Regional Planning Background

In 2007, Tennessee suffered a drought of record in many parts of the state. At the same time the state managed through those extreme conditions, there was a desire to be better prepared for water resource scarcity and the stress that growth and development are placing on resources in some communities.

In response to those issues and in accordance with §69-7-309 of the Tennessee Water Resources Information Act, the Department of Environment and Conservation (TDEC) organized a Water Resources Technical Advisory Committee (WRTAC) to make recommendations on water resources issues. The 16-member committee, representing state and federal agencies, non-governmental associations and academia, provided helpful insight with the objective to help refine and improve water management policies and options for TDEC.

One of the first priorities of the WRTAC was to consult with the department in the development of a drought management plan, which was finalized in February 2009. *TDEC's Drought Management Plan* is an update of a drought management plan released in 1987. Its purpose is to outline TDEC's role during a drought, facilitate planning, and provide a framework for action and cooperation in water resources management among the many local, state, and federal agencies with drought-related responsibilities.

TDEC also developed the *Guidance for Developing Community Water System Drought Management Plans* to provide community water systems with the necessary elements of a drought management plan. This guide promotes preparation to mitigate the adverse impacts of drought. The guidance includes suggested drought management planning steps.

As the WRTAC reviewed impacts from the drought of 2007, discussion centered on the benefits of regional water resource planning. The Committee recommended that the department pilot regional water resource planning projects to validate those benefits and develop a model regional water plan for the state.

In late 2008, TDEC partnered with the U.S. Army Corps of Engineers Nashville District, members of the WRTAC, and other regional planning experts to initiate a water resources planning pilot in two areas significantly impacted by the drought of 2007:

1. **North Central Tennessee region—**Sumner County, including Portland, Gallatin, Castalian Springs/Bethpage, White House, and Westmoreland.
2. **Southern Cumberland region—**consisting of portions of Franklin, Grundy, Marion, and Sequatchie Counties and the towns of Tracy City, Sewanee, Altamont, and Monteagle.

2007 Drought in Tennessee

During the drought of 2007, in excess of 500,000 people were on community water systems that imposed mandatory water restrictions. Despite the severity of the 2007 drought, because of the planning that had occurred, the interconnection between systems, and the communication and collaboration among agencies and water systems, only one community water system, Orme, ran completely out of water. Volunteers, driving a tanker truck hauled about 25,000 gallons of water to Orme each day from Bridgeport, Alabama, 2½ miles down the road. After the drought, Orme and Bridgeport installed a pipeline as a permanent interconnection.

After the 2007 drought, the Tennessee Duck River Development Agency began working on a Comprehensive Regional Water Supply Plan for Bedford, Coffee, Marshall, Maury, and southern Williamson counties. The Plan, finalized in 2011, is designed to meet future water needs and address concerns about possible water shortages brought on by drought conditions over a 50-year planning period.

The *South Cumberland Regional Water Resources Planning Study* and the *North Central Regional Water Resources Planning Study*, both finalized in 2011, are posted on the TDEC Regional Planning webpage at http://www.tn.gov/environment/water/water_regional_planning.shtml.

In early 2013, the WRTAC compiled the principles developed through the two pilot studies and produced the *Regional Water Resources Planning Guidelines for Tennessee*. The purpose of the guide is to provide recommended procedures for regional planning that should be used in other regions across the state. It includes recommended methods for assessing existing sources and systems, projecting future unmet need in the region, and evaluating alternatives.

Current Charge to the Water Resources Technical Advisory Committee

Public Chapter 986 of the Acts of 2012 rewrote Tennessee Code Annotated §69-7-309 concerning the technical advisory committee on water resource issues effective October 1, 2012. Instead of requiring such a committee, the law authorized the Commissioner of TDEC to appoint such a committee. In January 2013, Commissioner Bob Martineau appointed eleven members to the Water Resources Technical Advisory Committee and issued a charge consisting of three items to be completed by specific due dates.

The first item of the charge asked the WRTAC to recommend a process for approving regional water supply plans. The *Regional Water Supply Plans Approval Process for Tennessee* was finalized in June 2013. The document includes information about defining a region and a checklist of items to be included in a regional water supply plan. It also outlines the process for obtaining approval of a submitted plan.

The second item of the charge required the Committee to propose a coordinated statewide system for reporting, maintaining, and accessing basic hydrologic and water system information. The *Statewide System of Basic Hydrologic and Water System Information*, finalized in December

2013, includes an assessment of the routinely collected hydrologic and water system information and the significant gaps in statewide water resources information. The document also includes a proposal for a statewide system for reporting, maintaining, and accessing basic hydrologic and water system information based on the assessment results.

In the third and final item of the charge, the WRTAC was asked to

- recommend ways to address the water resources data gaps identified in the prior submittal;
- make preliminary determinations of several hydrologic and water system statues; and
- recommend an agency or organization to develop the capacity for statewide analysis of hydrologic and water system information and a projection of their required resources to perform this function.

The response to this charge item follows.

Statewide Analysis of Hydrologic and Water System Information—WRTAC Recommendations

- **Water Resources Data Gaps**

Several water resources data gaps were identified in the *Statewide System of Basic Hydrologic and Water System Information*. The WRTAC recommends the following ways to address those gaps:

Identified Gaps	Recommendations for addressing them
Legislated gaps due to agricultural exemptions in the Water Withdrawal Registration Act limit the amount of available information related to irrigation.	Meeting between the TDEC and Tennessee Department of Agriculture commissioners and deputy commissioners to discuss trends in Tennessee agricultural practices.
Currently U.S. Geological Survey (USGS) gage groundwater data obtained from approximately 15 real-time wells in western Tennessee with no wells instrumented in middle and upper east Tennessee to look at drought conditions.	Existing line item in 2015 USGS budget for nationwide groundwater monitoring effort including some locations in TN.
Lack of standardized statewide method for determining ecological flow requirements in streams and rivers.	Meetings are underway between representatives of TDEC, the Tennessee Wildlife Resources Agency, The Nature Conservancy, USGS (Instream Flow Working Group) to develop draft approach. Ecological flow describes the quantity, quality and

Identified Gaps	Recommendations for addressing them
	timing of water flows required to sustain freshwater systems and the human livelihoods and well-being that depend on these ecosystems.
No generally available information on Aquatic Resource Alteration Permits issued by TDEC for self-supplied uses such as agriculture or landscape irrigation.	TDEC's current effort toward electronic availability of permit, etc. information in a data warehouse should include these permits.
Information from utilities on water use by sector (e.g., commercial, residential, industrial, etc.)	TDEC in cooperation with USGS conducted two water system surveys on water use. The first survey was conducted for the 2005 calendar year and the second survey was conducted for the 2010 calendar year. Both water system surveys contribute to past, current, and future cooperative water use studies in cooperation with TDEC, the Nashville District Corps of Engineers (USACE), and USGS. The water system survey on 2005 water use was used as a supplement to the water system survey on 2010 for studies with the TDEC and the USACE. TDEC and USGS also tested an online version of the water system version on 2010 water use. The system operators were pleased with the online version. These surveys capture water distribution; water distributed; water sold to other water supply systems; water sold and billed to residential, commercial, and industrial customers; and losses.
Historic data from the Nashville District Corps of Engineers' (USACE) extensive network of stream and rainfall gages in the Cumberland River basin not readily available for access by public.	USGS investigates their capability for presenting data not directly QA/QC'd by them to see whether the data can be posted on the USGS site (would require that USGS and the USACE determine funding sources for the hardware, software, and maintenance).

- **<u>Preliminary Hydrologic and Water System Determinations</u>**

  - **Estimated water needs—both immediate and long term—in areas most often impacted by drought or growth**

Appendix A includes a map created by the WRTAC comparing the Census population for the Hydrologic Unit Code (HUC) 8 basins and a calculated population that could be supported based on stream flow at select points. The assumptions supporting the assessment are included in Appendix A. The map gives a preliminary indication of areas of concern across the state. The WRTAC recommends further analysis to refine the data presented. Appendix A also includes maps from the U.S. Drought Monitor that show areas of the state most often impacted by drought.

  - **Listing of water systems with least reliable sources and few interconnections for emergency support; listing of water systems principally relying on spring sources, low-yielding wells, or other source water vulnerabilities**

For an initial assessment, the WRTAC developed a map of systems across the state relying on wells or springs with an overlay of the regional aquifers in Tennessee. That map is shown in Appendix B. As with the stream flow map, the map shows some areas that require further analysis to fully determine the vulnerability. The groundwater systems in West Tennessee are among the most prolific aquifers in the Nation and are capable of supplying very large public-water systems. The limestone aquifers in the Valley and Ridge of East Tennessee are capable, in local areas, of supplying water to large public-water systems.

The limestone in the Central Basin and the sandstone underlying the Cumberland Plateau are the least productive aquifers in Tennessee. The public-water systems on the Cumberland Plateau using groundwater produce less than 0.1 million gallons per day (Mgal/d). The public-water systems in the Central Basin using groundwater produce less than 0.25 Mgal/d unless the groundwater is connect to surface water.

The WRTAC also compiled a list of groundwater systems that withdraw approximately 250,000 gal/day (0.25 Mgal/d) or less along with those systems to try to identify smaller systems that might have greater risk. Fifty-four of the small public-supply systems are located in West Tennessee. The source capacity of the wells to meet long-terms needs for the systems is unknown for 19 of the 54 systems. The West Tennessee aquifers however, can support the public-water systems. In local areas, just west of the Tennessee River, the aquifers may be thin and the aquifers may be less reliable.

Forty-six small public-water systems are located in Middle and East Tennessee. The source capacity of the wells or springs to meet long-terms needs for the systems is unknown for 36 of the 46 systems. Of the 46 systems, seven purchase 20 to 70 percent of the total water used by the system to meet public-supply needs. The higher percentage of purchased water may indicate less reliability of the source. The source capacity and the interconnection to other systems need to be evaluated for these systems in order to fully evaluate the source reliability and system risk.

A similar analysis for the source capacity and connection to other water systems could be conducted for small surface-water based systems on small reservoirs or unregulated streams.

- **Evaluation of water conservation practices, successes, and models of sustainability across the state**

Through the pilot studies in North Central Tennessee and the South Cumberland, the WRTAC learned that conserving water and managing, even restricting, its use are the main strategies that sustained many Tennessee utilities through the drought of 2007 and 2008. They are common strategies in times of drought, and they are becoming more commonplace in times of normal rainfall because they can reduce costs—both for utilities and for customers—and postpone the need to invest in expensive, new water-supply sources and treatment plant expansions. However, there is no compiled information available on the water conservation practices of water systems across the state.

Obtaining this information would provide a baseline of current conservation practices in Tennessee and identify best practices available to water systems and is part of the recommendations from the WRTAC.

- **Proposed agency or organization to develop the capacity for statewide analysis of hydrologic and water system information and the projection of required resources**

The WRTAC concluded that an academic institution would provide the technical expertise and neutrality to best serve as the permanent home for statewide analysis of hydrologic and water system information. Proposals were requested from three of the state's universities with existing centers focused on water. Tennessee Technological University's GIS Laboratory and the Center for the Management, Utilization and Protection of Water Resources; the University of Memphis' Center for Partnerships in GIS and Ground Water Institute; and the University of Tennessee-Knoxville's Tennessee Water Resources Research Center within the Institute for a Secure and Sustainable Environment submitted a collaborative proposal to develop the capacity for statewide analysis of hydrologic and water system information and to project the required resources to maintain and support the database. Their proposal is attached as Appendix C.

Recommended Next Steps

The following are recommendations from the WRTAC to TDEC based on the body of work completed since the organization of the Committee in 2008:

Incentives for Regional Planning

In the *Regional Water Resources Planning Guidelines for Tennessee*, the WRTAC identified several benefits of regional planning including

- increasing system flexibility during droughts through sharing water resources that remain viable;
- preparing for the uncertainty of climate variability;
- encouraging utilities and municipalities/counties to work together to address water resource and supply issues;
- increasing sustainability by minimizing demand on resources;
- eliminating duplicate solutions and promoting efficiency; and
- providing funding advantages for utilities, municipalities, counties, and ultimately citizens.

However, many water systems perceive regional planning as ceding control over their systems and weakening their ability to reliably serve their customers. Some systems have pursued consolidation with another utility only after facing their financial inability to continue operating independently. The WRTAC believes it is critical that scoring advantage be given to projects consistent with an approved regional plan when evaluating them for potential State Revolving Fund (SRF) loans. The recently passed revision of SRFs under the Water Resources Reform and Development Act include a provision that in 2016, SRF recipients must certify in a manner chosen by each Governor that they have chosen the most sustainable and cost effective approach to the project. The WRTAC recommends that TDEC incorporate regional planning into the SRF certification requirements for Tennessee.

Conservation and Efficiency

As stated in several of the previous documents, the WRTAC believes that conservation / water efficiency, both by utilities and their customers, is an often untapped resource for addressing

Potential Losses from Water Leaks

Malfunction	Leaking Flow Rate (gallons per minute)	Water Loss	Estimated Cost of Water Loss
Leaking Toilet	0.5 gpm	21,600 gallons per month	$2,100 per year
Drip Irrigation Malfunction	1.0 gpm	43,200 gallons per month	$4,300 per year
Unattended Water Hose at Night	10.0 gpm	5,400 gallons per day	$16,000 per year
Broken Distribution Line For:			
One Night	15.0 gpm	8,100 gallons	
One Day	15.0 gpm	21,600 gallons	
One Week	15.0 gpm	151,200 gallons	Up to $64,000 per
One Month	15.0 gpm	648,000 gallons	year

http://www.epa.gov/watersense/commercial/managing_water.html#tabs-business_case

supply deficits. Addressing water leaks can be an important first step for utilities to increase their efficiency and reduce costs. Utilities that take steps to increase efficiency and reduce costs may encourage their customers to be more cooperative with other water conservation programs that would rely on individual actions. Each of the pilot studies conducted by the WRTAC included conservation and demand management as part of the recommended alternatives.

Increased energy efficiency is another area of potential cost savings for utilities. The University of Memphis conducted energy audits of two utilities involved in the pilot studies. At one of the utilities, it was discovered that replacing pumps at the raw-water pump station would result in an annual energy savings of approximately $10,000.

The WRTAC recommends that TDEC continue to encourage utilities to pursue conservation and efficiency by addressing leaks and other system losses, improving energy efficiency, and implementing programs to encourage their customers to conserve.

Statewide Analysis of Hydrologic and Water System Information

The *Statewide System of Basic Hydrologic and Water System Information*, produced by the WRTAC, includes a proposal for a statewide system for reporting, maintaining, and accessing basic hydrologic and water system information based on assessment results. The WRTAC recommends that this information system be developed by an academic entity as part of the development of the capacity for statewide water resources analyses. It also is appropriate that they research the existing water conservation practices of water systems across the state and identify best practices currently in use. The collaborative proposal included in Attachment C provides a starting point for further discussion with these entities.

The WRTAC recommends that Governor Haslam provide the public with a summary of the accomplishments of this effort emphasizing the great importance of water to Tennessee's future.

APPENDIX A – Stream Flow Analysis / Drought

Public-water systems in Tennessee produce water form reservoirs, unregulated streams, and the regional aquifers. As part of the WRTAC charge, an analysis was conducted to evaluate the ability of the unregulated streams to meet current and future needs for water supply and water availability. The analysis was conducted at a basin scale (8-digit HUC) that includes streams such as the lower Duck River, Harpeth River, Sequatchie River, Buffalo River, and the upper Nolichucky River. Basins with a significant reservoir were not included in the analysis. The basins in West Tennessee where public-water systems have access to abundant groundwater were not included in the analysis.

The analysis is based solely on the available stream flow and does not include any evaluation on the use of groundwater for public-water supply in Middle and East Tennessee or the use of small lakes or reservoirs. The analysis does not include an evaluation of the feasibility or cost effectiveness for extending pipelines to the downstream portion of the basin. Interbasin transfers of water, water-harvesting during high-flow conditions, or the degree of interconnection between public-water were not considered as part of the evaluation. The analysis also assumes that the total population will be supplied by public-water systems with no wells or springs used for domestic water supply.

The stream flow analysis for public-water supply has two components; the total population in each basin, and the available stream flow The population for each basin is based on the 2010 Census utilizing the population for each county by the detailed census tract. The census tract population was aggregated to each of the hydrologic basins to estimate the population for that basin. The basin population was also projected to 2030 by applying the county level population projects developed by UT-CBER to the census tract populations for each county. The stream flow component relies on historic stream flow data from the U.S. Geological Survey(USGS) and accounts for the flow rates used by TWRA and the amount of water estimated to be needed to maintain the biota/ecology of the stream.

Stream flow data from about 200 sites across Tennessee were used to estimate the stream flow characteristics needed for the analysis. TWRA utilizes the September median flow for a stream as part of their process. The available stream flow records were used to generate the E85 flow term (the E85 flow is the flow rate exceed 85% of the time), which is generally equivalent to the September median flow and was available for a large number of sites. Additionally, the amount of flow that is needed is excess of the E85 to support all of the biologic and ecologic functions of the stream was also estimated. The ‘ecoflow' was estimated as 0.1 cubic feet per second (cfs) per square mile drainage area. For example, the Harpeth River River at Bellevue, Tennessee has a 408 square mile drainage area and the ecoflow would be estimated as 41 cfs. The ecoflow of 0.1 cfs/sq-mile is based on research and analysis by Rodney Knight and Scott Gain, USGS Nashville, Tenn.

The amount of water available for public-water supply was calculated as the amount of flow (E85) minus the ecoflow (0.2 cfs/sq-mile). The Buffalo River at Lobelville, Tennessee, for example, has an E85 flow of

318 cfs, a 702 sq-mile drainage area, and an estimated 70 cfs ecoflow. The water available for public-water supply would be calculated as;

Available = E85 – ecoflow

Available = 318 cfs – 70 cfs

Available flow = 248 cfs

In regions of the State where the streams do not receive significant spring flow or input from groundwater, the streams are relatively low-flowing and the calculated E85 is relatively low. The Emory River at Deermont, Tennessee is of similar size to the Buffalo River at Lobvelville, but the flow characteristics are very different. The Emory River at Deermont has an E85 flow of 44 cfs, a 702 sq-mile drainage area, and an estimated 70 cfs ecoflow. The water available for public-water supply would be calculated as;

Available = E85 – ecoflow

Available = 44 cfs – 70 cfs

Available flow = -26 cfs

The negative available flow indicate the stream is not as well supported by groundwater and spring inflow, will be more susceptible to drought, and will be less reliable as a public-water supply.

The available stream flow from this analysis was converted from cubic-feet per second to million gallons per day and then converted to a population that could be supported based on a state wide average for public-water systems of 140 gallons per person per day. The actually per capita water use by public-water systems in Tennessee varies widely and future evaluations can incorporate the variability. The statewide per capita average, for this analysis, provided a consistent value for region to region evaluation.

The population that could be supported by available stream flow was compared to the total basin population for 17 basins in Tennessee where public-water systems were not supported by reservoirs or the West Tennessee aquifers. The lower Duck River was included in this analysis because of the stream flow and release requirements for Normandy Reservoir in the upper Duck River basin. The available stream flow and population analysis was used to evaluate the ratio of the population supported by available stream flow to the 2010 and projected 2030 population in the basin. The evaluated basins were classified as;

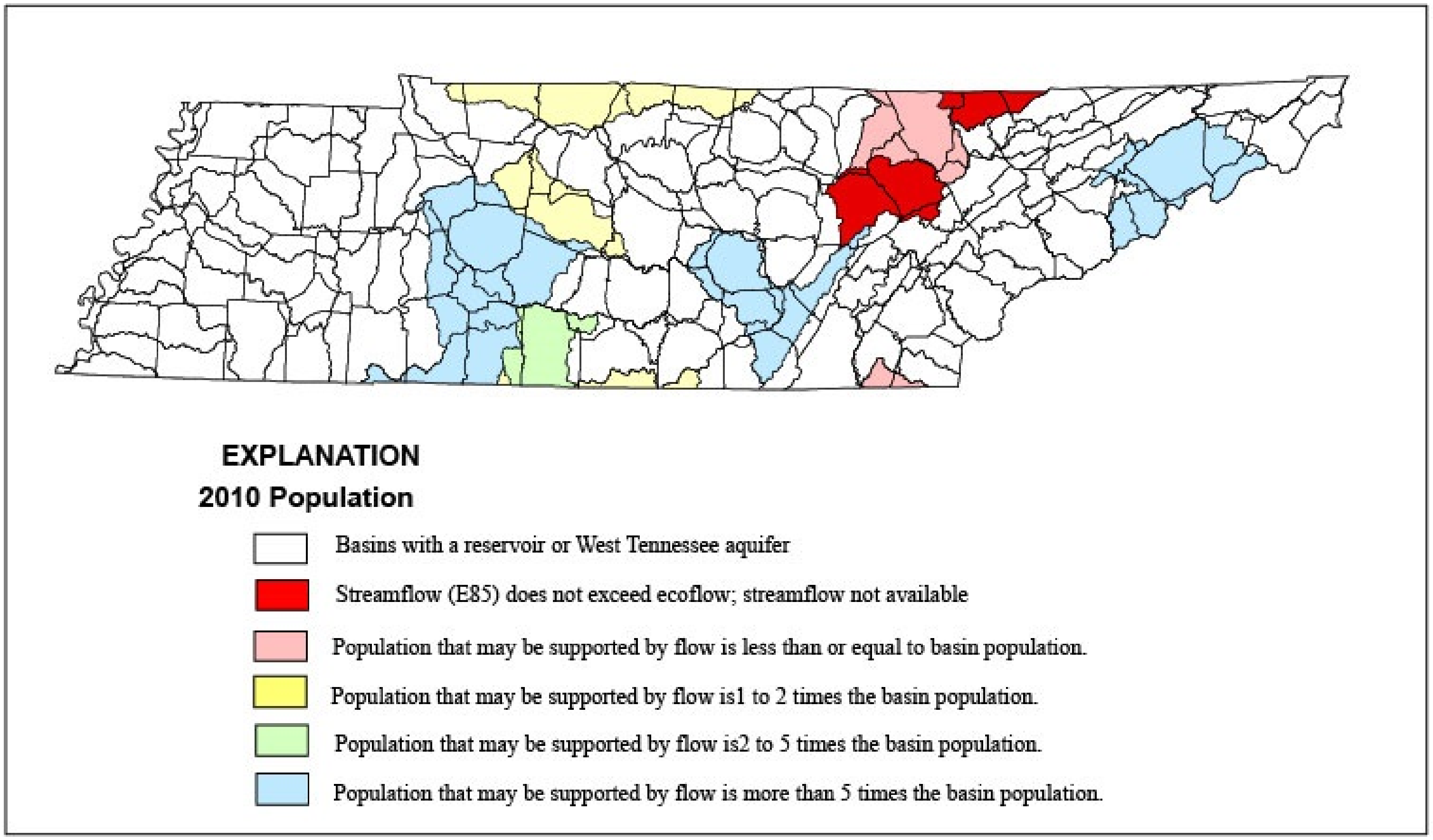
E85 does not exceed ecoflow, calculated available flow is negative, Stream flow supports population that is equal to, or less than the basin population,

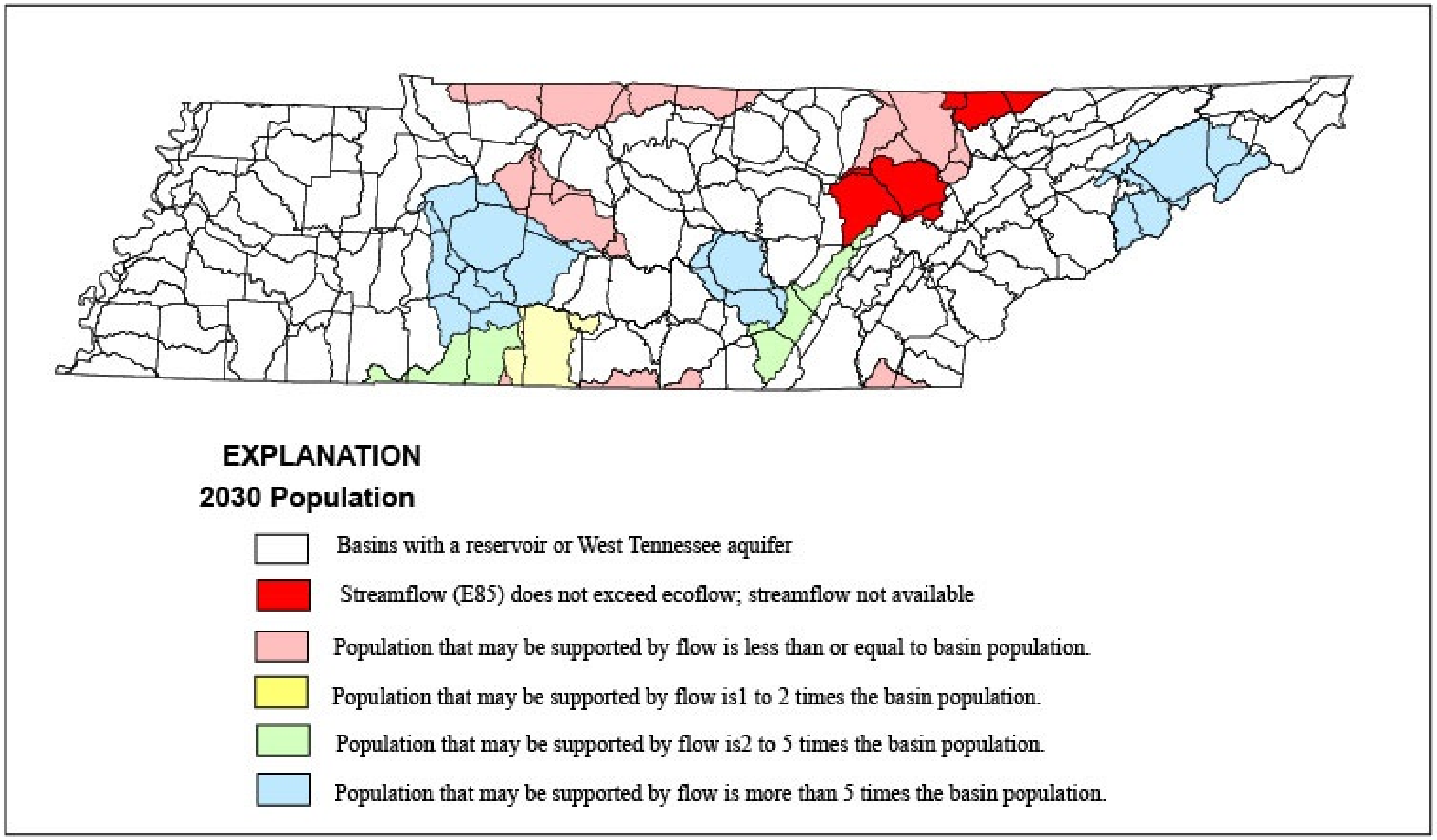
Stream flow supports population that is 1 to 2 times the basin population,

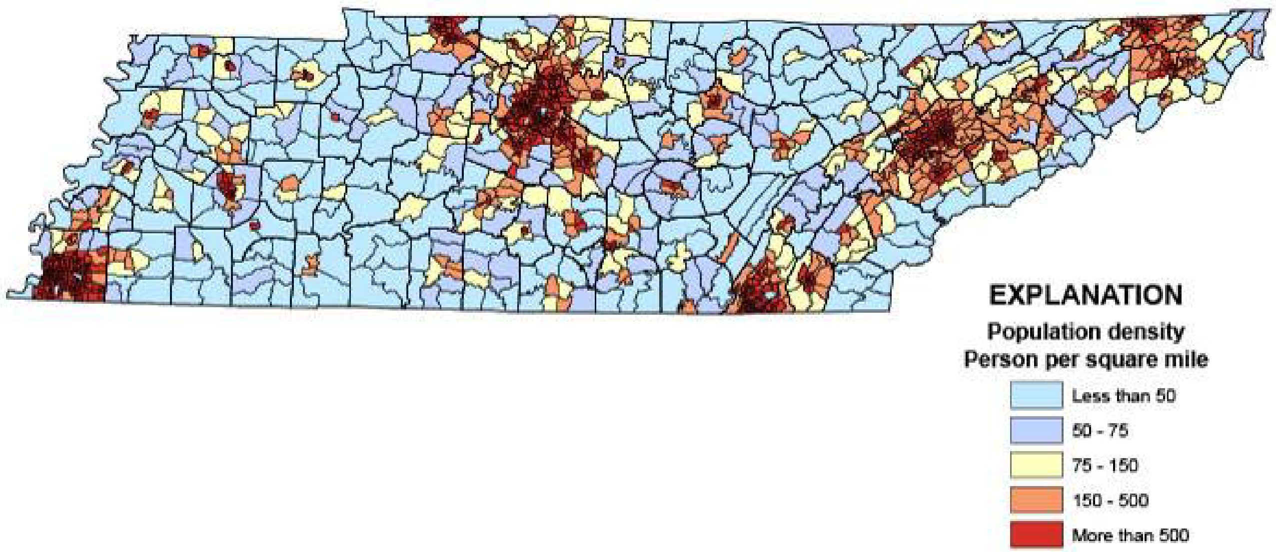
Stream flow supports population that is 2 to 5 times the basin population, and

Stream flow supports population that is more than 5 times the basin population.

Two basins on the northern Cumberland Plateau had flow characteristics where the E85 flow did not exceed the calculated ecoflow and the calculated available stream flow is negative. In 2010, only two basins had populations that were more than or equal to the population that could be supported by the available stream flow. By 2030, that number has increased to 6 basins as the population increases, especially in the Harpeth River basin and along the northern Highland Rim.


EXPLANATION
2010 Population
Basins with a reservoir or West Tennessee aquifer
Streamflow (E85) does not exceed ecoflow; streamflow not available
Population that may be supported by flow is less than or equal to basin population.
Population that may be supported by flow is1 to 2 times the basin population.
Population that may be supported by flow is2 to 5 times the basin population.
Population that may be supported by flow is more than 5 times the basin population.

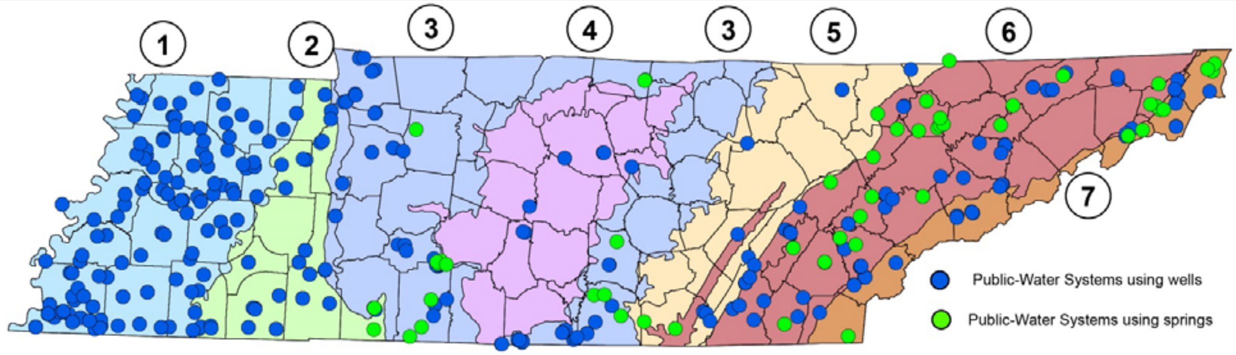

EXPLANATION
2030 Population
Basins with a reservoir or West Tennessee aquifer
Streamflow (E85) does not exceed ecoflow; streamflow not available
Population that may be supported by flow is less than or equal to basin population.
Population that may be supported by flow is1 to 2 times the basin population.
Population that may be supported by flow is2 to 5 times the basin population.
Population that may be supported by flow is more than 5 times the basin population.



2010 population density by census tract in Tennessee

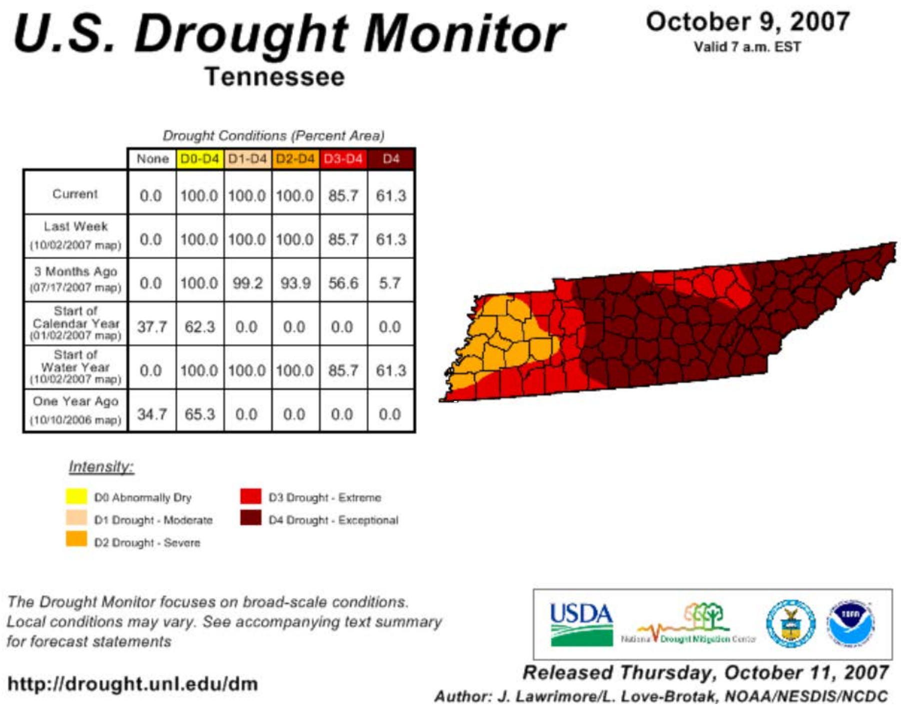
APPENDIX B – Systems Relying on Wells or Springs

Description of the regional aquifers in Tennessee and location of groundwater based public-water systems



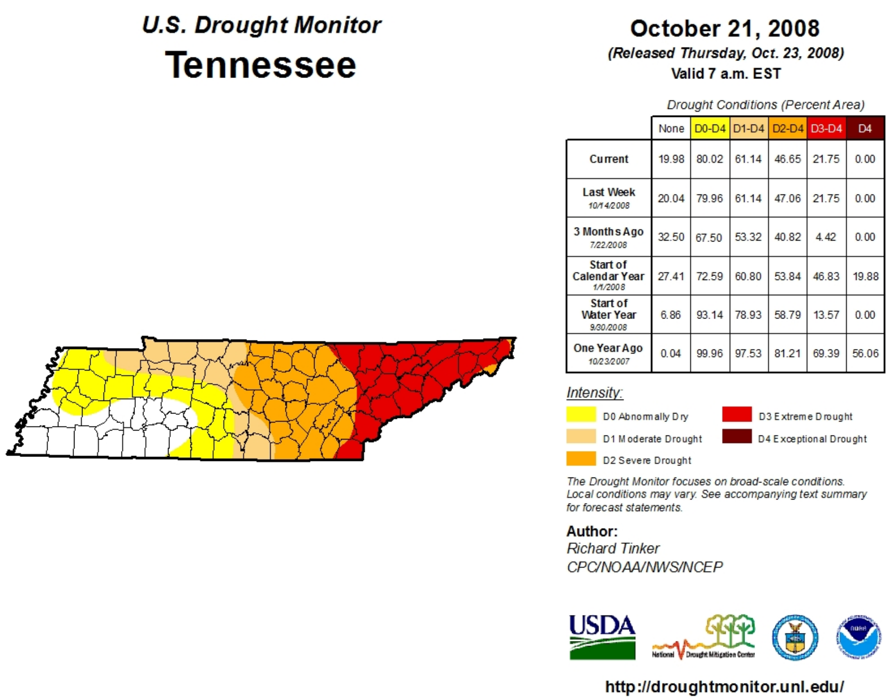
EXPLANATION

1	Tert Sand	Tertiary sand aquifer – most productive aquifer in Tennessee. Capable of sustaining very large withdrawals (>20 Mgal/d) for public-water systems.
2	Cret Sand	Cretaceous sand aquifer – generally a productive aquifer in Tennessee. Capable of sustaining large withdrawals (3 - 5 Mgal/d) for public-water systems except in areas near the eastern boundary or where sands are thin.
3	Highland Rim	Highland Rim – Limestone aquifers, can be productive locally. Currently supporting public-water systems using 0.3 to more than 1 Mgal/d.
4	Central Basin	Central Basin – Limited capacity to sustain public-water supply. Currently supporting public-water systems using less than 0.25 Mgal/d. Can supply >1 Mgal/d in local areas where the aquifer connects to surface water.
5	Cumberland Plat	Cumberland Plateau – sandstone aquifers with limited capacity to sustain public-water systems. Currently supplying <0.1 Mgal/d to individual supply systems.
6	Valley-Ridge	Valley and Ridge, Sequatchie Valley – Limestone aquifers can be very productive and can sustain large withdrawals (3 – 5 Mgal/d) for public-water systems. Supplies can be limited depending on local conditions.
7	Blue Ridge	Blue Ridge – Variable conditions. Fractured rock in the uplands typically sustain small water systems (<0.25 MGal/d). Limestone aquifers in the coves and valleys can sustain large systems (3 – 5 Mgal/d).


U.S. Drought Monitor
Tennessee
October 9, 2007
Valid 7 a.m. EST
Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.0	100.0	100.0	100.0	85.7	61.3
Last Week (10/02/2007 map)	0.0	100.0	100.0	100.0	85.7	61.3
3 Months Ago (07/17/2007 map)	0.0	100.0	99.2	93.9	56.6	5.7
Start of Calendar Year (01/02/2007 map)	37.7	62.3	0.0	0.0	0.0	0.0
Start of Water Year (10/02/2007 map)	0.0	100.0	100.0	100.0	85.7	61.3
One Year Ago (10/10/2006 map)	34.7	65.3	0.0	0.0	0.0	0.0

Intensity:
D0 Abnormally Dry
D1 Drought - Moderate
D2 Drought - Severe
D3 Drought - Extreme
D4 Drought - Exceptional
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements
http://drought.unl.edu/dm
Released Thursday, October 11, 2007
Author: J. Lawrimore/L. Love-Brotak, NOAA/NESDIS/NCDC


U.S. Drought Monitor
Tennessee
October 21, 2008
(Released Thursday, Oct. 23, 2008)
Valid 7 a.m. EST
Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	19.98	80.02	61.14	46.65	21.75	0.00
Last Week 10/14/2008	20.04	79.96	61.14	47.06	21.75	0.00
3 Months Ago 7/22/2008	32.50	67.50	53.32	40.82	4.42	0.00
Start of Calendar Year 1/1/2008	27.41	72.59	60.80	53.84	46.83	19.88
Start of Water Year 9/30/2008	6.86	93.14	78.93	58.79	13.57	0.00
One Year Ago 10/23/2007	0.04	99.96	97.53	81.21	69.39	56.06

Intensity:
D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.
Author:
Richard Tinker
CPC/NOAA/NWS/NCEP
http://droughtmonitor.unl.edu/

APPENDIX C - Statewide Analysis of Hydrologic and Water System Information Proposal

Introduction

Tennessee Technological University's (TTU) GIS Laboratory and the Center for the Management, Utilization and Protection of Water Resources (CMUPWR); The University of Memphis' (UOM) Center for Partnerships in GIS (CPGIS) and Ground Water Institute (GWI); and The University of Tennessee-Knoxville's (UTK) Tennessee Water Resources Research Center (TN WRRC) within the Institute for a Secure and Sustainable Environment (ISSE) have formed a partnership (the Consortium) to provide the Tennessee Department of Environment and Conservation (TDEC) this proposal to develop the capacity for statewide analysis of hydrologic and water system information and to project the required resources to maintain and support the database.

Water stress issues within the state will affect the response of water utility systems within Tennessee to future droughts. In addition, water stress in neighboring states is equally critical since it has implications for inter-state water transfers and/or disputes within the region. A statewide assessment of comprehensive water resources that considers past water management practices, the current state of water resources, and the management and response to future stressors is imperative for a sustainable and resilient Tennessee.

Core Objectives

TDEC requested four key objectives be addressed by this study, including:

1. Determine the immediate and long-term estimated water needs in areas most often impacted by drought or high growth;
2. Identify areas of potential conflicts due to in-stream flow issues;

3. Develop a listing of water supply systems with the least reliable sources and few interconnections for emergency support; and
4. Develop a listing of water systems principally relying on spring sources, low yielding wells or other source water vulnerabilities.

To meet these objectives proposed by TDEC, the Consortium referenced the March 2013 *Regional Water Resources Planning Guidelines for Tennessee* to develop the study approach including data needs and analysis approaches. Core strategies and methodologies for each objective listed above as well as data management and workload organization were determined by the expertise provided by the Consortium.

Core Objective Process

While each item outlined above will require a unique set of tools and methods to successfully achieve its core objective, the workflows and methods utilized will follow a single strategy or approach.The Consortium proposes a standardized process to evaluate and resolve each core objective which includes:

1. Identify data needs

While some of the data that will be required for each objective will be known from the outset, others will become apparent through meetings with stakeholders and after the initial analyses are complete. As each objective is explored in further detail below, a cursory list of requisite data will follow that is intended to lay out a proposed line of reasoning that is subject to change as the Consortium engages in the project.

2. Identify what data exist

Much of the data that will become part of the final database are already collected, whether they come from an existing state database, file, or report currently generated as a part of existing drought management plans. A core component of the project will be the development of a suite of extraction, transformation, and loading (ETL) tools that will enable the merging of a disparate collection of data into a single dataset required for statewide tracking, assessment, and planning. These tools will be built utilizing a variety of technologies and techniques and will be developed in such a way as to support ongoing maintenance with the least amount of effort or expense. ETL tools not only assist in the conversion of data from one format into another (e.g. KML to geodatabase, csv to database table, etc.) they also assist in the standardization of attributes, recoding multiple values into standardized codes that are identical across the state.

In addition to the transformation of data into a single compatible format, another key process in the assimilation of existing data is the application of basic quality control measures to guarantee that the most accurate data possible are loaded into the final repository. Data scrubbing is important not only for guaranteeing the accuracy and reliability of the final database, it is also critical for ensuring database performance and efficiency. Examples of the sort of processes that will be a part of this portion of the project include evaluating text fields to eliminate spelling errors; elimination of variations in identical values that have resulted from free text entry; and development of domains (pre-determined values that limit selection options when creating new features),value ranges, and other quality control measures to ensure accurate values going forward.

3. Identify data gaps

After meeting with stakeholders, completing the first round of analyses, and compiling the initial list of available data, it will become more apparent what data are still needed for each of the four core objectives. Once gaps in data are identified, they will be prioritized and ultimately selected for creation or rejection depending on a set of criteria developed by the Consortium. Data to be created can be split into two parts: those requiring mobile collection, and those that can be collected in an office environment. Should data require mobile collection, custom applications tailored for each dataset will be developed to ensure that the proper quality control measures are put in place so that the most accurate data possible return for uploading into the project database.

The data collection applications developed for this project will be built using ESRI's ArcGIS for Android Application Programming Interface (API). Similar to other GIS field survey techniques, it will contain a series of custom data entry forms that allow users to edit survey information in a controlled format which will eliminate errors due to misspellings or inconsistent values. Data entry will be controlled in such a way that it utilizes drop down menus, check boxes, and pre-loaded data entry lists so that the amount of typing is greatly reduced. This will contribute to the overall efficiency of data collection as well as overall quality control of values entered.

In addition to controlling data entry through custom forms, the application will also utilize many of the tablet's internal sensors in order to streamline data collection and place all utilities needed by field technicians into a single handheld device. The application will also utilize a combination of the tablet's GPS receiver and locally cached aerial imagery to improve the accuracy of mapping individual features.

Survey crews will interact directly with the tablet when conducting the survey. Either they will be placing new points (e.g., collecting new features) or editing existing ones (e.g., collecting new attributes for existing features) and entering all necessary data through a series of interactive forms. Each site location will be determined through a combination of GPS-derived location as well as the highest resolution aerial imagery available.

Past field mapping by CPGIS used a combination of real-time data collection (i.e., field crews were tied directly back to the University geodatabase) and disconnected editing (i.e., data was checked out on the tablet (cached) and rechecked back into the database upon returning from the field). Depending on the unique circumstances of the data to be collected, field technicians may work in either a connected or disconnected environment. In circumstances where technicians are required to be in remote locations with weak or unattainable cellular signals, we will implement a fully disconnected editing environment in which data will be pushed back into the project database for review and quality assurance and quality control.

4. Tool Development

Tool development includes both the creation of a suite of tools required to perform all analyses required to complete each objective as well as a collection of tools that will enable users to access and work with the data. Regarding tools that are developed in support of each of the four objectives, where applicable, they will be developed using publicly available and open source technology so that their use and replication are available to the widest possible audience. Additionally, like the ETL tools that will be created to process and merge existing data, consideration will be given to the development of tools that will enable easy and efficient updating so that future maintenance is achievable with little to no expense or effort.

Data Design and Strategy

The overarching goal for this project is the development of spatially enabled, centralized database that pulls together existing datasets that evaluate and track water resources throughout the state of Tennessee. This geographic database, or geodatabase, will merge together and leverage existing data resources in order to provide analysts and decision makers with accurate, up-to-date data that supports analysis beyond jurisdictional boundaries.

Traditional relational database management systems (RDBMS) maintain connections among objects using simple tabular relationships that link tables together and control behavior using a similarly related value, or key. While spatial databases are able to leverage much of this same functionality, they excel in their ability to go beyond simple attribute relationships to explore the connection between data that have no direct attribute relationship; allowing users to evaluate the effect that location has on one set of data versus another. In terms of data management, the core strategies which will form the foundation of this project are to develop a system that supports statewide drought management programs, facilitates analysis in a consistent and comprehensive manner regardless of location, provides ease of access, remains current and relevant, and is flexible enough to meet user needs regardless of technical needs or demands.

Database Design

Database design involves not just the development of how each individual dataset interacts and relates to other datasets within the database, but also how the overall design controls and supports how the data will ultimately be used. This support includes the processes by which data can be accessed and utilized in an efficient manner, but also the ways in which updates and maintenance can occur with as little effort as possible. In addition to evaluating how data are to be managed, this phase will begin to lay the foundation for how data will ultimately be consumed by and updated through a variety of access points designed to provide user access that meets the technical needs and capabilities of all users. Much of the detail surrounding what data will become part of the final system and their format will be determined by what data currently exist. Once all existing data required for each objective have been identified and collected, a final determination will be made regarding the format that best supports the integration of each data point and then all tools required for merging will be developed.

Data Collection, Assimilation, and Creation

Data collection is a multi-part process that involves a complete survey of all resources including stakeholder input, surveys of existing plans and procedures, an assessment of existing sources and systems, and an evaluation of national level datasets for determination of relevance. The goal is to collect as much data and information as necessary and then filter through all available resources in order to determine which are necessary to achieve the goals and objectives of the project and to identify potential needs that are currently unmet.

Stakeholder collaboration

The first step in assessing what data currently exist is to work with stakeholders to gain a better understanding of how data are currently collected and managed. Stakeholder involvement can bring ideas and resources to the table that foster enthusiasm and synergy around new ways of doing business. Stakeholders will be experts who embody and represent various perspectives and will be concerned about a wide range of water resource problems. Determination of these stakeholders will begin by identifying parties responsible for; and/or parties who are possible benefactors of proposed watershed resource management activities and initiatives designed to promote resource and economic growth; protect water quality; safeguard ecological resources; and ensure a stable, dependable and safe water supply for all needs. Such stakeholder groups may include farmers, advocacy organizations such as the Farm Bureau, environmental organization representatives, flood plain managers, urban and regional planners, commercial and residential riparian property owners, water utility officials, educators, and community officials. Metadata for each category of stakeholders will be created for each watershed in Tennessee. The metadata can be queried using GIS tools to assess information about possible stakeholders located within each watershed of interest.

The Consortium will leverage open access data, past projects, and existing collaborators in the State of Tennessee to build a database. For example, UTK has ongoing collaboration with the Tennessee Valley Authority (TVA) to compile, categorize, and organize precipitation, flow, and reservoir data throughout the TVA system. Access to this expansive data set gives our team unique insight into one of the major water sources within the State of Tennessee.

Data requirements and needs assessment: Operational

Water supply utilities' operational data will be collected through surveys, state agencies, and field offices to determine infrastructure condition, operation and maintenance (O&M) issues. The data will include (but will not be limited to) infrastructure age, materials used, maintenance schedules, water loss, water metering, energy requirements, and water pricing. Substantial seasonal and drought water storage is essential for water management. Surface storage data behind dams need to be monitored to operate reservoirs above safe yields. Therefore, surface storage data and information obtained will be evaluated to determine gaps in data that must be addressed to properly manage the resources. Groundwater storage capacity throughout the state will be assessed and made accessible for resource managers and planners for evaluating groundwater storage as an alternate water source during droughts.

Water pricing is another crucial dataset that will be collected from water utilities and local governments. Factors, such as property values, income levels, and education levels will be collected and used to assess a community's ability to pay for water supply capital improvements and associated O&M costs.

The Cumberland and Tennessee River basins contain a wealth of biological diversity. The region is well known as a hotspot of freshwater biodiversity in North America. The native fish, crayfish, mussel and snail species have requirements for certain temperature and flow regimes to meet their ecological needs and to successfully complete their life cycles. The quantity, quality and timing of water releases or withdrawals from reservoirs (i.e. dam operations) and other impoundments have a strong bearing on the ability of freshwater species to exist and flourish in a given water body. One or more state agencies in Tennessee have prioritized the application of in-stream flow methodologies to better manage the state's waterways and their resident biota. There is also a precedent for using structured decision-making approaches to investigate options for meeting multiple demands on waterways for recreation, water supply, and endangered species conservation. To support endangered fish operations, plans are needed for the conservation of water in upstream reservoirs to create cold pools of water that can be released during the coming warmer months for species needs. Detailed projected operations for upstream tributaries, which are focused in part on protecting fish species that use these rivers, will be collected.

Data requirements and needs assessment: Technical

Historical Rainfall

Historic rainfall data will inform watershed modeling development and calibration. Data will be gleaned from TVA rainfall data sets obtained by UT and from rainfall monitoring stations throughout Tennessee accessible from such sources as the National Climatic Data Center.

Simulated Rainfall

The Community Earth System Model (CESM) version 1.0 will be used for climate simulations. It consists of atmosphere, ocean, land surface and sea-ice components and the atmospheric dynamics uses a finite-volume (FV) method with a 0.9^{o} by 1.25^{o} horizontal resolution and 26 vertical levels. The global climate outputs will be further dynamically downscaled to the regional Weather Research and Forecast model (WRF) as initial and boundary conditions to generate high resolution (36km, 12km and 4km) precipitation products.

The CESM model will be used to simulate both the present climate (2001 to 2004) and future climate (e.g. 2050s) under the Representative Concentration Pathways (RCP4.5 and RCP8.5) scenario or other reasonable future emissions scenarios. The advantage of using simulated precipitation data is that a much more extensive characterization of extreme events can be obtained, compared to relying solely upon limited historical records. Characteristics of accumulated precipitation and extreme precipitation events will be analyzed on both spatial and temporal resolutions in regard to downscaled regional simulations over Tennessee. According to the spatial distribution of simulated precipitation supplemented with the intensive precipitation observation network, areas with drought and intense precipitation could be identified at various temporal intervals. Changes in drought and extreme precipitation events in the following decades will be predicted for impact assessment on hydrology, water demand and reservoirs, helping pinpoint the most vulnerable regions.

Historical/Simulated Streamflow (Water Availability)

Understanding the trends in the streams through a historic analysis will enable decision makers, communities and water utility systems to plan for future water management strategies. Hydrologic data pertaining to the flows will be gathered from various sources including USGS, TVA, USACE, and NWS for a statewide streamflow assessment. A thorough data analysis will be conducted to identify data gaps. As needed, additional streamflow simulations will be performed. Additional quality control protocols will be implemented on the data to remove outliers. The data compiled during this exercise will be transformed into a compatible database schema.

For streamflow simulations, Hydrologic Engineering Center's (HEC) modeling packages including HEC-HMS and HEC-RAS models will be developed for the selected river/reach sections with limited or no streamflow data, and for specific areas of interest. Additional advantage of using HEC-HMS and HEC-RAS models is the availability of automated tools in ArcGIS environment that exist which significantly reduces the model development. The topographic data required to build these models are already freely available at national scale. HEC models can also be efficiently integrated with the OASIS modeling framework. In addition, these models can be integrated to simulated rainfall projections from CESM models (see Simulated Rainfall section) for future climate and changes in water supply patterns under varying climate will be studied.

Reservoir Volume Curves

As part of the Consortium, UT has access to reservoir volume curves through ongoing collaboration with TVA. Volume curves for any remaining reservoirs will be gathered based on publically available bathymetric data and/or discussion with stakeholders such as the USACE.

Population Growth Projections

The Center for Business and Economic Research (CBER) at UT serves as the lead agency for the Census State Data Center (SDC) program in Tennessee. As such, Consortium members affiliated with the CBER will assist with compiling these data for associated analyses of water demand.

Current Water Use

Current water use will be estimated using existing data on water withdrawals for uses such as public supply, irrigation, livestock, industrial, mining, and thermoelectric power at an 8-digit HUC level. Estimates of water losses in urban areas due to leaking potable water infrastructure will also be made to account for the uncertainty associated with this parameter.

Water Demand Projections

Current water use estimates will be modified based on such factors as population growth projections, anticipated land use modifications, expected increases in irrigated cropland, etc. Estimates will be made at the 8-digit HUC level to inform watershed modeling and scarcity estimates.

Source yield and reliability

The types of water sources in Tennessee are generally grouped into surface-water reservoirs, free-flowing streams and ground-water aquifers. Therefore, estimating the yield for a certain water utility system, community or region will depend on its location, its geography, its water resources, and utility connections. Depending on the water source, the estimation of water yield will include defining the critical drought for each water source using the historical and simulated precipitation and streamflow data. Similarly, the reliability of the water source, specifically reliable yield of the reservoirs, will be estimated. According to USACE (2011), this is defined as the maximum amount of water that can be delivered every day during the worst drought in recorded history while preserving 20% of its usable storage in a reservoir. A comprehensive dataset will be developed and added into the database for all water utility systems. This dataset will contain information about their available water sources, their estimated source yield, and reliable yield.

Interconnections and Emergency Support

A comprehensive assessment for water resources planning would require knowledge on how the utilities and water systems plan to interact with neighboring systems under drought stress conditions and an analysis of their emergency storage and supply options. To facilitate this issue, statewide data of existing interconnections and emergency support for all the water systems will be collected. The collected data will be transferred into the proposed database with its specified schema.

Water Quality Monitoring and Modeling

The water quality of streams, lakes, and other water bodies is crucial for to water utility systems they supply. In addition, the effluent water quality from water and wastewater utilities will influence existing surface water quality. Knowledge of the presence of impaired streams will be important for future water resources planning. To account for these issues, data will be collected from existing federal, state and local agencies, as well as other entities that are currently monitoring water quality within watersheds. This will include conducting a detailed data review and analysis to examine data type; quality (i.e. whether one has gathered data of the right type and of adequate quality); methodologies and inferences to identify any significant temporal or spatial data gaps. For regions with no gaps in water quality data or absence of water quality measurement data, water quality modeling will be performed.

Core Strategies and Desired Outcomes

Objective No. 1 - Determine the immediate and long-term estimated water needs in areas most often impacted by drought or high growth

- *Task 1: Identify areas of the state likely to undergo significant growth in water demand by 2050*

The initial step in identifying areas likely to experience significant growth in water demand will be for our partners at UT's CBER to project population growth rates at a HUC 8 watershed level and classify individual or groups of HUC 8s as high, moderate or low projected population growth. Next, water demands likely to undergo significant change over the next three decades will be identified. For example, the rapid growth in irrigated agriculture in West Tennessee is likely to continue into the future and could significantly impact water demand in that region. The geospatial pattern of these changes in demands will be projected across the state and, together with the population projections, will be used to identify watersheds and aquifer systems likely to experience significant growth in water demand.

- *Task 2: Identify areas of the state currently susceptible to water shortages in the event of drought*

Identifying areas susceptible to water shortages in the event of a decrease in water availability will involve two parallel processes. First, relative water scarcity will be analyzed at the 8-digit HUC scale using the U.S. Forest Service's Water Supply Stress Index (WaSSI) water supply and demand accounting model (Sun et al 2008a, b; Averyt et al. 2013). The WaSSI model estimates water supply as the sum of surface water supply [derived from a water balance model (Zhou et al. 2008) that operates on a monthly time step and considers potential evapotranspiration, land use type, canopy interception capacity, plant rooting depth, soil moisture content, and precipitation], groundwater supply (estimated from USGS historical records of groundwater withdrawals) and return flow (estimated from historical USGS records of return flows for seven sectors - commercial, domestic, industrial, irrigation, livestock, mining, and thermoelectric) (Sun et al. 2008b). The WaSSI model estimates water demand as the sum of water use by each of the seven sectors and public use and losses and transfers (Sun et al. 2008b). As water scarcity may not capture susceptibility due to such factors as inadequate infrastructure, areas actually adversely impacted by recent droughts will also be identified.

- *Task 3: Determine current water use and estimate projected water use through 2050 for areas that are either currently susceptible to water shortages or likely to experience significant growth in water demand*

  Current water use will be estimated using existing data on water withdrawals for each of the following uses public supply, domestic, irrigation, livestock, industrial, mining, and thermoelectric power at an 8-digit HUC level (Averyt et al. 2013). For groundwater resources in West Tennessee, current water use will be estimated based on water withdrawal provided by public supply (municipalities/public utilities). Water withdrawals for domestic, irrigation, livestock, industrial, mining, and thermoelectric power will be based on the county level from current USGS data. In addition, water withdrawal for individual industry sectors will be calculated using the method and data from Blackhurst et al. (2010a) and Blackhurst et al (2010b) and the output value of each sector recorded by the IMPLAN economic input-output model (Menard et al. 2011). Consumptive use will be estimated using adjustment factors (Fadali et al., 2012 and Huston et al., 2004). Projections of future demands will be based on population projections and on estimates of associated changes in the water demands listed above.

Objective No. 2 - Identify areas of potential conflicts due to in-stream flow issues

Low flow in streams is a concern for water resources management for a number of operational and ecological reasons. Minimum thresholds exist for river systems being used as cooling sources for power generation, below which energy production must cease or be restricted. Further concerns over low flow are related to ecological impacts. Many biota in surface waters within Tennessee rely on some amount of flowing water to maintain uninterrupted life processes.

- *Task 1: Determine areas of the state susceptible to low flow effects on power generation*

Reservoirs within the TVA system (and similar regulated river systems) are operated under a number of operational controls to ensure multiple demands are met downstream. One of the most critical demands is that of power generation. UT's experience collaborating with TVA allows an understanding of the operational controls for each reservoir in the TVA systems and the associated downstream flow needs for cooling (and thus power generation). Critical flow values for power stations within the TVA system and elsewhere will be obtained through the data gathering process. These values will be compared to stream modeling output under both existing and projected climate and demand regimes. These comparisons will inform analyses of critical points in Tennessee where low flow effects may result in diminished energy production.

- *Task 2: Determine areas of the state susceptible to low flow effects on stream ecology*

In locations where water availability is low relative to demand, typically associated with large withdrawals for such uses as cooling for power plants, River2D IFIM habitat modeling will be performed. This model will allow an understanding of potential low flow stresses on stream biota, and help determine which areas are most susceptible. These analyses will inform decisions as to how best to allocate available resources and allow an understanding of the subsequent tradeoffs of these decisions.

Objective No. 3 - Develop a listing of water supply systems with the least reliable sources and few interconnections for emergency support

To achieve this objective, a decision-making model/tool, which includes socio-economic, political, environmental and physical factors, will be developed to determine water supply systems that are vulnerable to emergency conditions. Step 1 of the model will focus on Initial Selection Criteria; Step 2 will explore utility water treatment and supply factors; and Step 3 will look at community socio-economic factors.

- *Step 1: Selection of Initial Criteria*

The initial selection criteria will include:

- Public health, drinking water violations (monthly customer satisfaction reports, TDEC Monthly reports)
- Record of water supply shortage during drought conditions
- Water utility wholesaler or distributor
- Public owned utility or private
- Demographic data

A community health survey will be developed and sent to Tennessee Health Department Regional Offices. Drinking water utility databases and locations will be obtained from TDEC. Drinking water drinking water quality violations also will be obtained from TDEC.

- *Step 2 – Utility Water treatment and Supply Factors*

The water treatment and supply factors for the water utility systems that will be considered are:

- Water supply source(s) i.e. river, impoundment or groundwater or combination
- Water treatment capacity and demand
- Domestic, commercial and Industrial demands
- Population growth projections
- Water supply Interconnections
- Operational data including
    - operator’s education and experience level, and certification(s);
    - use or existence of an operation and maintenance (O&M) manuals;
    - annual O&M costs;
    - current operations conditions;
    - amount of lost water through distribution system.
- Regulatory control information for each water treatment plant will be obtained from the Tennessee Department of Environment and Conservation.

The University of Tennessee, College of Business uses assessed property values and median household income to calculate an ability to pay index (ATPI) for communities. Using the ATPI and the respective community’s water users charge system, the funding issues can be assessed.

- *Step 3 – Socio-Economic Factors*

  Demographic information and data will be used to better understand each community's needs. Environmental conditions will help identify each community's environmental issues.

All the databases and their associated metadata will be stored in GIS format, which will be accessible by decision-makers.

Objective No. 4 - Develop a listing of water systems principally relying on spring sources, low yielding wells or other source water vulnerabilities

Source water vulnerability is a concern to all PWS. The outcome of this objective would be to create a tool to allow regulators, municipalities, and public utilities to identify potential source water vulnerabilities based on operational and technical data acquired or created during this project.

Potential vulnerabilities based on source water type:

1. Surface Water (River or Reservoir)
    a. Low stream flow or reservoir level
    b. Water quality degradation
    c. Potential contaminant sources
2. Groundwater (Well or Spring)
    a. Declining groundwater levels
    b. Water quality degradation
    c. Potential contaminant sources
    d. Low yielding wells

Vulnerabilities associated with low stream flow or reservoir level, particularly during drought, will be provided by Objective No. 1, Task 2. Spatially and temporally adequate groundwater level data for the

State of Tennessee may be limited. However, an attempt will be made to produce a regional trend in groundwater levels based on USGS and other public data.

General water quality parameters will be collected from PWS or USGS data. As a water source is depleted, water quality degrades and water treatment capabilities may become an issue. Potential contaminant sources will be acquired by Wellhead Protection Plans and annual Contaminant Source Inventories, as regulated by TDEC.

Low yielding wells will be based on geology of the area and the ability for the aquifer to meet current and projected needs. The prolithic unconsolidated sand aquifers of West Tennessee typically result in high yielding wells. The consolidated, sandstone and limestone aquifers of Middle and East Tennessee vary, but are low (5 to 200 gallons per minute) compared to the Tertiary sand aquifers (200 to 1000 gallons per minute) of West Tennessee (Webbers, 2003). Aquifer characteristics will be collected from test wells and pump tests completed by the PWS or USGS to determine if production wells would help meet the current and projected needs of the area.

Data Management and Dissemination

Once all data have been collected, standardized, and compiled into a centralized database, the next phase will be the development of a system by which users can access and utilize the database. From the outset, the intent of the overall system has been to provide access that meets each user on their technical level and provides a set of tools relevant to their specific needs. As the expectation is that this group of users will range from technical analysts to managers to policy makers, it is important that a suite of tools be developed that provide a different conduit of access and a different interface with which the data may be interacted.

Dissemination

The web has become the de facto exchange medium for information, and it will be the preferred mechanism for non-technical users to interact with the data collected and created as a part of this project. As the average decision maker is not skilled with some of the more advanced mapping software, the web has become the easiest means by which this group can benefit from spatially enabled information. A range of custom tools are available that will enable users to explore spatial relationships across multiple datasets and to perform a range of more complex analyses that will become apparent over the course of the project. Examples of potential tools that may be available in the web map may include identification of individual records or features, queries based on attributes, queries based on spatial location, extraction of tabular information, composition and printing of custom maps containing data that each individual user feels is most relevant, visualization of what-if scenarios based upon pre-defined or user-generated assumptions, or visualizing temporal change for various data.

Extraction

The webmap discussed in the previous section will enable non-technical users to access, utilize, and leverage the database in a spatial environment. However, this comprises but one tool in a larger suite that when combined will allow complete and unhindered access to all of the information collected or created over the course of the project. Upon completion, the project database will serve as a central hub through which data can be redistributed at a variety of geographic scales and in a range of formats. Building this level of versatility into the distribution system will ensure that each user will be able to access raw data for use in their workflows in formats with which they are most comfortable.

Critical to this piece is an effective cataloging and indexing system that will enable users to not only locate the resources that they need to accomplish their work, but the discovery of other resources which may be just as critical, but were previously unknown. This discovery can occur either through spatial relationships, keyword queries, or relational access. Spatially enabled web portals, or geoportals, help maintain the relevance of data through the maintenance metadata, or information about a particular dataset such as processing history, time relevance, contributors, or related datasets.

Partners and Center Expertise

The University of Tennessee

The Tennessee Water Resources Research Center (TN WRRC) is a federally designated state research institute supported in part by the U.S. Geological Survey. The Center serves as a primary link among water-resource experts in academia, government, and the private sector, and the diversity of its staff in terms of background and expertise enhances flexibility and positions the Center to establish productive partnerships. Over the last 2 years the TN WRRC has been conducting an internal research project to build an extensive database integrating the various water-relevant data pertinent to the hydrology of the Tennessee Valley Authority. It is housed within the Institute for a Secure and Sustainable Environment (ISSE) at the University of Tennessee Knoxville.

The Center for Business and Economic Research (CBER), a department within the College of Business Administration at the University of Tennessee, Knoxville, conducts research on national and state economic trends for UT Knoxville, state agencies, and public and private organizations. The CBER has performed county-level population projections for Tennessee through 2064 on behalf of the Tennessee Advisory Commission on Intergovernmental Relations (TACIR).

Tennessee Technological University

Center for the Management, Utilization and Protection of Water Resources

The Center for the Management, Utilization and Protection of Water Resources (Center) at TTU was formed around an interdisciplinary team of professionals that works to address the increasing demands on water resources in Tennessee, the surrounding region and the nation. These professionals are nationally and internationally acclaimed for their expertise and are often sought out through invited presentations to disseminate their research on the important topics facing the future of our water resources. The Center's mission is accomplished through research, education and public service, leading the Center closer toward its vision of being a recognized leader in environmental research in Tennessee and the Southeast region.

The Center's work is focused in the areas of environmental resource management and protection—including natural ecosystems, fisheries management, engineering natural systems, watershed resource management, and the *emerging research areas of climatic effects on endangered species*; environmental hazards—including fate and transport of contaminants, pesticides research, water and wastewater treatment, and advanced oxidation processes, and the *developing areas of emerging pathogens, nanoparticles, microconstituents*; and environmental informatics—including GIS applications and the *emerging research area of rainfall forecasting using satellite data and climatic effects on water* *resources*. Each year, the Center's core faculty and associate faculty pool their expertise to address the water-related needs in these focus areas.

Fisheries Assessment

The Center has supported the work of numerous research projects in the areas of fisheries assessment, especially in the area of climatic effects on endangered species. Center faculty associates Jim Layzer and Phil Bettoli, in TTU's Tennessee Cooperative Fishery Research Unit, have spearheaded these efforts. The TNCFRU helps protect the vast array of freshwater fish and mussel communities in Tennessee and helps ensure that the state's valuable sport fishing and commercial musseling industries are intact. According to a report from the Tennessee Wildlife Resources Agency, the economic impact of sport fishing in Tennessee in 2001 was more than 1.1 billion dollars. The TNCFRU has garnered millions of research dollars toward maintaining the stability of these Tennessee's fishing waters. TNCFRU researchers have written numerous refereed articles and presented more than 100 presentations and won several state and regional awards in their efforts to alert the population to the importance of endangered species recovery and protection.

Environmental Informatics

Recently, the Center furthered its efforts at enhancing environmental education through research by supporting the development of a new School of Environmental Studies and two new degree programs: the bachelor of science in Environmental and Sustainability Studies (ESS) and the Professional Science Master's with a concentration in Environmental Informatics (PSM-EI). The bachelor's in ESS offers students the opportunity to study in environmental science; environmental technology; or society, culture and communication. The PSM-EI focuses the university's environmental informatics experts in a degree that provides a business background and concepts applicable across fields as diverse as sociology, public policy analysis, business, sustainable systems, and terrestrial/aquatic ecosystem management.

GIS Lab

To support the Center's research, it is equipped with a GIS computer lab that enhances the analysis of groundwater and surface-water quality, hydrology and watershed analysis, networking and three-dimensional analysis, and integrated stream assessment and aquatic habitat analysis. The Center also provides an ARCGIS software suite that allows for the realistic representation of naturally and humanly developed spatial features for assessment and planning applications. The lab supports a network of Windows workstations with connectivity to various printers and scanners. The HP800PS plotter and the HP Color LaserJet 5550dn printer allow principal investigators to produce high-quality color maps and presentation materials to support the Center's research efforts. The lab also maintains large spatial databases and hydrologic models developed from research.

Environmental Quality Lab

The Center is also equipped with an Environmental Quality Lab that is equipped according to procedures accepted by the Environmental Protection Agency, Tennessee Department of Health, Tennessee Department of Environment and Conservation, American Society for Testing and Materials, and the U.S. Geological Survey. The lab has been certified by the State of Tennessee and the EPA for analysis of selected drinking water parameters. The lab also has a Leica confocal microscope for microbial analysis and facilities for water and wastewater pilot plant studies.

The University of Memphis

Center for Partnerships in GIS

The Center for Partnerships in GIS (CPGIS) is a multidisciplinary GIS resource center based at the University of Memphis. Created in 2007, CPGIS has quickly established itself as one of the premier GIS centers throughout the region through its expertise, experience, and ability to develop a wide range of GIS solutions that meet the needs of its clients. Our use of multidisciplinary teams and faculty-student and student-student mentoring has made CPGIS a working model for providing academic support services, advancing scientific research, and facilitating community-oriented project design. To date, we have been awarded more than thirty contracts and have yet to turn in a single project late or over budget.

Contractual services have included GIS data migration from legacy systems, spatial analyses, mobile data collection, and web development for interactive mapping. Through its broad scope of research and contractual services CPGIS has proven to be highly recognized for its partnership with other universities and local, state and federal government, non-profit organizations, and private industry.

In addition to utilizing the most advanced functions of GIS, critical to our success as a GIS center has been our student workforce. Our student technicians come from a variety of disciplines including civil, mechanical, and electrical engineering, geography, city and regional planning, nursing, geology, computer science, and business. All students are put through a rigorous training regimen that requires that they learn not just the intricacies of the specific project to which they are assigned, but that they spend numerous hours learning how to work proficiently with various GIS software. After students have demonstrated their proficiency with GIS, they are assigned to help mentor other students or assist project managers on project development and deployment. We are proud to say that we are helping to produce some of the most proficient GIS specialists in the region who not only understand how to utilize GIS, but also understand the data that goes into it.

The staff at CPGIS is comprised of some of the best GIS professionals in the industry, and our diverse backgrounds allow us to provide a wide array of solutions for a wide range of clients. With any project, our goal is to work with our clients, be they university faculty, private industry representatives, or government agencies to find the best solution that fits their particular needs. Whether it's the development of a customized web mapping solution, the designing of a personalized geodatabase, or conducting mobile surveys, CPGIS has all of the expertise, hardware, and software necessary to fulfill any technical demand.

While we have the ability to design virtually any solution for any problem, over the past several years we have consistently demonstrated our capabilities in three primary areas: legacy data migration, web application development, and mobile data collection. Over the course of the past 6 years, CPGIS has had the honor of working with such organizations as the Shelby County Office of Preparedness, Tennessee Department of Environment and Conservation, City of Memphis Public Works Division, Memphis and Shelby County Historic Landmarks Commission, Urban Land Institute, Shelby County Office of Early Childhood and Youth, an international rail road company, as well as numerous others.

Ground Water Institute

Established in 1991, the Ground Water Institute's (GWI) mission engages in applied research excellence, education, and leadership toward sustaining community ground water resources. To fulfill its mission, GWI houses expertise on groundwater issues and conducts research related to the Mississippi embayment aquifer system that underlies nine states in the mid-south region.

The Ground Water Institute:

- Is committed to being a neutral voice in evaluating ground water issues in the Mid-South region. It is an independent and central source of information.
- Evaluates the quantity, quality, reliability, and sustainability of all aspects of groundwater resource assessment, management, and development.
- Provides technical support to local governments and the Shelby County Ground Water Quality Control Board through specialized studies and investigations.
- Shares its research with other local water utilities, government agencies, academic community and the public.

The GWI is a central source of information, providing technical support to local governments (Bartlett, Collierville, Germantown, Memphis and Millington), Memphis Light Gas & Water (MLGW) and the Shelby County Ground Water Control Board through specialized studies and investigations.

Budget

TDEC requested an estimated project cost, but not a detailed timeline. Though a detailed timeline is not provided, the Consortium estimates that the project will take approximately 2 years to complete. Project costs include: visits to local stakeholders; meeting with TDEC and other agencies like TAUD, USGS, TVA, and others; data compilation/creation and analysis; data collection and dissemination tools; modeling of precipitation; and population growth and water interconnectivity. The Consortium approximates that the 2-year project will cost approximately $2 million. This cost does not include annual maintenance and update of the database after the first 2 years as without knowledge of the full data amount, such an estimate would be difficult to provide at this time. However the Consortium believes the out-year costs will not be large, especially based upon the toolsets created for this effort and the use of third-party databases.