Strategies for Mitigating Drought: An Evaluation of State and Local Drought Triggers

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1. INTRODUCTION

As South Carolina emerged from the most recent multi-year drought ending in 2002, it became clear that the sustainability of the state's water resources could no longer be taken for granted (Mizzell, 2002). This extreme event became a necessary "springboard" to elevate the public's perception and capture decision makers' attention to the challenges associated with managing South Carolina's water resources. Major natural hazard events that are well publicized usually stimulate stakeholder interest, increasing the acceptability of policy changes. The drought brought about a change in the State's water resources management reinforcing the need for improved coordination and planning within and between levels of government and water users. South Carolina's drought response program emphasizes integrated planning and response, which includes a committee composed of local and state representatives who are responsible for evaluating drought conditions to determine if action beyond the scope of local response is needed. 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.

The foundation of local drought management plans and policies is system specific drought triggers, identification of alternative water supplies, and public education. A unique component of each plan is the designation of drought triggers specific to each system that can be used separate from, or in conjunction with state-level drought triggers. System-specific drought triggers include information such as reservoir levels, number of days of supply remaining, and average daily use while the State uses more traditional indices such as the Palmer Drought Severity Index (Palmer, 1965) and Standard Precipitation Index (McKee et al., 1993) for state level declarations. This project will demonstrate the effectiveness of using the integrated planning approach by comparing drought intensity, frequency, and duration of droughts indicated by local vs. state triggers.

2. HISTORY OF DROUGHT

Historically, droughts have had severe adverse impacts on the people and economy of South Carolina. Drought impacts were diverse, causing a ripple effect through the economy (Wilhite, 1993). This was made especially clear during the drought of 1998-2002 that impacted many sectors, including agriculture, forestry, tourism, power generation, public water supply, and fisheries. The economic repercussions associated with the 1998-2002 drought will likely surpass any other drought in South Carolina's history. 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 (State Hazard Mitigation Plan, 2004).

3. EVOLUTION OF SOUTH CAROLINA DROUGHT MANAGEMENT

South Carolina's water allocation history dates back to the drought of the 1950s. The state began examining 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 for formalizing a drought plan by passing the South Carolina Drought Response Act, in 1985. South Carolina is unique in dealing with drought management through legislation

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and its associated regulations. Enacting and amending this law has required cooperation between scientists and policy makers.

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 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, i.e. to adjust drought management areas to correspond with the State's four major river basins, restructure local drought committees, and clarify existing procedures to identify and address water shortages. Since the record drought of 1998-2002 the South Carolina Department of Natural Resources (SCDNR) revised the State Water Plan, publishing a second edition that reflects the lessons learned during the drought. In turn, the Drought Response Act should be amended based on recommendations in the revised State Water Plan and based on policy shortfalls witnessed during the drought.

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 that was developed by the SCDNR, South Carolina Department of Health and Environmental Control (SCDHEC), and the South Carolina Water Utility Council (SCWUC). SWUC 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 are often developed without the input of the primary stakeholder, which leads to distrust and opposition to the overall process. By including SWUC it was 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 being imposed on them by bureaucrats who have no idea how to run a water system.

The model consists of a section devoted to drought planning and a section outlining the ordinance requirements. The Drought Management Plan required 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 outlined 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.

4. TRIGGERS FOR DROUGHT RESPONSE: AN INTEGRATED APPROACH

An important component of both the state and local water system drought plans is the use of trigger mechanisms for drought declarations and demand management. Developing appropriate triggers is the backbone for improved drought mitigation. The state has an integrated approach with specific indicators listed in the legislation that are used in the drought declaration process by the State Drought Committee. The statewide indicators are usually more nationally produced indices such as the Palmer Drought Severity Index, Crop Moisture Index, and Standardized Precipitation Index. Table 1 lists the triggers currently designated by South Carolina's Drought Response Act and supporting regulation. While most of these indices are available at the climate division and sometimes county level, this spatial resolution is insufficient for local drought response, hence South Carolina's requirement that each local water system identify in their plan system- specific drought or water shortage indicators. System-specific drought indicators include information such as reservoir levels, number of days of supply remaining, and average daily use. Table 2 provides examples of local water system triggers for the SJWD and Duke Energy water systems.

The drought declaration made by the State Drought Response Committee based on the national indices sets into action the local water system Drought Management Plans and Response Ordinances. Based on the statewide drought declaration and the system specific indicators the appropriate drought response is determined. Ideally each water system should have tested their triggers based on historical data before submitting them. For many, however, this was technologically impossible or overlooked.

This project will demonstrate the importance of developing and testing drought indicators and prove the effectiveness of using the integrated planning approach by evaluating drought intensity, frequency, and duration as indicated by state triggers and local triggers

Incipient			
PDSI -0.50 to -1.49 SPI 0.00 to -0.99 DM D0	CMI 0.00 to -1.49 KBDI 300 to 399	Static water level in aquifer is 11-20 feet above trigger level for 2 consecutive months	Average daily streamflow 111%-120% of minimum flow for 2 consecutive weeks
Moderate			
PDSI -1.50 to -2.99 SPI -1.00 to -1.49 DM D1	CMI -1.50 to -2.99 KBDI 400 to 499	Static water level in aquifer is 1-10 feet above trigger level for 2 consecutive months	Avg daily streamflow 101%-110% of minimum flow for 2 consecutive weeks
Severe			
PDSI -3.00 to -3.99 SPI -1.50 to -1.99 DM D2	CMI -3.00 to -3.99 KDBI 500 to 699	Static water level in aquifer is between trigger level and 10 feet below for 2 consecutive months	Average daily streamflow is between minimum flow and 90% of minimum for 2 consecutive weeks
Extreme			
PDSI -4.00 and below SPI -2.00 and below DM D3 or higher	CMI -4.00 and below KBDI exceeds 700	Static water level in aquifer is more than 10 feet below trigger level for 2 consecutive months	Average daily streamflow less than 90% of minimum for 2 consecutive weeks

Table 1. State level triggers designated by regulation (PDSI =Palmer Drought Severity Index, SPI=Standard Precipitation Index; DM=U.S. Drought Monitor, CMI=Crop Moisture Index, KBDI=Keetch Byram Drought Index)

<table>
<tr><th>System Name</th><th>Source</th><th>Moderate</th><th>Severe</th><th>Extreme</th></tr>
<tr><td>SJWD Water District</td><td>Water treatment plant with ground and elevated storage tanks.</td><td>1. Reservoir 85% full
2. Storage falls below 841 ft. MSL at Lake Lyman.</td><td>1. Reservoir 75% full
2. Storage falls below 840 ft. MSL at Lake Lyman.</td><td>1. Reservoir 50% full
2. Storage falls below 8 ft. MSL at Lake Lyman.</td></tr>
<tr><td rowspan="5">Duke Energy (Triggers are still under development in LIP process - Last Trigger (Stage 5) not listed)</td><td rowspan="5">Catawba-Wateree Lakes</td><td colspan="3">1. Storage index based on combined storage in all lakes (under development in LIP)</td></tr>
<tr><td colspan="3">2. US Drought Monitor Three-Month Numeric Average</td></tr>
<tr><td>> 1, but < 2</td><td>> 2, but < 3</td><td>> 3, but < 4</td></tr>
<tr><td colspan="3">3. Sum of actual rolling six-month average streamflow (SARSMS) at designat USGS gages compared to sum of long term rolling six-month average streamflows (LTRSMS) for that period.</td></tr>
<tr><td>SARSMS between 55% and 70% of LTRSMS</td><td>SARSMS between 40% and 55% of LTRSMS</td><td>SARSMS between 30% and 40% of LTRSMS</td></tr>
</table>

Table 2. Example local-level drought triggers for SJWD and Duke Energy

for several water systems and one power generating facility.

5. DATA SOURCES

5.1 SJWD Water District

The SJWD Water District depends on water from Lake Lyman reservoir, which was created by impoundment of the Middle Tyger River in Spartanburg County, South Carolina. The Lake Lyman drainage basin is approximately 44.6 square miles. When full, the lake covers 412 acres and impounds approximately 1.27 billion gallons (Black & Veatch Corporation Technical Memorandum, B&V Project 132920.110, May 2003).

SJWD Water District drought indicators are based on reservoir levels, more specifically, drought operating curves for Lake Lyman. These curves are based on the percentage of storage volume remaining in the reservoir. When the reservoir stage drops to designated levels, the District can implement the appropriate response measures defined in the Drought Response Ordinance. The data used for this drought trigger comparison study include Lake Lyman storage volume for the local trigger and the climate division values of the PDSI, 3-month SPI, 6-month SPI, 9-month SPI and streamflow measurements from two United States Geological Survey (USGS) gages. Ideally, streamflow from the Middle Tyger River upstream of Lake Lyman would be used, however, no data were available and other gages were analyzed as possible data sources for inflow estimation. The criteria for the candidate gages were that drainage areas and elevations were similar to those at Lake Lyman and that no upstream impoundment would affect flows. Two USGS streamflow gage stations met these criteria, North Tyger River near Fairmont, South Carolina, (period of record October 1, 1950, to September 30, 1988) and the North Pacolet River near Fingerville, South Carolina (period of record October 1, 1930, to September 30, 2004) (Black & Veatch, Lake Lyman Mass Balance Model, May 2003).

5.2 DUKE ENERGY

The mainstem river of the Catawba-Wateree Basin is regulated by a series of seven hydroelectric dams. The reservoirs formed by these dams are commonly referred to as the Catawba-Wateree chain lakes. All are owned by Duke Energy and were created to generate electricity. Demands have escalated on the river basin serving 17 counties, 22 municipalities and close to 2 million people across two states. Duke’s Federal Energy Regulatory Commission license to operate the dams on the Catawba River expires in 2008. As a part of the relicense, Duke is developing a Low Inflow Protocol (LIP) for the Catawba-Wateree Project. This LIP provides trigger points and procedures for how the Catawba-Wateree Project will be operated by the Licensee, as well as water withdrawal reduction measures for other water users during periods of low inflow. The LIP is intended to provide additional time to allow precipitation to restore streamflow, reservoir levels, and groundwater levels to normal ranges. The amount of additional time that is gained during the LIP depends primarily on the diagnostic accuracy of the trigger points, the amount of regulatory flexibility Duke Energy has to operate the Project, and the effectiveness of Duke Energy and the water users in working together to implement their required actions and achieve significant water use reductions. The triggers are still being evaluated by us and other parties, but are currently based on lake elevations, the U.S. Drought Monitor, and streamflow from USGS gage South Fork Catawba River at Lowell, N.C.; Catawba River near Pleasant Gardens; Johns River at Arneys Store, N.C.; and Rocky Creek at Great Falls, S.C. (Table 2).

6. METHODS

Triggering mechanisms are a fundamental component of drought management plans giving decision-makers scientific thresholds for activating various responses (Hrezo et al., 1986). Over the past two decades there have been documented advances in the development of drought triggers by utilities and state and local governments throughout the U.S. (Fisher and Palmer, 1995; Steinemann, 2003). In South Carolina, however, the emphasis came by necessity during and after the record drought of 1998-2002. This project evaluates South Carolina's integrated approach to drought management by evaluating the state-level and local-level drought triggers.

Frequency distributions and duration curves were computed for the state-level triggers (defined in Table 1) using monthly climate division Palmer Drought Severity Index values obtained from the National Climatic Data Center and three monthly climate division Standard Precipitation Index (SPI) indicators based on 3, 6, and 9-month anomalies (SPI-3, 6, 9). Frequency distributions and duration curves were also computed for the state-designated two-week average streamflow measurements (Table 1). The frequency distribution and duration curves for the local level triggers were computed for SJWD Lake Lyman storage volume and for the streamflow from the four rivers feeding the Duke Energy chain of lakes in the Catawba-Wateree basin.

7. RESULTS: EVALUATION OF TRIGGERS

This project found a similar PDSI and SPI frequency occurrence of each drought level as documented in other studies (Karl, 1986; McKee, 1993). The major difference between the PDSI and SPI anomalies was for moderate and severe drought with the PDSI indicating moderate drought twice as often as all the SPI anomalies and half as often at severe. A key component of this project was to illustrate to water systems the importance of developing system-specific drought triggers rather than depending on state-designated triggers that often lack the spatial and temporal resolution. Preliminary results demonstrate this with the state-level PDSI and SPI triggers indicating a 20-40% greater cumulative occurrence of any drought level as compared to the cumulative frequency occurrence indicated by SJWD and Duke Energy's local triggers. The greatest difference was found for the first stages of drought (Incipient and Moderate) with less than a 5% difference for Severe and Extreme. Table 3 shows the difference in frequency of occurrence between the PDSI and SPI triggers and the Lake Lyman local drought indicator frequencies for SJWD. Table 4 shows the difference in frequency of occurrence between the PDSI and SPI triggers and the streamflow conditions being tested for inclusion as a trigger in Duke Energy's Catawba-Wateree Low Inflow Protocol.

	Number of months within each level					Percentage of time within each level				
	PDSI	SPI 3	SPI 6	SPI 9	Storage	PDSI	SPI 3	SPI 6	SPI 9	Storage
Extreme	8	19	23	23	21	1	3	3	3	3
Severe	35	38	32	40	23	5	6	5	6	3
Moderate	158	58	62	62	14	24	9	9	9	2
Incipient	87	211	209	192	7	13	31	31	29	1
Normal	384	346	346	355	607	57	51	51	53	90

Table 3. Frequency of drought phase for SJWD based on monthly data from 1949-2004 (PDSI =Palmer Drought Severity Index, SPI 3,6,9=Standard Precipitation Index 3,6,9-month; Storage=SJWD Lake Lyman Storage)

	Number of months within each level					Percentage of time within each level				
	PDSI	SPI 3	SPI 6	SPI 9	Streamflow Sum	PDSI	SPI 3	SPI 6	SPI 9	Streamflow Sum
Extreme	9	15	19	13	14	1	2	3	2	2
Severe	26	41	31	35	54	3	5	4	5	7
Moderate	168	69	74	83	89	22	9	10	11	12
Incipient	137	242	257	237	34	18	32	34	31	5
Normal	415	388	374	385	564	55	51	50	51	75

Table 4. Frequency of drought phase for Duke's Catawba-Wateree based on monthly data from 1942-2004 (PDSI =Palmer Drought Severity Index, SPI 3,6,9=Standard Precipitation Index 3,6,9-month; Streamflow Sum=Duke Energy Combined Streamflow Triggers(preliminary not yet approved for LIP)

It is important, however, that water utilities not exclude the importance of the earlier onset signals gained by the PDSI and SPI, since hydrologic indicators such as reservoir levels may underestimate drought severity by not accounting for increased demand associated with dry periods (Fisher and Palmer, 1995). This emphasizes the importance of multiple triggers such as those based on demand as well as supply.

7.1 Triggers of the 1998-2002 Record Drought

As stated the record drought of 1998-2002 stimulated the development of local drought management plans in South Carolina with an emphasis on local triggers. Figure 1 shows the monthly progression of drought as indicated by different indices discussed above as well as the U.S. Drought Monitor for Spartanburg County. The U.S Drought Monitor (Svoboda, et. al., 2002) was not included in the frequency comparison due to the limited period of record (the index began August 1999). This index has gained popularity among local utilities and is currently being tested for inclusion as one trigger in Duke Energy's Catawba-Wateree Low InFlow Protocol. Figure 1 also includes the official declaration by the South Carolina Drought Response Committee as it existed for each month for Spartanburg County. Figure 1 illustrates the earliest onset of drought by the PDSI and 3-month SPI with the expected lag of drought indication by the hydrologic indicator of Lake Lyman Storage. The Official State Declaration of drought did not follow a pattern based on any set of triggers and surprisingly stayed at the moderate drought level from May 2000 through May 2002 despite indication by multiple triggers that the drought was worse. During this time when the Official Declaration was moderate, and routinely only requires voluntary water conservation, those water systems with strong drought plans and system-specific triggers were able to fully support their decision to require mandatory water restrictions from their customers. Figure 1 also shows the unprecedented recovery from the drought during September and October 2002 as indicated by all the triggers. While hydrologists projected that the recovery from the 1998-2002 drought would take years, it generally occurred in less than 12 weeks due to seven to twelve inches of above normal rainfall during two months. Groundwater (not shown) was the last to recover, taking between three to five months. Hence the official drought committee incipient declaration until April 2003.

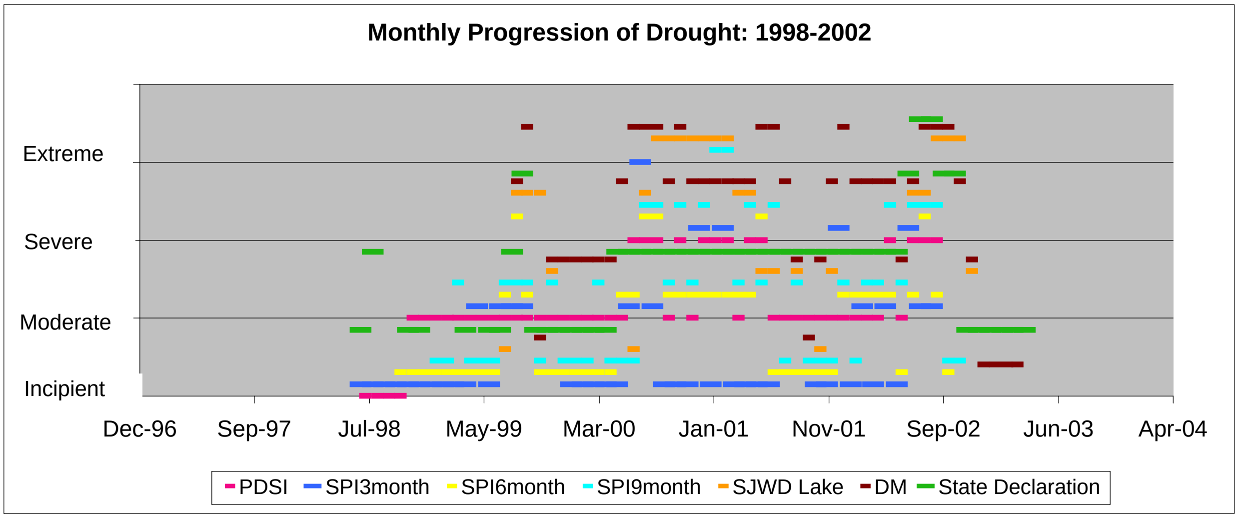

Figure 1. Monthly progression of drought indicated by state and local triggers (PDSI=Palmer Drought Severity Index, SPI=Standardized Precipitation Index 3, 6, 9-month, SJWD Lake= SJWD Water District Lake Storage, DM=U.S. Drought Monitor (Index began August 1999), State Declaration=Official SC Drought Response Committee Declaration

8. CONCLUSION

Effective water supply management includes a drought contingency plan that outlines a systematic evaluation of drought conditions with specific response measures. The ability to mitigate the effects of drought-induced water shortages depends on the "diagnostic accuracy" of the trigger points and the effectiveness of the water users in working together to implement actions to achieve significant water-use reductions. This should be accomplished by using historical data to determine whether the drought indicators consistently trigger an appropriate drought phase, indicate drought conditions too often, or do not provide an adequate indication of drought severity. This project demonstrated the effects of using an integrated planning approach for state and local drought management.

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