SPI 6-month, SPI 9-month, Blend 1, and Blend 2 drought stages compared to LIP storage, LIP 6-month streamflow, 3-month average DM stages, January 2002 – April 2003.

	Storage	DM	Streamflow	SPI6	SPI9	Blend 1	Blend 2
Jan-02	1	2	4	1	2	2	2
Feb-02		2	4	1	1	2	1
Mar-02		3	4	2	1	2	1
Apr-02		3	3	2	1	2	2
May-02		3	3	2	2	2	2
Jun-02		3	3	1	2	2	1
Jul-02	1	3	3	2	3	2	2
Aug-02	1	3	4	3	3	3	3
Sep-02	2	4	4	2	2	3	2
Oct-02	2	4	4	1	1	2	1
Nov-02	1	3	4		1	1	0
Dec-02		2	3			0	
Jan-03		1	1				
Feb-03		0	1				
Mar-03		0					
Apr-03		0					
Higher Stage than Storage				Lower Stage than Storage			

The next comparison focuses on the 2006 to 2008 drought period. Beginning in August 2006, the LIP was voluntarily followed by Duke Energy and the Catawba-Wateree Drought Management Advisory Group (CWDMAG) so Table 4.64 reflects the actual stages for storage, streamflow, and the DM. The official LIP was upgraded to Stage 1 in May 2006. Even though storage recovered to Stage 0 in June 2002 the official LIP was not downgraded to Stage 0 until January 2007 because groundwater had not recovered to the lower stage. Groundwater indicators kept the official stage at 0 for six additional months after all indicators had recovered. Water systems and users in the basin expressed minimal complaints since Stage 0 does not require any major actions and is considered a drought "watch" phase. Most water users supported the Stage 0 designation stating that until groundwater recovers all stakeholders should monitor the conditions.

By summer 2007, another extended dry period began, with the storage indicator reaching Stage 1 by August 2007. Stage 1 was supported by streamflow and the DM. Conditions rapidly deteriorated in the basin with an increase to Stage 2 in September 2007, supported by storage, streamflow, and the DM. Once again, only the SPI 6-month was at Stage 2. Stage 3 was reached in mid-October (Table 4.64 reflects Stage 3 in November 2007 since it only shows monthly stages) supported by storage, streamflow, and the DM. The official stage changes are made at the first of each month according to the LIP; however, because storage was dropping quickly an exception was made, and in mid-October 2007 the official stage was upgraded to Stage 3. The CWDMAG and Duke Energy wanted to be proactive since all conditions indicated the drought was intensifying rapidly. The SPI 6-month was the most consistent indicator with the storage indicator in detecting the drought levels during the onset and intensification of the drought during late summer and early fall 2007. The SPI 9-month was in lower stages than the storage indicator from June to September 2007, but did reflect the same stages (Stage 2 and Stage 3) in October and November 2007. Blend 1 and Blend 2 never reached Stage 3 during the 2007-2008 drought period.

Storage recovered to Stage 2 in December 2007, Stage 1 in January 2008, and to normal by February 2008 due to beneficial winter rains. The streamflow and the DM were much slower to reflect improvement, remaining in Stage 3 through April 2008 (end of this study period). Groundwater remained at Stage 3 until March 2008 and was at Stage 2 in April 2008. The SPI 6-month recovered to Stage 1 by January 2008 and to

Stage 0 in April 2008. All replacement indicators had a faster recovery than streamflow and the DM.

Table 4.64 SPI 6-month, SPI 9-month, Blend 1, and Blend 2 drought stages compared to LIP Storage, LIP 6-month streamflow, 3-month average DM stages, August 2006 – April 2008.

	Storage	DM	Streamflow	SPI6	SPI9	Blend 1	Blend 2
Aug 06	0	1	3	1	0	0	1
Sep 06	0	0	2		0		
Oct 06	0	0	1		0		
Nov 06							
Dec 06							
Jan-07							
Feb-07							
Mar-07							
Apr-07							
May-07		0				0	
Jun-07	0	1		0		0	
Jul-07	0	1	0	1		0	
Aug-07	1	1	1	1	0	0	0
Sep-07	2	2	2	2	1	1	1
Oct-07	2	2	3	3	2	1	2
Nov-07	3	3	4	2	3	1	2
Dec-07	2	3	4	2	3	2	2
Jan-08	1	4	4	1	2	2	2
Feb-08		4	4	1	2	2	2
Mar-08		4	4	1	2	2	1
Apr-08		3	3	0	2	1	1
Higher Stage than Storage				Lower Stage than Storage			

The inconsistency between the current LIP indicators during Winter 2007 and Spring 2008 resulted in confusion and complaints by water systems and users in the basin. Water systems complained that the Stage 3 LIP confused their customers since the lakes returned to target elevations in February 2008. Stage 3 requires mandatory water restrictions that limit outdoor watering to no more than one day a week for most water systems. It also prohibits car washing, using water for ornamental fountains, and filling new swimming pools. The landscape industry requested that restrictions be lowered based on the premise that the lake elevation(s) had returned to normal levels. The CWDMAG agreed it would cause more confusion to change the LIP indicators and required responses while the drought was ongoing. The changes will be considered after the drought has ended and further indicator evaluations are conducted.

The CWDMAG conducted regular meetings to better understand the indicator levels and to encourage consistent response as required by the LIP. Stakeholders in the basin agree that the overall success of the mandatory restrictions may be attributed to consistent stage declarations and response. For many water systems, their local drought ordinance implementation required approval by either a board, commission, or county/town/city council. This can be a major political battle, however, due to the LIP and consistent response by small and large water systems, the political road-blocks were mostly avoided. Many smaller water systems emphasize that having the largest water system in the basin, Charlotte-Mecklenburg Utility Department, leading the effort was a major advantage.

The study period was limited, but did cover two significant drought episodes. The evaluation of the SPI 6-month, SPI 9-month, Blend 1, and Blend 2 indicators showed some promising alternatives to replacing the DM in the LIPs. All were generally more consistent with the storage indicator during the recovery phases providing shorter lag-time. Blend 1 and Blend 2 did not perform as well as SPI 6-month or SPI 9-month in comparison to the storage indicator, suggesting that transforming indicators to percentiles and then combining the multiple indices using blends or weights did not improve drought detection over the use of single indicators. Converting the single indicators to percentiles (SPI 6-month and SPI 9-month) did improve drought detection both during the onset and recovery as compared to the 3-month DM. Additional blends could be tested in future research to confirm these results.

The CWDMAG also should consider shortening the 6-month streamflow average to avoid the slower recovery experienced during spring 2008. The 3-month streamflow indicator was more consistent with the storage indicator used by Alcoa/Progress Energy for the Yadkin-Pee Dee River Basin LIP. Another component of Alcoa/Progress Energy's LIP that proved to be successful was the recovery criteria based on their storage indicator (High Rock Lake) returning to a certain elevation which automatically cancels the LIP regardless of the other indicators' stages. Since the storage elevation is a key indicator for determining water availability in LIP river basins adding a recovery condition based solely on storage should be investigated by the CWDMAG and other entities developing LIPs in South Carolina. The recovery from the LIP should consider both a slow recovery, where all indicators must reach a lower level before the stage is lowered, to a more rapid recovery that accounts for the storage recovering to a certain elevation for a user-determined time period.

In summary, this research provides some possible solutions for reducing the scientific and operational inconsistencies found among the LIP indicators. The City of Rock Hill indicator analysis demonstrates the importance of indicator consistency to achieve basin-wide response. Lastly, the study found that transforming indicators to percentiles and then combining the multiple indices using blends or weights did not improve drought detection in the Catawba-Wateree basin over the use of single indicators.

CHAPTER 5 DROUGHT INDICATOR SURVEY

The emphasis in the previous chapters focused on the scientific validation of drought indicators. This research objective concerns the link between the scientific justification for and operational relevancy of drought indicators and drought detection. A survey was conducted to evaluate which drought indicator characteristics met the needs of water systems and power companies in S.C. The survey results provide insight into their understanding of state and local drought indicators. Based on their responses, an analysis was undertaken to determine whether water systems and power companies look for different qualities in state versus local drought indicators. Lastly, the survey asks the managers to reconstruct the historic sequence of the 1998-2002 drought impacts to better understand their ability to tolerate drought. The survey results and correspondence with water users and decision makers will be used to verify which indicator(s) meet the user's needs and more closely detect the drought impacts on their operations.

The discussion proceeds by first providing a background on survey development, population surveyed, and response rate. A signed-rank test was used to determine the statistical significance of the survey data. The survey results are presented in two sections. Section 5.1 uncovers water system manager's understanding of drought indicators and what characteristics make a more effective indicator. The study also analyzes whether system size and water source influence the system manager's identification of effective indicator characteristics. This is followed by a subsection summarizing their reconstruction and perception of the 1998-2002 drought impacts.

Section 5.2 provides a unique analysis of drought indicator comprehension and needs by all four power companies in South Carolina. Their reconstruction of the 1998-2002 drought is presented to better understand their vulnerability to drought. Lastly, section 5.3 presents implications of the research for improving S.C.'s drought response.

The survey was pretested and revised based on input from four water system managers and one retired power company hydropower manager. The survey followed the University of South Carolina's Institutional Review Board requirements. The full survey and example cover letter are included in Appendix 1. The input and guidance from the pretest were instrumental in making the survey more focused and understandable for the water system managers/operators and power company representatives.

The survey was mailed to 108 water systems and four power companies. The 108 water systems were randomly selected from a database of water systems provided by the S.C. Department of Health and Environmental Control (SCDHEC). SCDHEC's database included 298 "federally-defined community water systems." The random selection was stratified by county and population served by the water system. The U.S. Environmental Protection Agency defines small systems as serving less than 3,300, medium systems serve 3,301-10,000, and large systems serve populations over 10,000. One system from each size category (small, medium, and large) per county was selected. Since all counties did not have small, medium, and large systems, the total survey per category size was 36. The original database from SCDHEC included 154 small systems, 75 medium systems, and 69 large systems.

The first survey mail-out yielded less than a 20 percent response. A follow-up survey was sent followed by a reminder postcard. A total of 47 surveys were received from 43 water systems and four from power companies. Table 5 provides a summary of the survey response. The survey results are summarized for all respondents and analyzed based on system size and system source. Results from the power companies were analyzed and summarized separately. The system source was derived from a survey question on whether their water source was a lake, river, or groundwater. The water system source was a lake for 12 systems, a river for 13, groundwater for 16, and two systems did not answer. The power companies listed lakes and rivers as their source.

Table 5.0 Survey response rate.

	Mailed	Received	Response Rate
Small Water Systems	36	11	31%
Medium Water Systems	36	10	28%
Large Water Systems	36	22	61%
Power Companies	4	4	100%
Total	112	47	42%

5.1 Water System Survey Results

Question 1: What drought indicator(s) does your system use?

The percentage of water systems using state, local, or a combination of both as their drought indicator are presented in Figure 5.11. Only 26 percent of the water systems stated they use a combination of state and local indicators. This is an unexpectedly low number considering the S.C. Drought Mitigation Plan and Model Ordinance issued by the SCDNR pursuant to the S.C. Drought Response Act’s supporting regulations (revised in 2001) recommends water systems use a combination of the state level declaration and local indicators. Sixty percent of the systems responded they use either single or multiple local drought indicators. The sixteen percent that stated they use a single local level indicator use lake levels, well levels, average daily usage for specific number of days, or salinity levels. The reliance on local level indicators has increased over the past decade as a result of SCDNR's Model Drought Mitigation Plan and Response Ordinance initiated in 2002. All South Carolina water systems had to revise their plan and ordinance to comply with the model. A key goal of the new model was for water systems to develop system-specific drought indicators that would be used in conjunction with the state-level declarations. During discussions since the survey's completion, water systems stated that persistent drought over the past decade has further demonstrated the importance of local indicators in the drought planning process.

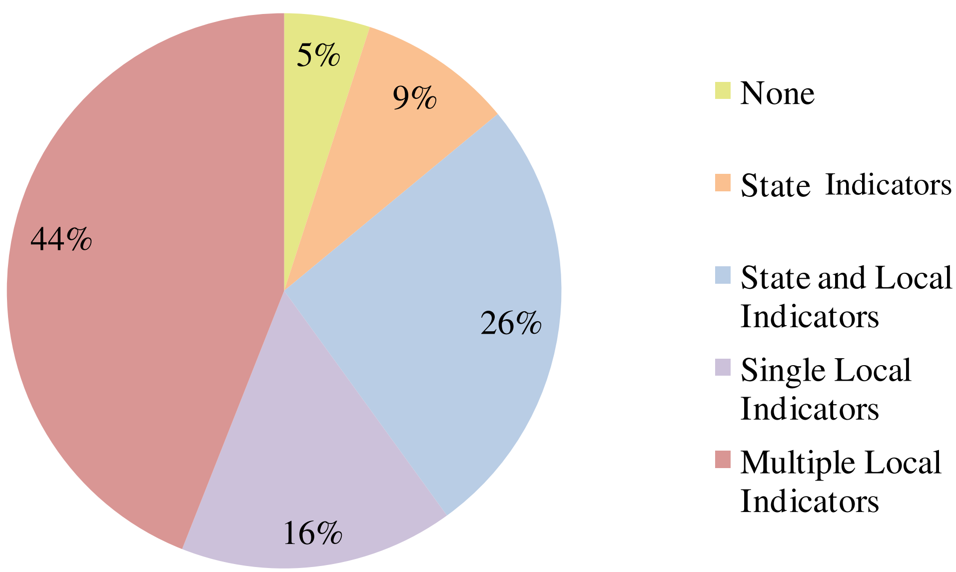


Figure 5.11 Summary of Indicator Type Used by Water Systems, N=43.

Question 2: How important is it to your system that drought indicators meet the following criteria. If you use both State and Local drought indicators please designate criteria for each. Choose Not Applicable if you only use indicators specific to your system. (Circle 1 for Not Important, 2 for Somewhat Important, 3 for Important, 4 for Very Important and 5 for Not Applicable)

Questions two and three focus on determining which drought indicator characteristics are most important for local and state drought indicators. The drought characteristics include whether the drought indicator captures the impact of extreme drought conditions, their ability to understand how the indicator is computed, whether there is easy access to the indicator data, if the indicator is widely publicized, and if the indicator provides appropriate lead time before entering each drought stage. Two of the characteristics were selected since they relate directly to the indicator's depiction of drought ("having the indicator capture the impact of extreme drought conditions" and the "ability of the indicator to provide appropriate lead time before entering each drought stage"). The remaining characteristics were selected to investigate the importance of indicator computation, visibility, and accessibility. In question two, if both state and local drought indicators were used they were requested to identify criteria for each. Even if a water system did not respond in question one that they use state indicators their results were still included since they may refer to the state indicators without using them in their official drought ordinance and plan.

In order to summarize the results of question two, the numerical equivalent score for each importance rating was averaged for each state and local indicator characteristic and provided in Table 5.12. The "5" response for not-applicable was not included in the averages. Since the data were not normally distributed the non-parametric signed rank test was used to evaluate the null hypothesis that the median difference between the observations is zero. The average scores for local and state indicators were between 3.0 and 3.9 with no single characteristic standing out as the most important. A score of 3 means important and a score of 4 means very important. The difference between the average scores for all state drought indicator characteristics ranged from 3.0 to 3.4. Water systems generally agreed that the three most important state drought indicator characteristics are having the drought indicator "capture the impact of the extreme event", "providing the appropriate lead-time before entering drought", and having the state "indicator widely publicized". The "ability to understand how the indicator is computed" received the lowest average score of 3. However, according to the signed rank test the differences between the state indicators are not statistically significant ($p \leq 0.05$).

The local indicator analysis of the importance ratings revealed that two characteristics received a statistically higher average score than the state indicators, the "ability to understand how the indicator is computed" and having "easy access to the indicator data". Almost all the systems agreed that having the indicator "capture the impact of the extreme event" and "having easy access to the indicator data" were the most important local drought indicator characteristic. Both were statistically more important than all other local characteristics. In contrast to the state indicator responses, having the local "indicator widely publicized" received the lowest average score (3.2).

Table 5.12 Average scores for state and local drought indicator characteristic.

	Captures impact of extreme drought conditions		Ability to understand how indicator is computed		Easy access to indicator data		Indicator is widely publicized		Provides appropriate lead time before entering drought stage	
All Systems Average Score	N=40	N=42	N=40	N=41	N=39	N=41	N=39	N=43	N=40	N=41
	State	Local	State	Local	State	Local	State	Local	State	Local
	3.4	3.9	3.0	3.5	3.2	3.8	3.4	3.2	3.4	3.5

The results were also summarized by counting the number of importance ratings for each state and local drought indicator characteristic (Figure 5.12). These results also showed that all characteristics for local indicators received more "very important" ratings than state indicators except having the "indicator widely publicized" which received almost equal numbers of "very important" ratings. Consistent with the results in Table 5.12, the highest number of systems gave the "very important" rating to the characteristic "capturing the impact of the extreme drought condition" (22 for state and 31 for local). Four systems responded that all the indicators were "non-applicable." Two of these were small systems that responded in question one that they did not have drought indicators. The other two were large systems - one whose source is a lake and the other depends on groundwater. The remaining "non-applicable" responses were primarily from systems that only use state level indicators.

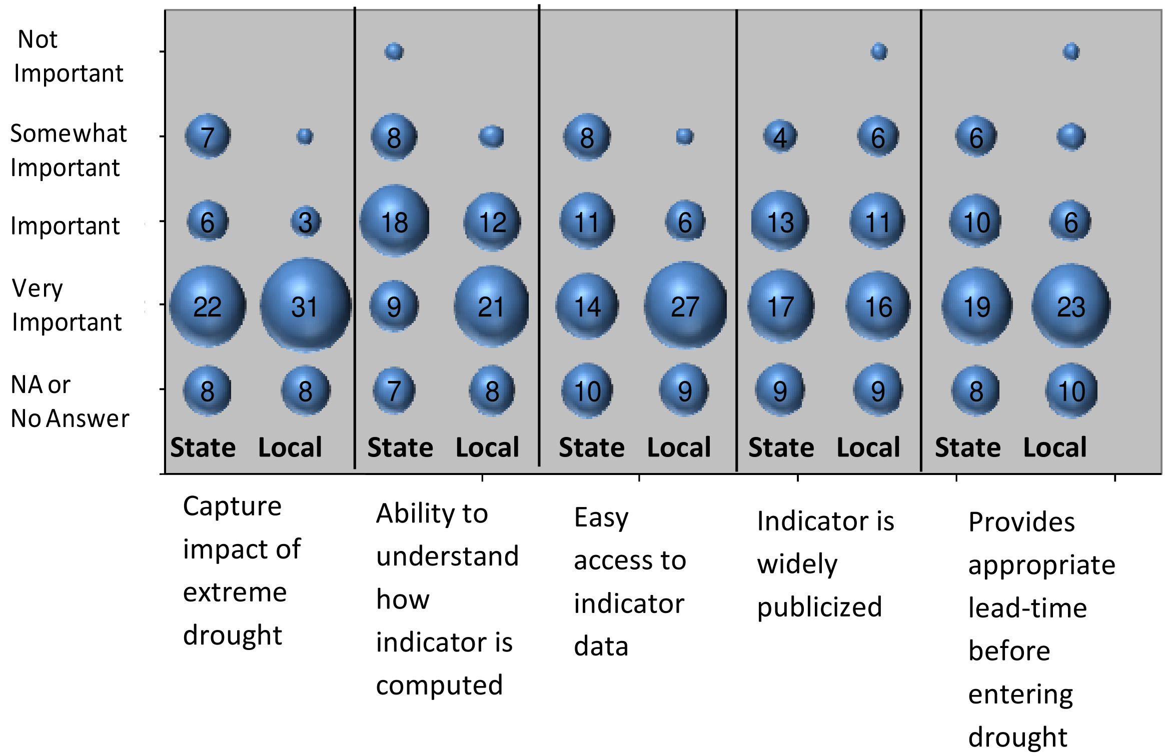


Figure 5.12 Importance of indicator characteristics to water systems.

A key discovery is that all indicator characteristics appear to be important or very important for many of the water systems. Only three systems responded that any of the characteristics were not important. Based on question two there are some similarities and only subtle differences between the drought indicator qualities water systems look for in state versus local indicators. Water system owners believe that having the drought indicator "capture the extreme event" is most important for both state and local indicators. However, they also need the state indicator to "provide appropriate lead-time before entering drought stage" and be "widely publicized." Local operators are less concerned that they have "easy access to the state indicator data", or the "ability to understand state indicator calculations", but it is important they have "access to the local indicator data" and "understand local indicator calculations." So even though access to the state level indicator data is less important, they do believe the indicator needs to be "widely publicized." But it is less important that a local indicator be publicized. Based on dialogue with water system operators, publicizing the declaration level is more important than publicizing the raw indicator data. They believe it is less important that the local indicators are "widely publicized" as compared to the other local indicator characteristics. Based on discussions with water system operators, many believe the raw local indicators such as lake or well levels may not be helpful to their customers and provision of numerical values will cause confusion. These results demonstrate that drought indicators must meet a wide array of needs, and those needs vary among water systems.

Question 3: Please rank the relative importance of these drought indicator characteristics on a scale from 1 to 5 with 5 being most important. This question builds on question 2 to help us understand your priorities better. (Each number should be used only once.)

Question three further examines the importance of drought characteristics by asking respondents to rank each characteristic on a scale from one to five (five being the most important.) In question two, the respondent could select the same importance level for all characteristics (i.e., select each as important), but in question three they are asked to rank the characteristics from least (1) to most important (5). Seven out of the 43 respondents were excluded from this question's analysis due to an incomplete response or incorrect interpretation of the question. Table 5.14 displays the results from question three for all systems and subdivided according to size. The number indicates an average of system rankings. The results based on all systems indicate that "providing appropriate lead-time before entering drought" is the most important drought characteristic (3.5). However, having the drought "indicator widely publicized" and also "capturing the impact of the extreme drought" received similar scores of 3.3 and 3.2 respectively. The "ability to understand how the indicator is computed" was the least important. This was the only characteristic that was statistically different than other indicators receiving the lowest average score of 2.6. This characteristic was statistically different than "having the indicator widely publicized" and the characteristic "providing appropriate lead time before entering drought stage."

Figure 5.13 provides a closer look at the number of systems that ranked each category in question three. For example, twelve systems ranked "providing appropriate lead-time before entering drought" as the most important. The least important characteristic based on results from all systems is the ability of the user to "understand how the indicator is computed" with a score of 94. Eleven respondents ranked it as the lowest (value of 1). Only five systems ranked it as the highest (value of 5). Figure 5.13 shows a difference among systems on what are the most important drought characteristics. Another interesting result was that only five water systems rated the indicator's "ability to capture the extreme event as most important", but 13 rated it as the second most important characteristic.

The subdivision by system size did uncover that size may be a factor in a water system's opinion of what characteristic(s) makes an effective drought indicator, however, the differences were not statistically significant. Large systems surveyed indicated that having the "indicators widely publicized" is most important (3.6), whereas small systems responded this was one of the least important characteristics (2.9). For medium systems, having the "indicators widely publicized" was tied with "providing appropriate lead-time" as most important. "Providing appropriate lead-time before entering drought" was either the most important or second most important characteristic regardless of size. Medium and small systems do appear to be more interested in the "ability to understand how indicators are computed," while large systems rated this characteristic as the least important.

Table 5.14 Average ranking for each drought indicator characteristic for all systems and subdivided by system-size.

	# of Systems *	Captures impact of extreme drought conditions	Ability to understand how indicator is computed	Easy access to indicator data	Indicator is widely publicized	Provides appropriate lead time before entering drought stage
All	36	3.2	2.6	2.9	3.3	3.5
Large Systems	17	3.2	2.2	3.2	3.6	3.4
Medium Systems	10	2.9	3.0	2.7	3.2	3.2
Small Systems	8	3.4	3.1	2.8	2.9	3.9
* 3 large systems excluded because of incorrect interpretation of the question						
* 3 small and 2 large systems did not respond to question						

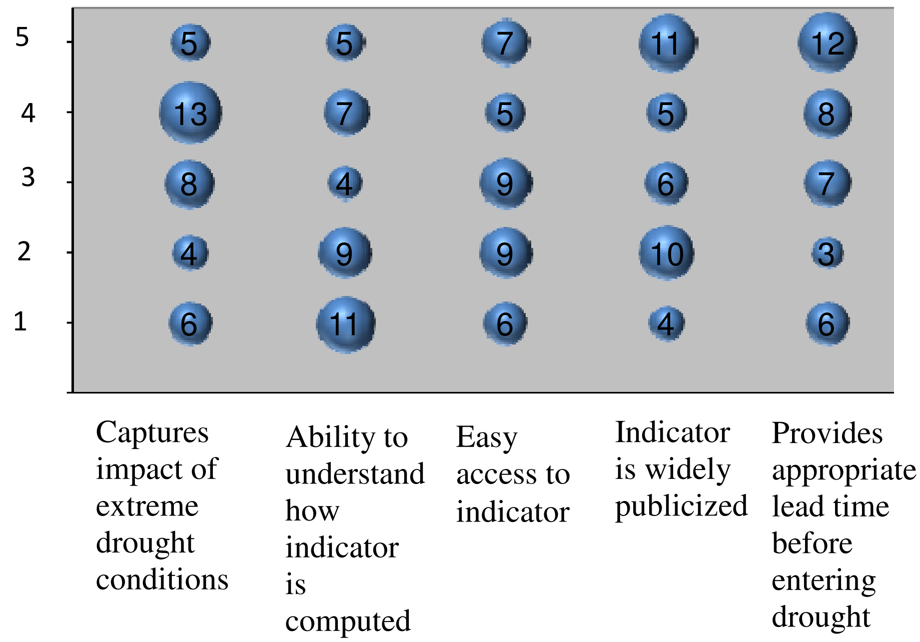


Figure 5.13 Number of systems that ranked each category.

It also appears that water system source may be a factor that influences a water system's classification of indicator characteristic importance (Table 5.1), but the differences are not statistically significant. The greatest difference is the system's "ability to understand how the indicator is computed." Groundwater systems indicated this was one of the most important characteristics while river and lake systems stated it was one of their least important. Systems with a lake(s) as the source responded that having "easy access to the indicator data" was most important. Groundwater systems ranked it as least important. Overall for groundwater systems there was minimal difference between the rankings for four of the five characteristics. Different characteristics were identified as the most important by the 13 groundwater systems resulting in the close average scores. Lake and river systems tend to have more of a consensus within each group as to the one or two most important characteristics and, likewise, the least important.

Table 5.15 Average ranking for each drought indicator characteristic for all systems and subdivided by system-source.

	# of Systems *	Captures impact of extreme drought conditions	Ability to understand how indicator is computed	Easy access to indicator data	Indicator is widely publicized	Provides appropriate lead time before entering drought stage
Lake Systems	9	3.5	2.6	3.8	3.2	3.0
River Systems	12	3.0	2.1	2.8	3.8	4.2
Ground-water Systems	13	3.1	3.2	2.5	3.1	3.2
* 3 lake systems, 1 river system, and 3 groundwater systems excluded b/c of answer						

In summary, results from question two and three provide insight into how water systems perceive the importance of drought indicator characteristics. The overall results, including those subdivided by size and water source, demonstrate qualitative differences among water systems on which drought characteristics are most important. No single characteristic stands out as the most important among all water systems. In general, most water systems believe the three most important drought characteristics are "providing appropriate lead-time before entering drought stages," "capturing the impact of the extreme drought," and the "indicator being widely publicized." Many of the results, however, are not statistically significant. Overall, most water systems surveyed selected the "ability to understand how the indicator is computed" as the least important characteristic.

Survey results demonstrate that water systems value both local and state drought indicators, but, they have higher expectations and depend more heavily on their local indicators. They want both the state and local indicators to capture the extreme drought conditions, but they are less interested in understanding how the state indicators are computed and having access to the state indicator data. They do, however, want the state indicators widely publicized.

System-size and system source influenced the water systems' opinion of what characteristic(s) makes an effective drought indicator. Large and medium systems indicated that having the "indicators widely publicized" is most important, whereas small systems believed it to be least important. Medium and small systems were more interested in the "ability to understand how indicators are computed," while large systems rate it as least important. Groundwater systems also are interested in the ability to understand how indicators are computed. River and lake systems stated this was one of their least important characteristics.

Another goal of the survey was to determine whether drought indicator consistency between water systems and their alternative water providers (Question 6) and consistency with upstream systems is a measure of drought planning effectiveness (Question 7). The SCDNR urges water systems in the model S.C. Drought Management Plan and Response Ordinance to have "cooperative agreements with alternative water supply sources" to strengthen conservation efforts. Currently, systems that share water have contracts that control the amount of water distributed between systems, but the contracts don't usually contain stipulations that reduce water amounts based on drought severity and its impacts. Water system drought plans have response actions for the system's domestic users, but often do not for their contractual and wholesale customers. Evaluations of water system local drought plans does not clearly demonstrate that water systems have consistent plans and whether they believe integrated agreements are important for effective drought planning.

While not specified in the model S.C. Drought Management Plan and Response Ordinance, drought plan consistency with upstream users is encouraged by SCDNR. Upstream users often control the flow of the river through releases from their dams or by the amount of water they take from the river itself. Rivers are often the primary source for downstream surface water users either directly or by feeding into downstream reservoirs. This is a complicated process since many of the state's rivers have multiple reservoirs controlled by different users.

Question 6: How important is it to your system that your drought indicators are consistent with drought indicators used by your alternative water providers? (Circle either not important, somewhat important, important, very important, don't know or not applicable)

The results from question six are presented in Figure 5.14. Almost one-third of systems surveyed said that drought indicator consistency with alternative water system providers was not applicable. Two are river-based systems, six have a lake as their source and six depend on groundwater. A review of their local drought plans available on the SDNR Drought Management Plan and Response Ordinance Inventory website (https://www.dnr.sc.gov/pls/drought/drought_survey_search) found that many of these systems have no alternative providers and responded accordingly. For three systems, the "not applicable" response is inconsistent with their local drought plans that state that water conservation agreements with wholesale customers are needed and being negotiated. It is unclear whether the conservation agreements would include consistent indicators. Three systems have cooperative agreements with wholesale customers with no plans to incorporate drought provisions in the agreements. Four of the systems did not provide a system name so their local drought plan could not be reviewed.

Only two of the systems surveyed did not know whether indicator consistency with alternative water providers is important. The remaining small systems (six) believe indicator consistency with alternative providers is important or very important.   The sample size is reduced when the systems that responded “not applicable” are removed from the comparisons. These responses were not included in the percentage comparisons discussed below. Fewer of the large and medium systems believe indicator consistency with alternative providers is important or very important (57 percent to 60 percent respectively). System-source does seem to influence the results, but it should be noted the survey size is small, especially for lake systems, after removing the “not applicable” systems from the sample size.   Of the six lake systems remaining, 83 percent responded that indicator consistency with alternative water providers is important or very important. Fifty percent of the river systems (five out of 10) and 67 percent of the groundwater systems believe it is important or very important. Despite the S.C. Drought Management Plan and Response Ordinance’s emphasis on “cooperative agreements with alternative water providers,” many water systems don’t believe indicator consistency with alternative water providers is important. Small systems and those using lakes as their source-water do think it is important. There was no overlap between the small systems and lake-based system responses. In many cases, the small system’s response can be attributed to their dependence on alternative water providers as their primary water source. In summary, indicator consistency with alternative water providers is a measure of effectiveness for drought planning for some systems. There is not a clear consensus among all water systems that this characteristic is important and the survey responses and the local drought plans are somewhat inconsistent.

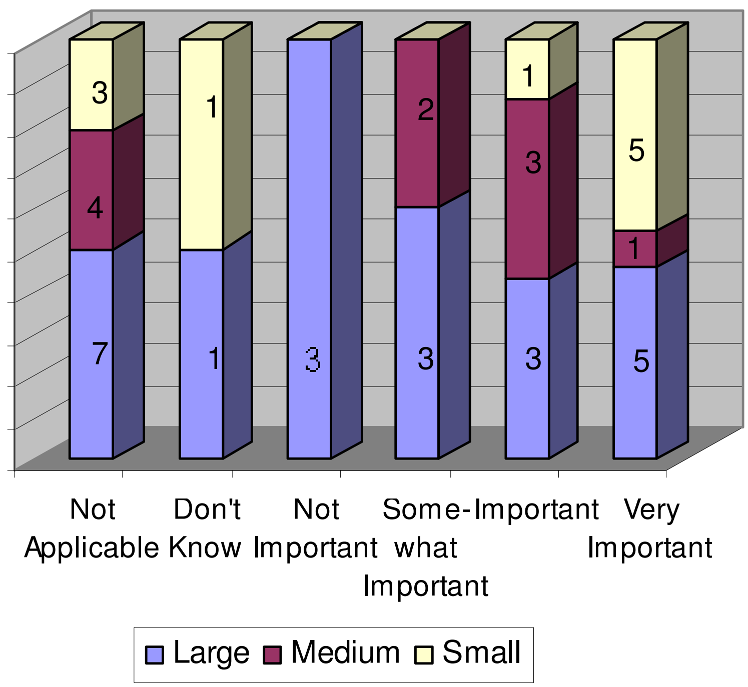


Figure 5.14 Drought indicator consistency with alternative water providers summarized by system size. N=22 large systems, 10 medium, 10 small.

Question 7: How important is it to your system that your drought indicators are consistent with drought indicators used by upstream systems? (Circle either not important, somewhat important, important, very important, don't know or not applicable)

Question seven in the survey addressed the importance of drought indicator consistency with upstream water systems and whether this is a measure of drought planning effectiveness. The results are presented in Figure 5.15. Twelve systems or 28 percent responded it was not applicable. Seven of these were groundwater systems. Unfortunately, this was a significant percentage of the medium and small systems surveyed. One large, groundwater system responded they didn't know. Six systems, (14 percent), which were mostly all large providers (three groundwater systems, two lake systems, and one river system), responded that indicator consistency with upstream water systems was not important. Sixty-two percent of the remaining systems stated that drought indicator consistency with upstream water systems is important or very important.

System-size appears to influence the evaluation. The medium systems think indicator consistency with upstream systems is important or very important (83 percent) while only 61percent of the large systems and 40 percent of the small systems responded as such. The sample size was only six for the medium systems. Two medium systems are part of the basin-wide drought planning associated with the Low Inflow Protocols that requires consistent drought indicators between upstream and downstream users.

System-source also appears to be a factor with 82 percent of river-based systems responding that indicator consistency with upstream systems is important or very important. This is expected since river-based systems are the most vulnerable to an upstream user's control of river flows. Only 37 percent of groundwater systems think indicator consistency with upstream users is important. This is also expected since their groundwater source does not depend on river flows. Approximately half of the lake systems (55 percent) think indicator consistency with upstream water users is important. Only one of the medium-sized systems retrieved their water from a river so there was no overlap in this comparison.

In summary, indicator consistency with upstream water systems is a measure of effectiveness for drought planning primarily for some surface water systems. There does not seem to be a consensus among all water systems that it is important.

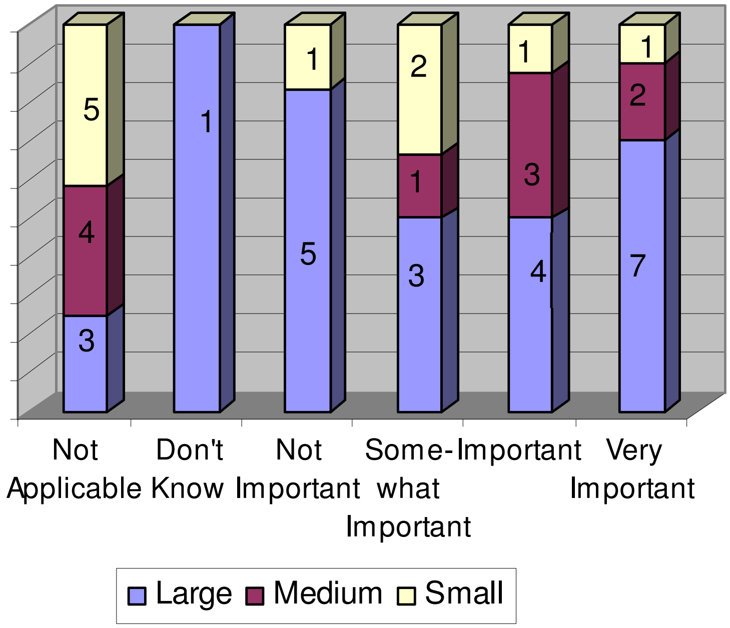


Figure 5.15 Drought indicator consistency with upstream water systems summarized by system size. N=22 large systems, 10 medium, 10 small.

5.11 Water system's reconstruction of the 1998-2002 drought impacts

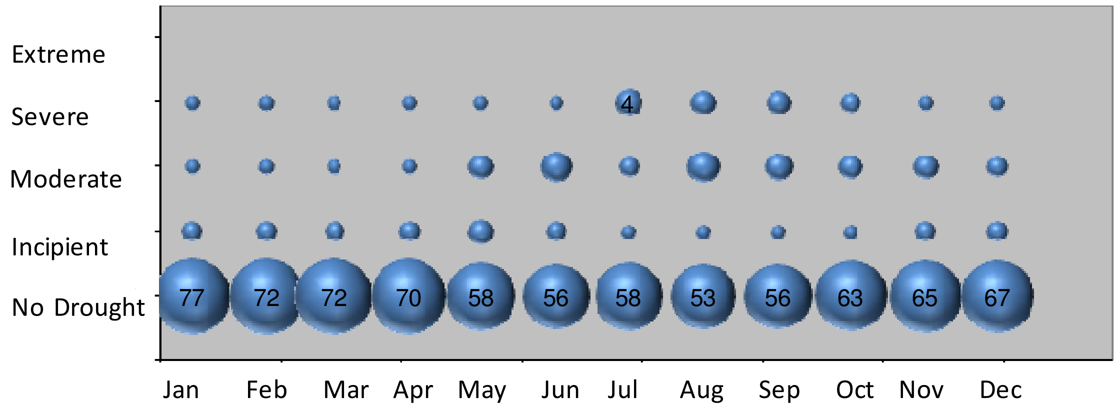
The purpose of question four is to determine the severity of drought experienced by water systems during and coming out of the 1998-2002 drought. These assessments are then compared to the historic sequences of drought (based on the S.C. Drought Response Committee's official declaration) to better understand the water systems' vulnerability to drought impacts and the duration and severity of their impacts compared to the Committee's declaration. The survey dates begin in 2000 rather than 1998 when the record drought began because the survey pre-test and development proved it was difficult for respondents to specifically designate conditions for each month going back more than five to seven years. Additional uncertainty and resulting biases should be considered in interpreting the responses for earlier years. The average number of systems responding that they did not know increased from 7 percent in 2006 to 23 percect in 2000. The survey was issued in March 2007, therefore it did not capture the 2007-2008 drought.

Question 4: For the years 2000-2006, or the periods you confidently remember, please indicate which months your system was impacted by drought. Draw a line through the drought-free months. Place an I for Incipient, M for Moderate, S for Severe, or E for Extreme in each date block for the severity of drought your system experienced. If you Don't Know, mark the month DK.

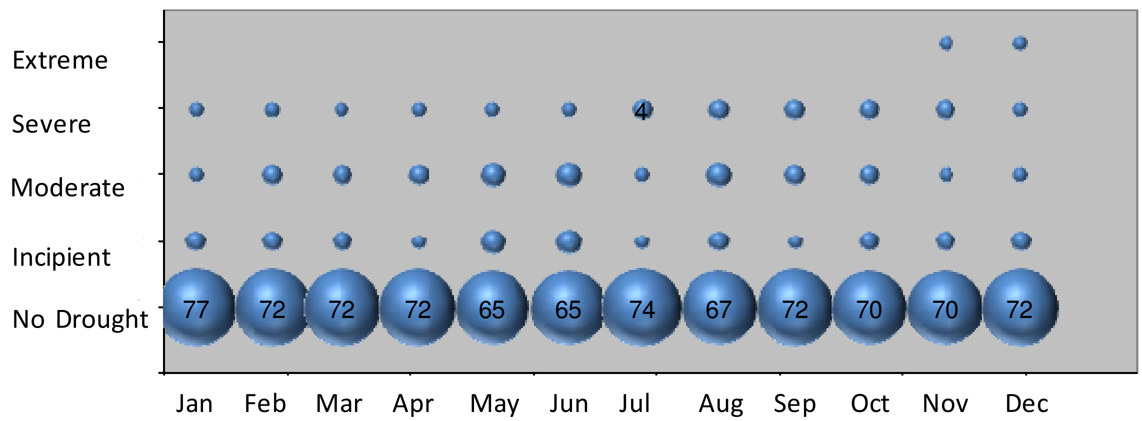
Figures 5.16, 5.18, and 5.20 display the percentage of systems that experienced the different levels of drought severity impacts for the period 2000-2001. Twelve out of the 43 systems, or 28 percent, designated that their system never experienced drought conditions during any month for the study period. At least one system in every month did designate some level of drought. According to the S.C. Drought Response Committee, the drought officially began during the summer 1998 and ended in April 2003; however, other brief drought periods were designated in 2004 and 2006. Figures 5.17, 5.19, and 5.21 display the percentage of the state in the highest level of drought based on the S.C. Drought Response Committee's declarations compared to the percentage of water systems experiencing drought impacts. The drought was upgraded and downgraded by the S.C. Drought Response Committee on numerous occasions, with it reaching severe in 1999 and again in 2002. In July of 2002, the committee upgraded the status to extreme, the highest level of drought according to the S.C. Drought Response Act. The only years without some level of declaration by the committee were 2003 and 2005.

During early 2000, most of the systems (70 percent to 77 percent) indicated they did not experience drought impacts (Figure 5.16). The official drought declaration by the S.C. Drought Response Committee was in the first stage of drought, or incipient, through April 2000 for most of the state (Figure 5.17). The Committee upgraded the state declaration in May 2000 for parts of state. A moderate declaration remained in effect for most of the state through 2000. As summer 2000 approached, more water systems indicated they were experiencing moderate to severe conditions, but the percentage of systems was still relatively low. During the study period, the trend was for a greater number of water systems to experience higher levels of drought impacts during the summer and early fall months when demand and evaporation are higher. Throughout most of 2001, especially May to September, fewer systems experienced drought impacts compared to 2000; however, by November 2001, one system indicated it was experiencing extreme drought impacts.

Figure 5.16 Percentage of water systems experiencing drought impacts, 2000-2001: a) 2000, b) 2001.



a) 2000



b) 2001

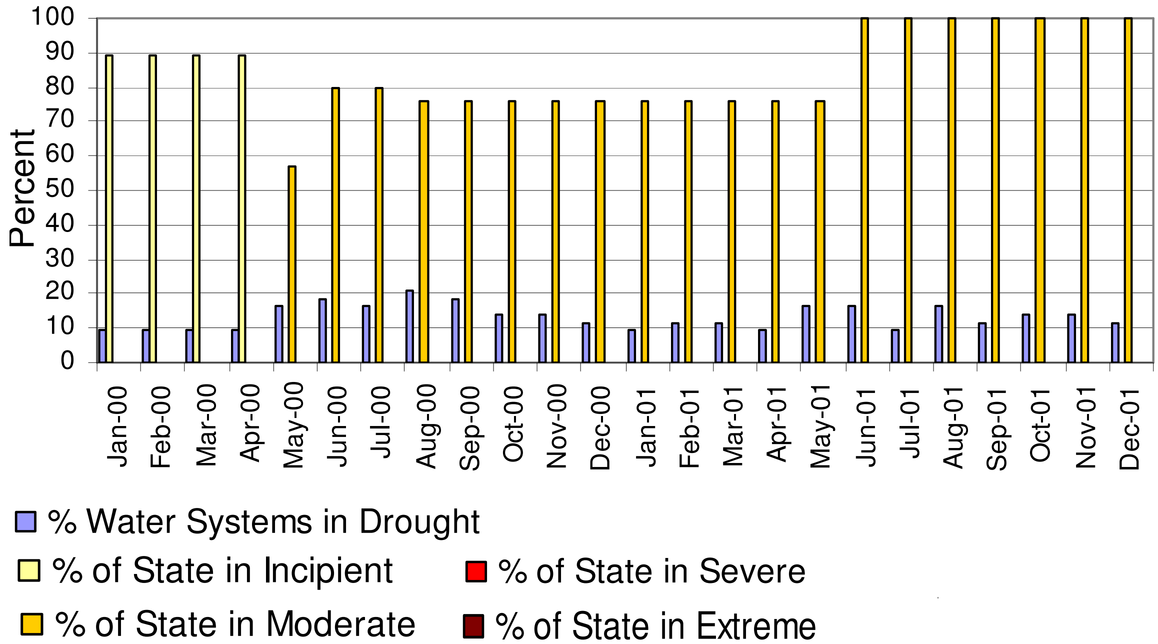
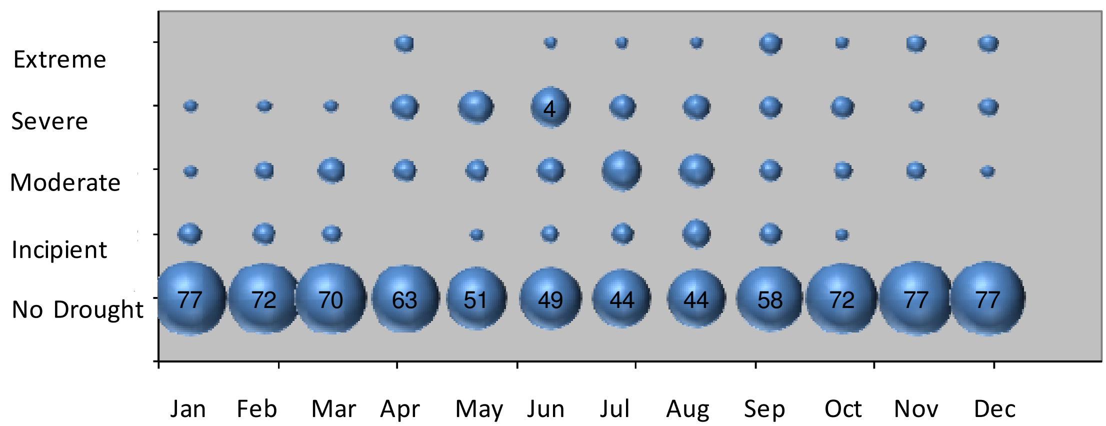


Figure 5.17 Percentage of the state in the highest level of drought based on the S.C. Drought Response Committee's declarations compared to the percentage of water systems experiencing drought impacts during 2000-2001.

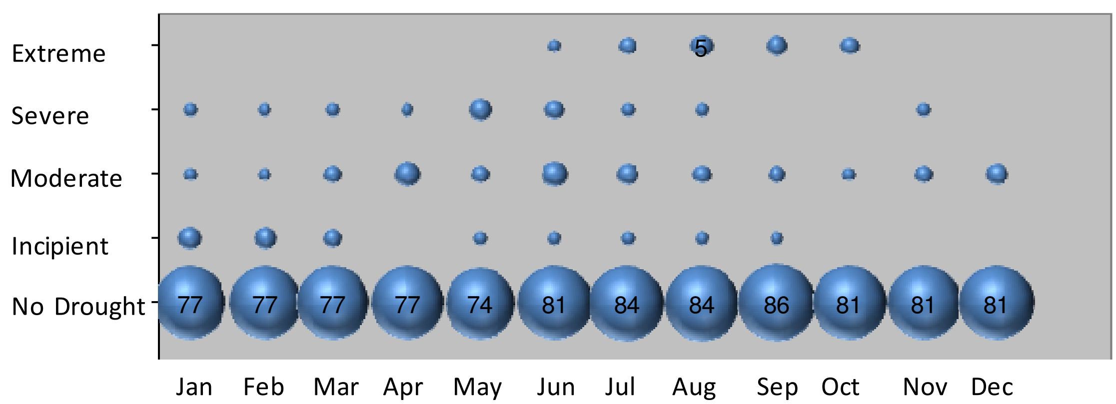
Based on the majority of actual drought indicators, the S.C. Drought Response Committee declarations and results from the survey, summer 2002 was the height of the drought with 40 percent of the water systems surveyed indicating some level of drought (Figure 5.18). The official state declaration (Figure 5.19) reached severe by June 2002 and extreme, the highest level of drought, in July 2002 (for most of the state). The number of water systems experiencing drought impacts increased throughout 2002 and by August five systems were experiencing extreme drought impacts, seven experiencing severe, and five experiencing incipient to moderate impacts.

According to actual indicator data, discussion with water systems, and survey interpretation, 2003 was the year most sectors recovered from the 1998-2002 record drought. There was no state declaration in place after April 2003. Survey results indicate a small percentage of the water systems continued to experience drought impacts through December. For all months from January 2003 through December 2006, 70 percent of the systems designated they were not in drought.

Figure 5.18 Percentage of water systems experiencing drought impacts, 2002-2003: a) 2002, b) 2003.



a) 2002



b) 2003

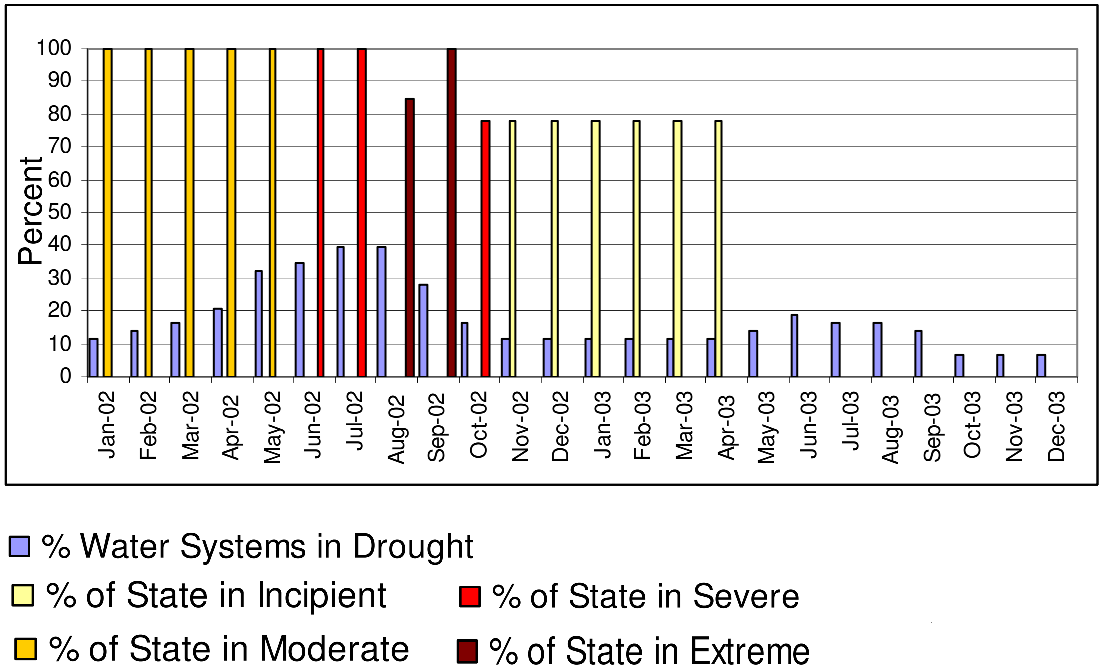
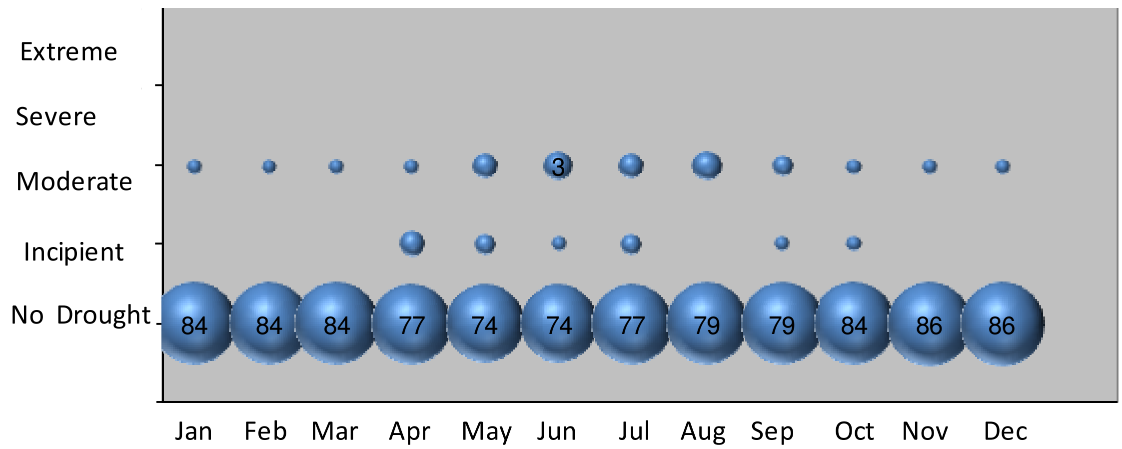


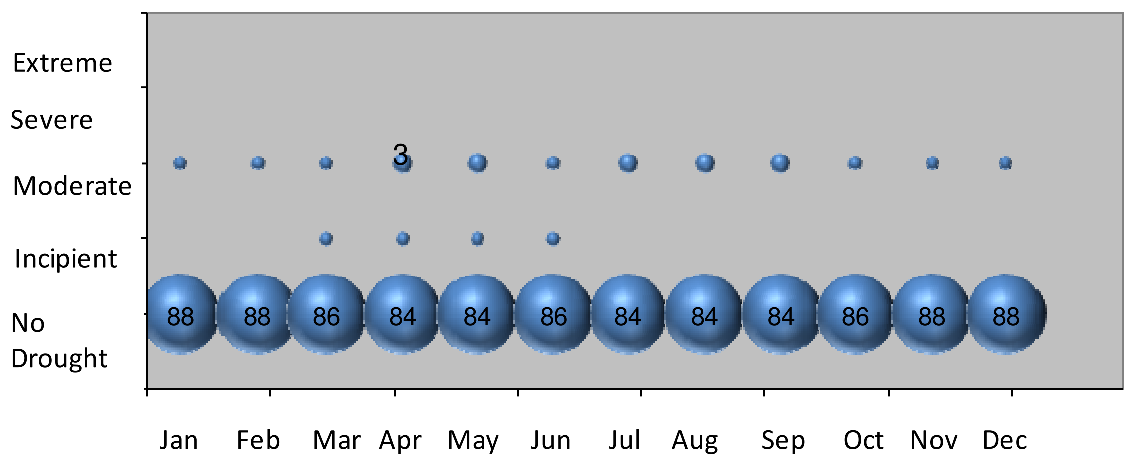
Figure 5.19 Percentage of the state in the highest level of drought based on the S.C. Drought Response Committee's declarations compared to the percentage of water systems experiencing drought impacts during 2002-2003.

Figure 5.20 shows that by 2004, only a few water systems experienced drought impacts. The number of systems experiencing drought impacts increased slightly during the summer months. The official state declaration was upgraded to incipient for one month: June 2004 (Figure 5.21). During 2005, the lowest number of water systems indicated drought impacts, with only one to three systems experiencing incipient or moderate drought during any month. No state declaration occurred during 2005. By summer 2006, a few more water systems stated they experienced drought impacts, but these numbers decreased by late fall. The state declaration was upgraded to incipient in August 2006 and to moderate in September 2006, but only for less than 35 percent of the state.

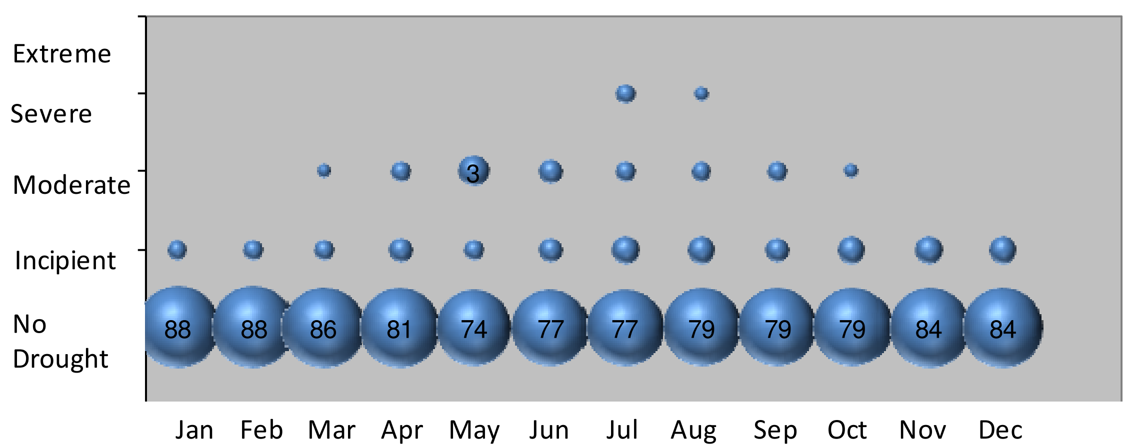
Figure 5.20 Percentage of water systems experiencing drought impacts, 2004-2006: a) 2004, b) 2005, c) 2006.



a) 2004



b) 2005



c) 2006

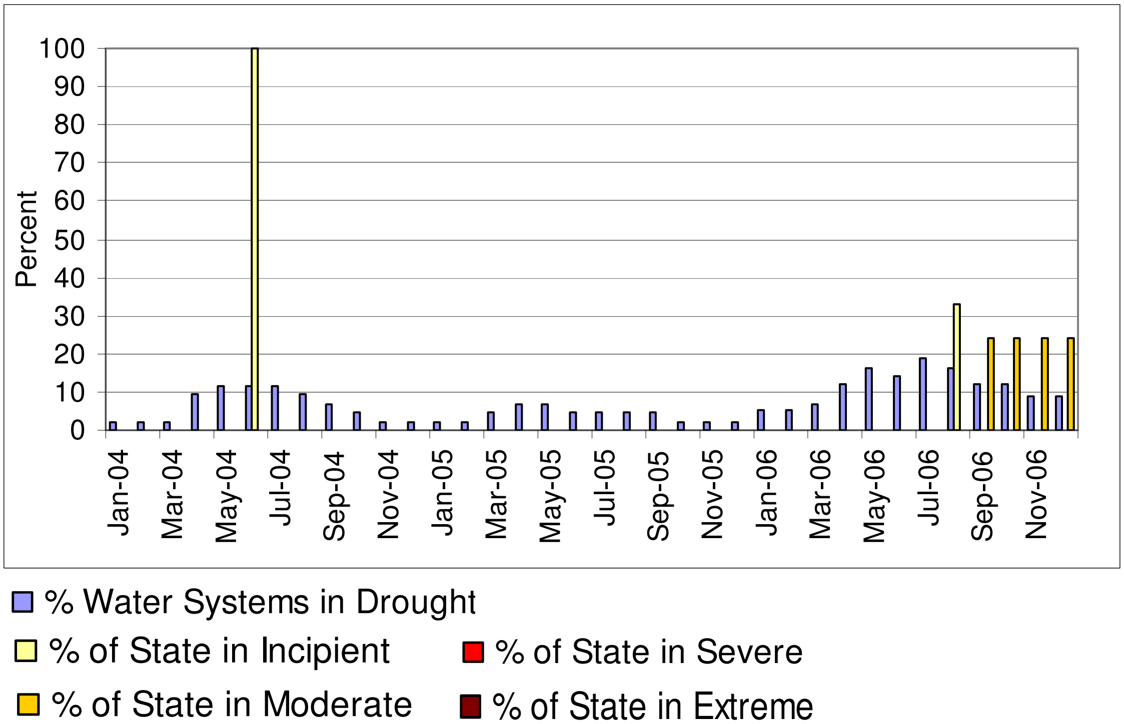


Figure 5.21 Percentage of the state in the highest level of drought based on the S.C. Drought Response Committee's declarations compared to the percentage of water systems experiencing drought impacts during 2004-2006.

In summary, the water systems' reconstruction of the drought impacts they experienced during the record drought period, 2000 – 2002, suggests that many of the South Carolina's water systems are not vulnerable to significant drought impacts. Twenty-eight percent of the water systems who responded indicated they never experienced drought conditions during any month for the study period. Even during the height of the record drought in 2002, 45 to 50 percent of the water systems indicated they did not experience any drought impacts. The highest percentage of systems to experience severe drought impacts during any month was 21 percent, which only occurred once, in July 2002. The highest percentage of systems to experience extreme drought impacts during any month was 11 percent, which only occurred once, in August 2002. There are limitations to the survey data that should be considered. The results were limited to a small subset of South Carolina water systems and it is difficult for water systems to confidently and accurately recollect impacts on their system beyond one to three years. The research results were, however, consistent with research conducted by Dow et. al. (2007) on S.C. public water system vulnerability to climate hazards. Only 38 percent of the systems they surveyed responded that they had experienced a drought emergency during the five years prior to 2000.

Results from this research suggest that state level declarations do not always represent the drought impacts experienced by most of South Carolina's water systems. The state declarations are usually at a higher severity level and tend to have a longer duration than individual water system declarations. This is because the S.C. Drought Response Committee's declarations consider drought impacts on multiple sectors, i.e. industry, electric power generation, agriculture, and forestry, with some sectors experiencing slower long-term drought implications and others sensitive to short-term changes. According to its chairman, the S.C. Drought Response Committee follows the guidance of key drought indicators and the input of local representatives from four drought management areas, but they make a conscious effort to avoid invoking and revoking stages too frequently (de Kozlowski, personal communication, 2008). If drought stages and associated management responses change too frequently, the declarations will lack credibility and create confusion. De Kozlowski (2008) emphasized that South Carolina's drought response is based on the S.C. Drought Response Act, which supports a two-tiered approach. The Committee's declaration serves as a broad, overarching representation of drought conditions in specific geographic areas of the state.

However, actual mitigation of drought impacts is conducted through planning and actions at the local level by water systems, power companies, and industry. Results from the survey and state declaration comparison further exemplify the importance of local drought planning with system-specific drought indicators that are scientifically justified and operationally relevant, but meet the operational needs of the user.

5.2 Power Company Survey Results

The following discussion focuses on results from the four power companies: Santee Cooper, South Carolina Electric and Gas, Progress Energy, and Duke Energy. Their names are omitted from the results and replaced with System 1 to System 4 (not in the order listed above).

Question 1: What drought indicator(s) does your system use?

The power companies use local indicators provided in their Low Inflow Protocols. Two companies stated they also consider the S.C. State Drought Committee's Declarations.

Question 2: How important is it to your system that drought indicators meet the following criteria. If you use both State and Local drought indicators please designate criteria for each. Choose Not Applicable if you only use indicators specific to your system. (Circle 1 for Not Important, 2 for Somewhat Important, 3 for Important, 4 for Very Important and 5 for Not Applicable).

Table 5.21 summarizes results from question 2 displaying power company responses and their average numerical scores for each state and local drought indicator characteristic. In general, power companies strongly believe that local indicators should meet all five drought characteristics. The characteristic "having the local indicator widely publicized" received an average score less than four. Some of the power companies were less concerned that the state indicators meet the different criteria, however, the differences were not statistically significant.

Among the different state indicator characteristics none of the averages were statistically significant. The small sample size contributed to this as did categorical data. The “ability to understand how the state indicators are computed” received the lowest average rating (2.5) and “capturing the impact of the extreme event” (3.3) and “having the state indicator widely publicized” received the highest average scores (3.5). One power company designated in the “other criteria comment” field that having state and local indicators correlate well with each other was important.

Table 5.21 Power company responses and average numerical scores for state and local drought indicator characteristics.

	Captures impact of extreme drought conditions		Ability to understand how indicator is computed		Easy access to indicator data		Indicator is widely publicized		Provides appropriate lead time before entering drought stage	
System Name	State	Local	State	Local	State	Local	State	Local	State	Local
System 1	3	4	2	4	4	4	3	3	2	4
System 2	2	4	2	4	2	4	3	4	3	4
System 3	4	4	4	4	4	4	3	4	4	4
System 4	4	4	2	4	2	4	3	3	3	4
Average Scores	3.3	4	2.5	4	3	4	3	3.5	3	4

Question 3: Please rank the relative importance of these drought indicator characteristics on a scale from 1 to 5 with 5 being most important. This question builds on question 2 to help us understand your priorities better. (Each number should be used only once.)

Question three examined the importance of each drought characteristic by asking power companies to rank them on a scale from one to five (five being the most important) using each number only once. There is little consensus on the most important characteristic with three out of the four power companies selecting different characteristics as most important (Table 5.22). Two rated having the indicator “provide appropriate lead-time before entering drought” as the most important. System 2 rated the “ability to understand how the indicator is computed” as most important. System 4 rated “capturing the impact of the extreme drought” as most important. “Having the indicator widely publicized” received the lowest average score (1.8) with three systems rating it as least important; one system stated it was the second most important. The differences were not statistically significant.

Table 5.22 Power company rankings for each drought indicator characteristic.

System Name	Captures impact of extreme drought conditions	Ability to understand how indicator is computed	Easy access to indicator data	Indicator is widely publicized	Provides appropriate lead time before entering drought stage
System 1	2	3	4	1	5
System 2	2	5	4	1	3
System 3	3	1	2	4	5
System 4	5	2	3	1	4
Average Scores	3	2.8	3.3	1.8	4.3

Some similarities between power companies and water systems become apparent based on question 2 and question 3. Both groups are more interested in local indicators than state indicators and having those indicators meet most or all of the criteria listed, power companies more so than water systems. The high expectations of power companies that the local drought indicators be multi-dimensional is probably influenced by their recent experience in developing drought indicators for their Low Inflow

Protocols. Their indicators were quickly tested during the severe drought of 2007-2008, so most have witnessed the importance of indicators and also have experienced the necessity of using multi-indicators to effectively trigger drought.

Power companies and water systems are less interested in understanding how either the state or local indicators are computed compared to the importance of the other characteristics. “Providing appropriate lead-time before entering drought” and “capturing the extreme event” both received high scores for water systems and power companies, indicating they are perceived as being important to very important. However, power companies seem much less concerned the local drought indicators are “widely publicized” as compared to the water systems. Follow-up discussion with power company representatives confirmed that they believe having the Stage declaration and required response publicized is very important, but not necessarily the individual indicators that support the declaration.

Question 6: How important is it to your system that your drought indicators are consistent with drought indicators used by your alternative water providers? (Circle either not important, somewhat important, important, very important, don’t know or not applicable)

The question was not relevant to power companies since it focused on the importance of drought indicator consistency with alternative water providers.

Question 7: How important is it to your system that your drought indicators are consistent with drought indicators used by upstream systems? (Circle either not important, somewhat important, important, very important, don’t know or not applicable)

Question 7 was especially relevant to power companies since their Low Inflow Protocols emphasize consistent basin-wide drought planning. All four responded that it was important or very important to have drought indicator consistency with upstream water systems.

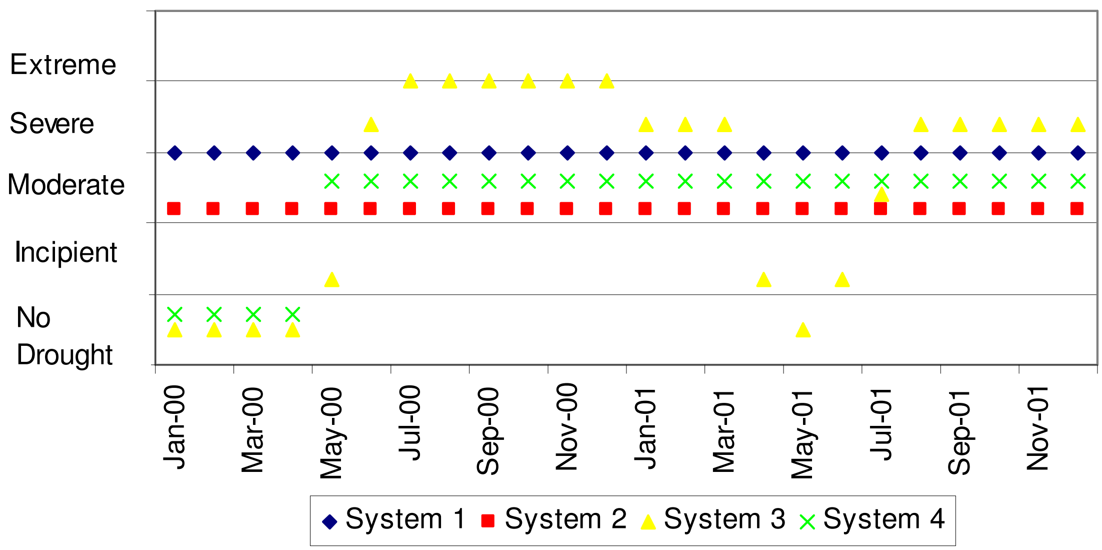
5. 21 Power Company's reconstruction of the 1998-2002 drought impacts

Question 4: For the years 2000-2006, or the periods you confidently remember, please indicate which months your system was impacted by drought. Draw a line through the drought-free months. Place an I for Incipient, M for Moderate, S for Severe, or E for Extreme in each date block for the severity of drought your system experienced. If you Don't Know, mark the month DK.

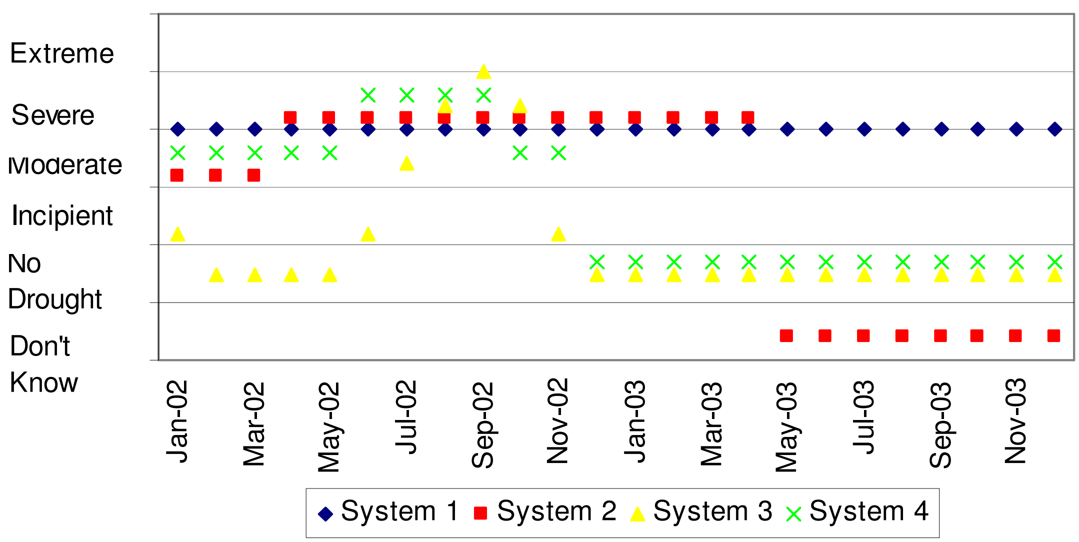
Figure 5.22 presents the power companies' reconstruction of the drought severity impacts to their operations during and coming out of the record drought of 1998-2002 for the period 2000-2003. Errors may be introduced in the earlier years due to the duration of time that has passed since 2000. None of the systems responded that they did not know what drought impacts were experienced during the earlier years, but two companies did not know what drought impacts they experienced in 2004 and 2005. Another potential caveat to the data is that one company stated they experienced severe drought impacts from January 2000 through December 2003, followed by a response that they didn't know the impacts during 2004-2005.

Beginning in May 2000 through 2001, most power companies indicated they experienced moderate to severe impacts. One company's response was surprisingly different indicating the greatest impacts (extreme designation) from July 2000 to December 2000. Most systems continued to experience moderate to severe conditions into 2002, but by August 2002 all experienced severe conditions. The summer of 2002 is considered to be the height of the record drought of 1998-2002. Above normal rainfall in fall 2002 helped relieve conditions, and the state declaration was downgraded to incipient in November 2002 and then to no drought by April 2003. Two of the power companies reflected this improvement, but one power company stated it was still in severe drought through April and another was in a severe drought through December 2003. In 2004 and 2005, all power companies responded they did not experience drought impacts (no figure provided). During 2006 (no figure provided), two power companies experienced incipient to moderate impacts, but at different times of the year.

Figure 5.22 Severity of drought impacts experienced by power companies, 2000-2003 and 2006. a) 2000-2001, b) 2002-2003.



a) 2000-2001



b) 2002-2003

The power companies' reconstruction of the 2000 – 2006 study period was different from the reconstruction by water systems. According to the survey results, power companies are impacted more by drought with the impacts lasting longer. All power companies indicated they experienced severe drought conditions on several occasions whereas only 21percent of the water systems surveyed stated they ever experienced severe drought. Only one power company stated they experienced extreme drought conditions; these impacts lasted six months during 2000 and again for one month in September 2002. The 2000 extreme impacts were not consistent with conditions experienced by water systems nor with the state's moderate declaration that was in place.

5.3 Survey Implications and Future Research

The survey reflects the challenge that drought affects a wide variety of sectors across diverging time scales, making it difficult to define and measure. The survey results demonstrate that water systems and power companies value local and state drought indicators, however, they tend to have higher expectations and depend more heavily on their local indicators. They need the drought indicator(s) to be multi-dimensional, but have differing opinions on which characteristics comprise the most effective drought indicator.

In general, two of the more important characteristics relate directly to the indicator's depiction of drought; "having the indicator capture the impact of the extreme drought" conditions and the "ability of the indicator to provide appropriate lead-time before entering drought." Based on results from the drought reconstruction and from a review of water system local drought plans and power company LIPs, lead-time differences are based on system-size, system-source, drainage area, and natural and manmade demands on the system. Some systems can transition in and out of stages at bi-weekly time scales. Whereas, other systems need one month or longer lead-times. Additional research is needed to more closely determine these influences.

Many water systems don't believe indicator consistency with alternative water providers is important. A higher consensus exists among small systems and those using lakes as their source-water that consistency with alternative water providers is important. There is less of a consensus among water systems that indicator consistency and consistent drought planning is important between upstream and downstream systems. Even though the sample size is small, system-size and source do seem to influence response, so additional research using a larger sample size would be valuable in affirming and expanding the analysis.

The water systems' reconstruction of the drought impacts they experienced during the record drought period, 2000 – 2002, suggests that many of the South Carolina's water systems are not vulnerable to significant drought impacts. Twenty-eight percent of the water systems who responded indicated they never experienced drought conditions during any month for the study period. Even during the height of the record drought in 2002, 45 – 50 percent of the water systems indicated they did not experience any drought impacts. Survey results suggest that power companies are impacted more by drought with the impacts lasting longer. All power companies indicated they experienced severe drought conditions on several occasions. Additional research should be conducted on a larger subset of water systems. Since this survey did not include a reconstruction of the 2007-2008 drought a follow-up survey could be conducted for confirmation and comparison. The survey ideally should be conducted immediately following the drought since the respondents memory can be biased over time.

CHAPTER 6 CONCLUSION

The persistent drought that impacted South Carolina over the past decade brought to the forefront many water management issues that can no longer be ignored. Ensuring sustainable water resources to meet the growing demand requires better management of existing supplies. The drought reinforced the need for improved coordination and planning within and between levels of government and water users. The value of preparing for, detecting, and responding to drought conditions has increased in importance and prominence not only in South Carolina, but nationally.

The backbone of the drought planning process is the identification of drought indicators that link the drought conditions to the responses. Determining the drought indicators and triggers, however, is no easy task given the complexity of drought. Drought affects a wide variety of sectors across divergent time scales, making it difficult to define and measure. This research enhanced South Carolina's drought response by evaluating the spatial and temporal distribution of drought intensity and frequency as indicated by South Carolina's state indicators and the recently defined FERC Low Inflow Protocol (LIP) indicators for the Catawba-Wateree and Yadkin-Pee Dee basin. Indicator discrepancies were identified and recommendations provided for improving the indicators at both the state level and in the LIP. The study addressed the link between the indicator scientific justification and operational relevancy by evaluating water systems' and power company's vulnerability to drought, their understanding of drought indicators, and which drought indicator characteristics provide the most effective drought response.

This research adds to the limited literature on developing drought indicators. Similar research has been conducted on drought indicators and plans for the Apalachicola-Chattahoochee-Flint river basin, (Steinemann, A., 2003), Seattle, Washington, (Fisher et al., 1997), and for the State of Georgia, (Palmer et al., 2002; Steinemann et al., 2006). This research provides the first detailed drought indicator analysis for South Carolina and for the newly formed FERC LIP's for the Catawba-Wateree and Yadkin-Pee Dee river basins. The research also benefits from the inclusion of survey information from 43 water systems and the four major power companies in South Carolina. The study implements key components of the National Integrated Drought Information System federal initiative that calls for integrated drought research and information at relevant spatial scales to facilitate proactive decisions.

The analysis identified significant discrepancies between the state indicators detection of drought. Several state indicators suggest South Carolina is in some level of drought 50 to 60 percent of the time while others show drought impacting the state only 20 percent of the time. Based on the streamflow triggers, the state's streams are in drought only 6 percent of the time. The inconsistencies among many of the indicators can be attributed to the inconsistencies in the drought level ranges defined by the S.C. Drought Response Act's regulations. These inconsistencies create confusion for the S.C. Drought Response Committee and S.C. water users. The S.C. Drought Response Committee should consider revising the trigger levels. The research confirmed recommendations by Steinemann (2005) that transforming indicators to percentiles is a viable solution for using multiple and often statistically inconsistent indicators. The triggers could be based on percentiles rather than raw indicator values. The decision maker can relate triggers to the concept of return periods or probabilities of occurrence and the trigger values associated with each drought level would be consistent.

The evolution and implementation of the drought plans or LIPs in the Yadkin-Pee Dee and Catawba-Wateree FERC licenses identified or demonstrated the need for additional research on drought indicator validation. The LIPs were new to the relicensing process for the two basins and the identification of drought indicators and trigger points presented challenges to the licensee (Duke Energy, Alcoa Yadkin, and Progress Energy) and the stakeholders. Additional questions have been raised as to the effectiveness of the proposed indicators in the LIP, due to conditions experienced in the most recent drought that began in 2006 and is ongoing through June 2008. These research results show significant discrepancies between the LIP indicators especially during the drought recovery phase. These discrepancies cause the greatest challenge for the stakeholders in the Catawba-Wateree basin since their LIP can not be downgraded until all indicators, including groundwater levels, reflect a lower drought stage.

Suggestions based on this research include shortening the 6-month streamflow average in Duke's LIP to avoid the slower recovery. The Catawba-Wateree Drought Management Advisory Group should investigate using the SPI 6-month indicator or the SPI 9-month indicator as a possible replacement for the 3-month average DM in the LIP. Transforming indicators to percentiles and then combining the multiple indices using blends or weights did not improve drought detection over the use of single indicators. Duke should also consider adding a recovery condition based on the storage returning to a certain elevation which would automatically lower or cancel the LIP regardless of the other indicator's stages. Since the storage elevation is a key indicator for determining water availability in LIP river basins, adding a recovery condition based solely on storage should be investigated by Duke, CWDMAG and other entities developing LIPs in South Carolina. The recovery from the LIP should consider both a slow recovery where all indicators must reach a lower level before the stage is lowered to a more rapid recovery that accounts for the storage recovering to a certain elevation for a user-determined time period. Stakeholders and system operators in the Yadkin-Pee Dee Basin confirm that the two additional recovery criteria based on storage in Alcoa/Progress Energy's LIP provided them with a more accurate representation of the drought's true impact on their system and compensated for the inconsistency in the indicators based on 3-month streamflow and the 3-month average DM.

A key contribution of the study was the survey's identification of water systems' and power company's vulnerability to drought, their understanding of drought indicators, and which drought indicator characteristics provide the most effective drought response. The survey results demonstrate that water systems and power companies value local and state drought indicators, however, they have higher expectations and depend more heavily on their local indicators. They need the drought indicator(s) to be multi-dimensional, but have differing opinions on which characteristics comprise the most effective drought indicator. In general, two of the more important characteristics relate directly to the indicator's depiction of drought; "having the indicator capture the impact of the extreme drought" conditions and the "ability of the indicator to provide appropriate lead-time before entering drought."

Despite the S.C. Drought Management Plan and Response Ordinance's emphasis on "cooperative agreements with alternative water providers" some water systems don't believe indicator consistency with alternative water providers is important. There is also less consensus among water systems that indicator consistency and consistent drought planning is important between upstream and downstream systems. Additional education is needed to demonstrate the importance. A possible model that could be followed for building consensus among drought plans is the FERC LIP for the Catawba-Wateree river basin. Numerous water systems, agencies and stakeholders from two states, and the power company worked together to develop a drought plan with consistent drought indicators that has been implemented and enforced by the majority of the water systems in the basin. Even though there are concerns over the indicators, the protocol includes a mechanism for making future enhancements and the overall basin-wide drought response has been successful.

Results from the survey suggest that state level declarations do not always represent the drought impacts experienced by many of South Carolina's water systems. The state declarations are usually at a higher severity level and tend to have a longer duration than individual water system declarations. The S.C. Drought Response Committee's declaration considers the drought impact on multiple sectors, with some sectors experiencing slower long-term drought implications and others that are sensitive to short-term changes. Results from the survey and state declaration comparison further exemplify the importance of local drought planning with system-specific drought indicators that are scientifically justified, but meet the operational needs of the user. Additional research should be conducted on a larger subset of water systems. Since this survey did not include a reconstruction of the 2007-2008 drought, a follow-up survey could be conducted for confirmation and comparison.

Central to the discipline of geography, this research implements techniques to better investigate hazards due to climate and hydroclimate variability (Gaile, G., and Willmott, C., 2003). The research contributes to the literature focused on understanding physical and spatial characteristics of drought and resulting impacts. The engagement of users through the survey and additional dialogue helps bridge the gap between the physical aspects of drought and resource management. The research also demonstrates the challenges underlying effective decision support (Dow, K. and G. Carbone, 2007). The research results can be used to improve planning and coordination within and between levels of government and water users to help reduce society's vulnerabilities to drought and ensure sustainable water to meet growing demands.

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March 11, 2007

Water System or Power Generating System Point of Contact
Address
City, State, Zip Code

This survey is being conducted as part of my dissertation work on South Carolina's Drought Planning Process. I'm a Ph.D. student at the University of South Carolina. I also work as the State Climatologist for South Carolina, which has given me the privilege to work with many of you over the past fourteen years. I've spent the majority of both my work and school career focusing on research and methods to improve South Carolina's response to drought. The purpose of the survey is to gain a better understanding of what makes an effective drought indicator and which indicators represent the drought's true impacts on water resources.

Drought impacts are difficult to quantify because drought episodes can be devastating for one sector, but less severe for others. As the demand for water continues to increase, decision-makers and stakeholders are realizing the importance of planning for drought. Effective drought planning depends on indicators and triggers that characterize drought conditions and guide drought responses. The goal of this survey and my research is to identify what makes an effective drought indicator through scientific evaluation of the indices in combination with a better understanding of water user needs and drought tolerance. Your system as well as the State will benefit by having a better understanding of which drought indicators consistently trigger appropriate drought phases, provide adequate indication of drought severity, and thus yield the greatest decision-making value.

Please complete the survey and return it using the enclosed self-addressed envelope by **April 18, 2007**. My research and data analysis will focus on group responses rather than results from individual surveys. You are not asked to indicate your name or the company's name in order to keep the information anonymous. However, if you are willing to share this information please enter it on the last page. This will allow me to compare your responses to numerical drought data for your area. By completing and returning the survey you are indicating your consent for the information to be used in the research. Thank you for your participation in this survey and for your efforts to insure that South Carolina has adequate supplies of quality water on a sustained basis.

Sincerely,

Hope Mizzell,
Ph.D. Candidate
University of South Carolina -Department of Geography
Callcott - 709 Bull Street
Columbia, SC 29208
Phone: 803-530-5793

Participation in this survey is completely voluntary and you may terminate your participation at anytime.

Drought Monitoring Survey

1.) What drought indicator(s) does your system use?

____

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2.) How important is it to your system that drought indicators meet the following criteria. If you use both State and Local drought indicators please designate criteria for each. Choose Not Applicable if you only use indicators specific to your system. (Please circle the number for each criteria)

Examples of Indicators used by the State Drought Management Committee in Drought Declarations include: Palmer Drought Severity Index, U.S. Drought Monitor, Keetch Byram Drought Index

Examples of Local or System Specific Indicators include: Reservoir Elevation, Streamflow, Number of Days Supply Remaining. Your system may use other indicators including those used by the State Drought Management Committee. Please use the indicators specified in your system's drought management plan to answer questions on local indicators below.

		Not Important 1	**Somewhat Important 2**	**Important 3**	**Very Important 4**	**Not Applicable 5**
Capture the impact of extreme drought conditions	State Indicators	1	2	3	4	5
	Local Indicators	1	2	3	4	5
Your ability to understand how the indicator is computed	State Indicators	1	2	3	4	5
	Local Indicators	1	2	3	4	5
Easy to access the indicator data	State Indicators	1	2	3	4	5
	Local Indicators	1	2	3	4	5
Drought indicator is widely publicized	State Indicators	1	2	3	4	5
	Local Indicators	1	2	3	4	5
Provides appropriate lead time before entering drought stage	State Indicators	1	2	3	4	5
	Local Indicators	1	2	3	4	5

Other Criteria: ____

____

3. Please rank the relative importance of these drought indicator characteristics on a scale from 1 to 5 with 5 being most important. This question builds on question 2 to help us understand your priorities better. (Each number should be used only once.)

Capture the impact of extreme events _______________

Your ability to understand how the index is computed _______________

Easy to access the indicator data _______________

Drought indicator is widely publicized _______________

Provides appropriate lead time before entering drought stage _______________

4.) For the years 2000-2006, or the periods you confidently remember, please indicate which months your system was impacted by drought. For the years that you remember, please draw a line through the drought-free months. Place an I, M, S, or E in each date block for the severity of drought your system experienced. If you Don't Know, mark the month DK.

I=Incipient (Drought beginning) **M=Moderate Impacts** **S=Severe Impacts** **E=Extreme Impacts** **DK=Don't know**

Draw a line through months without drought

For Example					
January	February	March	April	May	June
DK	-----------	-----------	-----------	---------	I
July	August	September	October	November	December
M	S	I	-----------	------------	DK

2006					
January	February	March	April	May	June
July	August	September	October	November	December
2005					
January	February	March	April	May	June
July	August	September	October	November	December
2004					
January	February	March	April	May	June
July	August	September	October	November	December

2003					
January	February	March	April	May	June
July	August	September	October	November	December
2002					
January	February	March	April	May	June
July	August	September	October	November	December
2001					
January	February	March	April	May	June
July	August	September	October	November	December
2000					
January	February	March	April	May	June
July	August	September	October	November	December

5.) List other periods and the drought severity level when your system experienced drought impacts. Please indicate months and years, e.g. July-Sept/1986 (as far back as you can confidently identify them):

____

____

6.) How important is it to your system that your drought indicators are consistent with drought indicators used by your alternative water providers? (Please circle)

Not Important	Somewhat Important	Important	Very Important	Don't know	Not Applicable

7.) How important is it to your system that your drought indicators are consistent with drought indicators used by upstream systems? (Please circle)

Not Important	Somewhat Important	Important	Very Important	Don't know	Not Applicable

8.) System Primary Water Source(s) (please circle):

Lake River Groundwater Well

Number of people served (please circle if applicable): <3,300 3,301-10,000 >10,001

Name of System (optional) ____________________________________

Thank You