

ARE CLIMATE VARIATIONS REDUCING THE RELIABILITY OF OUR WATER SUPPLIES

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Abstract. Climate variability affects the availability and quality of water resources. Unanticipated extremes, such as unprecedented periods of drought, temperature, and intense rainfall / runoff, will affect water treatment and supply operations. Facilities have been designed and managed for a set of historical conditions that may well be changing. Utilities need to prepare themselves for additional uncertainties associated with a changing climate. Specifically, how might a changing climate affect the yield and reliability of existing and future water supplies?

Since 1998, the southeastern United States have experienced record low stream flows and periods of drought extending over several years. Record low reservoir levels have been observed in municipal water supplies, while new and lower safe yields have been calculated. Is this a coincidence, or is a pattern emerging?

Through the use of several examples in the Southeast, this paper will discuss the potential effects of climate variability on reliable water quantity, as well as possible water quality concerns. Comparisons of individual and system safe yield, before and after recent periods of drought (1998-2002, 2005, 2006-2008) will illustrate this issue.

INTRODUCTION

Droughts are like an economic recession. It is hard to tell exactly when they first occur and hard to know exactly when they are over. Generally, drought is a deficiency of precipitation over an extended period of time, causing a shortage in water supply.

The southeastern United States experienced one of its worst multiyear droughts on record from 1998 through 2002; and five years later parts of the region are once again experiencing extreme drought conditions. Record low reservoir levels have been observed in municipal water supplies, with calculations of new and lower safe yields. Is this a coincidence, or is a pattern emerging?

Examples from several locations in South Carolina, Virginia, and North Carolina illustrate the potential effects of climate variability on reliable water quantity. Comparisons of individual and system safe yield, due to historical and recent periods of drought, illustrate the natural variability of these systems and associated

concerns about future safe yield and reliability of the systems.

This paper will present a review of findings from studies in these three states, along with examples of how water utilities are learning to adjust to less reliable water supplies.

BACKGROUND

Water utilities engage in long-range water supply planning to ensure adequate water supply for the future. Traditionally, planners have used the term “safe yield” to quantify reliable reservoir withdrawal rate. The *safe yield* is an extremely important value because engineers use it to estimate available water supply and to determine if additional water sources are required.

While some states may have their own definition for safe yield, in general, the term can be defined as the maximum quantity of water that can be withdrawn from a reservoir during a critical dry period. This statistical value is usually determined through simulation of reservoir storage volume over an extended period (usually 50-years or more), using historical hydrological and meteorological data.

While *safe yield* is an invaluable tool for long-range water supply planning, the term can be a somewhat misleading. Since safe yield is typically calculated based on the worst historical drought, a reservoir can only reliably produce the safe yield if that drought of record is not exceeded. As a result, safe yields can be recalculated based on more frequent and severe droughts. Because of this, some have even suggested using the term “historical critical-period yield” in lieu of safe yield.

Regardless, many states use the term, and require water suppliers to plan for future water supplies based on reservoir safe yield.

SJWD WATER DISTRICT, SOUTH CAROLINA

The SJWD Water District (SJWD) is a public water purveyor located in northwestern South Carolina. Due to recent drought conditions, and recent modifications to their

water supply configuration, SJWD realized the importance of updating and refining their Drought Contingency Plan.

Since the completion of their previous drought plan in 2003, SJWD's water supply system has grown from one surface water reservoir, to three reservoirs; with two additional surface water supplies available for emergency use. As a part of this update, an integrated reservoir model was developed with multiple constraints to optimize water supply sources and demand management strategies during periods of drought.

South Carolina regulations require public water suppliers to develop system specific drought ordinances. Typically, these ordinances include measures (or triggers) for assessing the severity of the system's water supply shortage, water use reduction goals based on drought severity, and reactive measures such as voluntary or mandatory conservation. Because of their strong desire to ensure adequate water supply availability, SJWD chose to also include proactive measures to stretch their existing water supplies in times of drought by developing a reservoir operational strategy.

Safe Yield Update. To develop an effective reservoir operational strategy, SJWD first needed to re-assess their available water supply. A safe yield analysis was previously conducted for Lake Lyman, SJWD's original water supply reservoir, in mid-2002. The other two supplies, Lake Cooley and the North Tyger Reservoir, had not had detailed yield analyses completed since the late 1980's and 1990's, respectively. Therefore, a mass-balance model approach was used to update the long-term safe yield of each of their reservoirs.

South Carolina regulations do not specifically define safe yield. Therefore, the safe yield for SJWD reservoirs

was determined using the most severe drought of record, based on the 77-year period of available streamflow data. Figure 1 shows the combined usable reservoir volume for SJWD's three surface water reservoirs over the historical period. As shown in the figure, the drought of record occurred in 2002. However, the second worst drought is the current ongoing drought which began in 2007.

The total safe yield for SJWD's system, as compared to previously estimated values, has dropped by 10-percent. Note that the 77-year period of record evaluated ends in February of 2008, and only encompasses a portion of the current drought. It is likely that if the yield were re-assessed after the conclusion of the current drought, the safe yield values may drop even lower.

Reservoir Recovery. In terms of reservoir modeling, a "drought event" is defined as the period of time starting when the reservoir level begins to drop and ending when the reservoir level rises back to its normal operating pool. The ability of a reservoir to recover (or re-fill to normal pool) is largely a function of the tributary area upstream of the reservoir.

SJWD's two largest sources of supply, Lyman Lake and Lake Cooley, have very similar storage capacities (1.3 and 1.7 BG). However, these two reservoirs react very differently to drought conditions. Lyman Lake, which is located on a major river and has a rather large tributary area, recovers quickly from droughts. Lake Cooley, on the other hand, is located on a small stream with a very small tributary area, and thus takes much longer to re-fill. Understanding the recovery potential of their reservoirs will allow SJWD to operate these reservoirs more efficiently during water supply shortages.

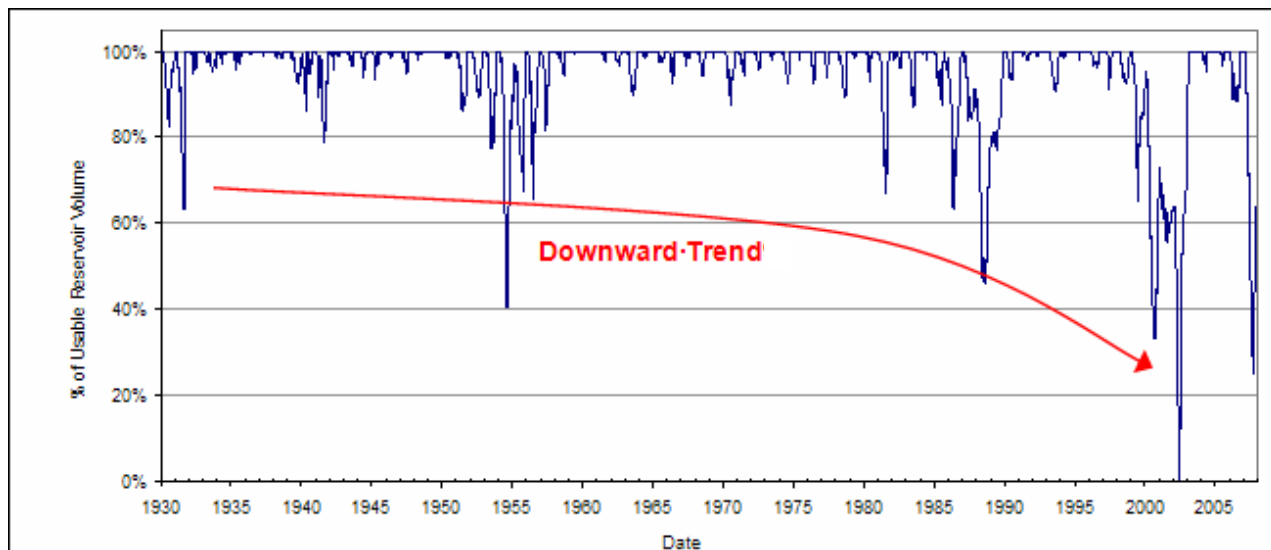


Figure 1. SJWD Safe Yield Reservoir Simulation

Reservoir Optimization. Planning for conservation and demand reduction may not be enough during times of drought. Water suppliers may need to optimize the way they operate their reservoirs. Instead of operating reservoirs as independent entities, water suppliers are now realizing the need to operate their reservoirs together in order to maximize their total system’s reliable yield. By doing this, a water supplier’s total system safe yield can actually exceed the sum of the individual reservoir yields.

Reservoir optimization may take several factors into consideration such as reservoir refill capacity, total storage, reservoir operation and outlet structure capabilities, long-term sustainability and climate change trends, and public perception.

As a part of the SJWD Drought Contingency Plan Update, an integrated reservoir model was developed to simulate reservoir operations and thereby determine the optimal reservoir optimization scheme. With each drought phase, SJWD plans to modify the percentage of raw water that they pull from each reservoir; and thereby, increase the total safe yield of their system.

The sum of the individual safe yields for Lake Lyman and Lake Cooley is 18.9 mgd. However, through implementing conservation and reservoir optimization, SJWD can effectively increase the combined yield to 22.8 mgd; an increase of nearly 21%.

ROANOKE, VIRGINIA

Seven municipalities of the Roanoke Valley of Virginia initiated a study of regional water supply options to satisfy their long-term needs. Following four years of cumulative precipitation deficits, water suppliers in southwestern Virginia were experiencing record impacts due to the continuing drought. The adequacy of existing sources to satisfy future demands was questioned, and a study was conducted to examine the optimization of existing sources as well as the development of new sources.

Virginia Safe Yield. The Virginia Department of Environmental Quality (DEQ) defines safe yield for complex intakes as “the minimum withdrawal rate available to withstand the worst drought of record in Virginia since 1930.” To evaluate their existing sources, the safe yields of their two predominate reservoir sources, the Spring Hollow Reservoir and the Carvins Cove reservoir, were calculated based on VA DEQ requirements.

Table 1 shows these results.

Rank	Spring Hollow		Carvins Cove		Combined	
	Year	Yield (mgd)	Year	Yield (mgd)	Year	Yield (mgd)
1	1931	15	2002	14.1	2002	31.4
2	1964	15.7	1982	14.5	1931	32.4
3	1934	16.1	1931	17.4	1981-1982	35.1
4	2002	17.3	1942	18.8	1934	36.2
5	1953	20.2	1934	20.1	1964-1966	37.1
6	1981	20.6	1954	20.9	1953-1954	41.1

Table 1. Safe Yield for Existing Regional Sources

The total safe yield resulting from coordinating reservoir operations is nearly 8% larger than the sum of the individual safe yields. Additionally, the study results demonstrate how each reservoir reacts differently to the same drought as the worst drought on record for Spring Hollow was in 1930 while the worst drought for Carvins Cove was in 2002.

Optimization of Existing Sources. One example of optimizing existing sources is the potential increased yield benefit realized from coordinated operation of the two large water supply reservoirs. Simulation of the reservoirs’ operation over a synthesized 75 years of record provided insight into periods of historical drought and severity of drought impacts. A conclusion of the evaluation was that the period from 1998 to 2002 defined the most significant drought affecting the Carvins Cove Reservoir, followed by the drought of the mid-1980s.

Conversely, the historical record indicates that the 1930s drought would have been the most significant drought affecting the Spring Hollow Reservoir, followed by the drought of the 1960s. The conclusion that the two reservoirs would be impacted differently under the same drought conditions identifies a potential benefit from coordinated operation. The combined operation will be more reliable in times of drought, and seasonal operating patterns can be considered, netting a benefit in non-drought situations.

Regional Approach. As the first study in 15 years to address water supply issues on a regional basis, the report is being used to advance dialogue and to identify opportunities for cooperation between the region’s

localities. Additionally, the study provided substance to the discussions of merging the two water systems of the City of Roanoke and Roanoke County by showing the benefits of coordinating reservoir operations.

Following much discussion and evaluation, the City and County merged to form the Western Virginia Water Authority. The different attributes of the two systems provide a number of opportunities to improve the reliability and efficiency of operations through coordination. The development of a raw water operational strategy and addition of infrastructure to enable the coordinated operation is being planned. Capitalizing on the positive results of conservation practices that were implemented during the drought is ongoing while the potential future use of highly treated, reclaimed wastewater for supply augmentation is under consideration. It is expected that continued coordinated planning of future supplies, interconnections with neighboring developing localities, and system improvements will result in similar regional benefits.

CABARRUS COUNTY, NORTH CAROLINA

The Water and Sewer Authority of Cabarrus County (WSACC) completed a safe yield update and regional drought study in 2003. Using the mass-balance model to simulate reservoir operations, it can be shown that the recent drought (1998-2002) was the most severe in the last 103 years of record with respect to reservoir yield and reliability. To quantify the effects of the recent drought, it was necessary to update the mass-balance models. Previous safe yield estimates were completed as a part of their 2002 Master Plan, but these estimates did not include the entirety of the 2002 drought.

The safe yield update includes the new drought of record for the four major water supply reservoirs serving Cabarrus County: Lake Howell, Kannapolis Lake, Lake Fisher, and Lake Concord. In addition, the collection of bathymetric information for these reservoirs coupled with a better representation of the inflows to the reservoirs needed to be incorporated into the safe yield calculations.

North Carolina Safe Yield. According to the North Carolina Water Supply Plan (2001), safe yield available from a reservoir should be based on a specific risk of water shortage. For water systems serving 50,000 or more people, a 50-year safe yield is recommended, meaning that the supply is expected to be inadequate in only one year out of 50 on the average. To meet the NC Department of Environment, Health, and Natural Resources guidelines, WSACC computed the 50-year safe yield for each of their four water supply reservoirs.

Since approximately 100 years of reservoir operations are simulated, the most detrimental drought event of the period is determined to have a 100-year recurrence, and the second most significant drought is determined to have a 50-year recurrence. The results of the previous and updated safe yield analysis are presented in Figure 2.

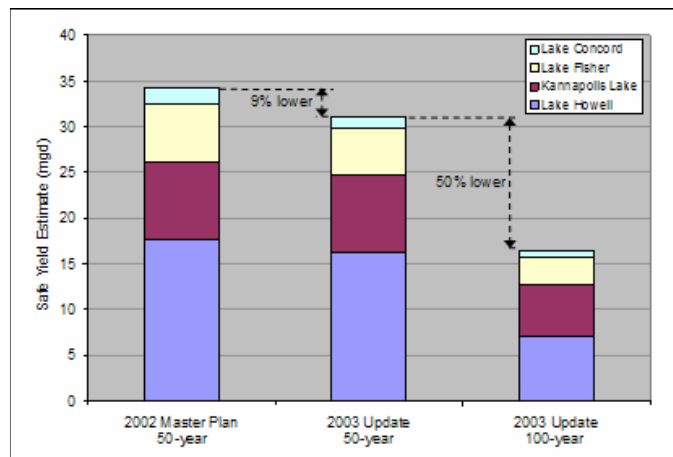


Figure 2. WSACC Safe Yield

By including the entirety of the 2002 drought along with updated bathymetric data, the 50-year safe yield for the four reservoirs dropped by 9%.

While North Carolina regulations use the 50-year safe yield for water supply planning purposes, it is significant to note that during the 2002 drought, withdrawals equal to the 50-year safe yield values could not have been sustained. The total safe yield from the four lakes equals 31.1 mgd considering a 50-year recurrence, and reduces to 16.5 mgd considering a 100-year recurrence.

A drought management strategy is needed to manage the sources, in conjunction with water use reductions and purchase of additional supplies, to ensure safe and reliable operations.

Regional Approach. The occurrence of the 2002 drought and the resulting record low levels in the water supply lakes provides great incentive to examine the benefits of managing and operating the water supplies of Cabarrus County in a coordinated manner. The objective of the evaluation of coordinated regional operations is to determine a sequence of operations that best extends the availability of the region's water supply storage in times of drought. A number of local, state, and river-based drought programs were investigated to provide information on similar programs implemented by others.

The analysis of safe yield shows that Lake Howell is limited in its ability to recharge, once its volume and elevation have dropped. Therefore, preserving the volume of water in this reservoir becomes a priority when incipient

drought conditions are present. Regional water use restrictions in concert with reductions in reservoir releases were recommended to ensure reliability of the water supply during drought.

CONCLUSIONS

Since *safe yield* is a statistical value, dependent on historical trends, water suppliers should be cognizant that as droughts become more frequent and severe, previously estimated safe yield values may no longer be reliable.

The 2002 drought is becoming the new “drought of record” for many reservoirs, with the current ongoing drought as a close second. Safe yield analyses conducted prior to the end of the 2002 drought should be re-evaluated. Coordinating reservoir operations can provide significant benefit to water suppliers.

Water utilities will benefit from planning for climate variations that impact reliable water supply. What we consider “drought” conditions today, could possibly become “normal” in the future. Regional approaches along with more “outside of the box” methods will likely become common practices.

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