Projection Methods for Off-stream Water Demand in South Carolina

South Carolina Department of Natural Resources
Land, Water and Conservation Division
1000 Assembly Street
Columbia, SC 29201

October 2019

Projection Methods for Off-stream Water Demand in South Carolina

Prepared by
Alex Pellett, Hydrologist
South Carolina Department of Natural Resources

South Carolina Department of Natural Resources
Land, Water and Conservation Division
1000 Assembly Street
Columbia, SC 29201

October 2019

STATE OF SOUTH CAROLINA

The Honorable Henry D. McMaster, Governor

South Carolina Department of Natural Resources

Table of Contents

1.0 Introduction..1
1.1 Scope 2
1.2 General Concepts 3
1.2.1 Source Water 3
1.2.2 Water Withdrawals 3
1.2.3 Water Use 3
1.2.4 Water Demand 4
1.2.5 Water Consumption 4
1.2.6 Return Flows 5
1.2.7 Aquifer Storage and Recovery 5
1.2.8 Permit Systems and Water-Using Enterprises 5
1.2.9 Categories 6
1.2.10 Drivers 6
1.2.11 Kinds of Water Use 6
1.2.12 A General Model of Water Demand 7
1.2.13 Weather and Climate 8
1.2.14 Baseline Period 8
1.2.15 Projection Scenarios 9
1.2.16 References 9
2.0 Thermo-electric Power 10
2.1 Kinds of Thermo-electric Water Use 10
2.1.1 Prime Movers 10
2.1.2 Cooling Systems 10
2.1.3 Base Load and Peak Generation 11
2.1.4 Alternative Sources of Electricity 11
2.2 Data Sources 11
2.2.1 Energy Information 11
2.2.2 Water Consumption Rates 11
2.3 Projections 12
2.3.1 Electricity Demand 12
2.3.2 Water-Demand Scenarios 12
2.3.3 References 12
3.0 Public Water Supply 14
3.1 Kinds of Public Water Supply 14
3.1.1 Public Supply Permits 14
3.1.2 Wholesales 14
3.1.3 Septic Systems 15

3.2 Data Sources 16
3.2.1 Service Areas 16
3.2.2 Local Planning 16
3.3 Projections 16
3.3.1 Population Projections 16
3.3.2 Business-as-usual 16
3.3.3 High-demand 17
3.3.4 Advanced Methods 17
4.0 Manufacturing 18
4.1 Manufacturing Projections 18
4.2 Business-as-usual 18
4.3 High-demand 18
5.0 Agricultural Irrigation 19
5.1 Data Sources 19
5.1.1 Irrigated Acreage 19
5.1.2 Mapping Irrigation 19
5.1.3 Irrigation Suitability 20
5.1.4 Factors Affecting Irrigation Depth and Timing 20
5.2 Projections 21
5.2.1 Agricultural Projections 21
5.2.2 Business-as-usual 22
5.2.3 High-demand 22
5.2.4 References 22
6.0 Other Categories 23
6.1 Golf Course Irrigation 23
6.2 Mining 23
6.3 Aquaculture 23
6.4 Livestock 24
6.5 Domestic Wells 24
6.6 Data Center Cooling 24
6.7 Lakefront Irrigation 24
6.8 Emergency Fire Control 24
6.9 Military Bases 24
6.10 Prisons 24
6.11 References 24
Appendix A: Formal Methods 25
Appendix B: Projections of Driver Variables 34
Appendix C: Public Comments on the First Draft 37

1.0 Introduction

The Department of Natural Resources (SCDNR) is responsible for developing the South Carolina Water Plan that describes water management policies in the state. Many topics are relevant to water management, but freshwater availability is one of the most fundamental to society. In a humid climate and with multiple large reservoirs and aquifers, South Carolina (SC) generally has abundant freshwater resources compared to many other states and different parts of the world. However, if not managed wisely, even abundant resources can be over-exploited.

To provide information for water resource management, computer models have been calibrated to simulate surface and groundwater availability in SC. The models are used to evaluate the potential for water shortages under different scenarios. This report documents methods to project future off-stream water demand, and the resulting projections will be used as input to the water availability models. Potential water shortages will be evaluated in each major river basin and addressed in the South Carolina Water Plan.

These water-demand projection methods have been developed in an inclusive process with water resource stakeholders in SC. A series of six Webex™ online teleconference meetings were held from August to November 2018, garnering attendance from a total of 110 stakeholders with diverse backgrounds in public water supply, government, golf, higher education, power, consultant firms, agriculture, industry, legal firms, and environmental or conservation interests. These meetings were open to the general public and advertised online at www.scwatermodels.com. Powerpoint™ slides were presented at each meeting to illustrate available data and proposed methods. Meeting invitations were distributed through email and included links to slides and draft reports. Attendees were invited to participate in dialogue, and an email contact was provided for written feedback. Stakeholder feedback provided valuable insight to interpret available data and led to additional data sources. As different methods were discussed over the series of meetings, a common theme of the discussions was to keep the methods simple. No method can be presumed totally reliable over a long-term planning horizon; simple methods are at least interpretable.

This report is written for stakeholders who want to understand the assumptions behind the projections. The aim is to describe the methods in plain language for a general audience. Appendices are provided for interested readers. The statistical models are formally defined using mathematical equations found in Appendix A.

Projections of electricity demand, population, economic productivity, and irrigated acreage are used to drive the projections of water demand. The projections of driver variables have been compiled from several referenced works and are available to the reader in Appendix B.

The first draft of this report was distributed in May 2019 to an email list of over 2,000 water-resource stakeholders and publicized online to solicit comments. Stakeholder feedback is documented in Appendix C, and this report includes many revisions based on that feedback.

Water users in each planning basin of SC, beginning with the Edisto, will be contacted to solicit feedback on the projection methods, data inputs, and draft results. Subsequent reports will summarize the water-user vetted projection results by sector and by planning basin. River Basin Councils (RBCs) will be formed in each regulatory basin of SC with the goal of developing regional water plans. The water demand projection results will be distributed to the RBCs to inform their planning efforts. If feedback is received leading to revisions or addenda to this report, updates will be found online at www.scwatermodels.com.

This report is an outcome of the United States Army Corps of Engineers (USACE) Planning Assistance to the States (PAS) agreement signed by representatives of USACE and SCDNR on May 23, 2018. The SC Water Resources Center (SCWRC) of Clemson University collaborated in the completion of this PAS agreement.

1.1 Scope

Off-stream water demand includes actual or expected flows of water for uses outside of a water body. Off-stream uses of water begin with a withdrawal from a river, stream, reservoir, or groundwater aquifer. Throughout this report, the term “use” refers to off-stream freshwater use. Surface water and groundwater resources in SC provide many values to society beyond off-stream uses as defined here: supporting fisheries and other wildlife, recreation, and hydro-power; assimilative capacity for wastewater; and aquifer inflows necessary to prevent saltwater intrusion, subsidence, and sinkhole formation. The purpose of projecting off-stream demand is to develop plans to meet off-stream demands while protecting the many other values of our water resources.

Projecting future scenarios is a planning practice in which hypothetical scenarios of future conditions are assumed and relevant outcomes are estimated. In this report, projections are based on explicit assumptions combined into two scenarios spanning a 50-year planning horizon, from 2020 to 2070. Projected water demands will be estimated for years 2020, 2025, 2030, 2035, 2040, 2050, 2060, and 2070. If the underlying assumptions are not too far from reality, then the short-term projections may prove accurate. Long-term projections will be highly uncertain, and stakeholders should carefully consider all assumptions when interpreting the results. While this study projects across a long-term planning horizon, it is expected that the results of this study will be reviewed and updated regularly. The current goal is to review and update the projections every five years.

Portions of the water resources of SC come from neighboring states: Georgia, North Carolina, and a smaller part of Virginia. While water demands in those states can certainly affect SC’s water resources, those demands are outside the scope of this study.

Projections of the future rely on information from the past and present. Not all off-stream water use in SC is quantified. Data are lacking for unregistered and unpermitted uses, and such uses are generally assumed to be negligible in this study.

The number of permit-holders can change over time as some enterprises cease to operate or are acquired by other permit-holders. Enterprises that have not previously operated in SC or have not previously needed a permit for water use may begin reporting water use in the future. These dynamics are not explicitly included in the methods described in this report. As major water-using enterprises start-up or shut-down, the projections will be updated accordingly.

The methods presented here are generalized to apply to many water uses across SC. Specific modifications will be made on a case-by-case basis to better represent individual water use permittees based on survey responses, interviews, and other forms of stakeholder feedback.

1.2 General Concepts

Key terms used in this study are described in this section. The meanings of these terms may vary from other literature.

1.2.1 Source Water

A source water body is any river, in-stream reservoir, or aquifer from which water is removed via an intake structure. Water removed from a source water body through an intake structure is termed a withdrawal. For the purposes of this study, water sources will be classified as either surface water, groundwater, or reuse of reclaimed wastewater. Costs and availability of source water can have significant impacts on water demand, and vice versa. As the methods presented here are designed to provide inputs for water availability models, the rational designation of appropriate source water is outside the scope of this study. Generally, two rough assumptions are applied: (1) when a water demand is currently supplied from a single source, it is projected to maintain that source; and (2) when a water demand is supplied from multiple sources, it is projected to maintain the same percent of withdrawal from each of its sources relative to the total. Some water users have described planned changes to their source water supplies, and the assumptions are modified when relevant information is available. As water planning proceeds, these assumptions may be modified again in an iterative process.

1.2.2 Water Withdrawals

In SC, water withdrawals from rivers, in-stream reservoirs, and aquifers totaling more than 3 million gallons per month are subject to regulations which require annual reporting of monthly withdrawal volume. Reported withdrawal data are stored in a database maintained by the SC Department of Health and Environmental Control (SCDHEC). Intake locations are available from the SCDHEC GIS Data Clearinghouse[1].

The digital records of monthly withdrawal volume provided by SCDHEC extend back to the early 1980's for some intakes. There have been changes in the regulatory reporting requirements over the earlier period, and the reports from 2013 to the present are generally more consistent. In earlier years, reports included some purchased water and water removed from off-stream storage ponds. Minor gaps and inconsistencies in the withdrawal data have been identified and corrected when possible.

1.2.3 Water Use

Off-stream freshwater use is distinct from water withdrawal. Not all water that is withdrawn is put to immediate use, and not all water that is used comes directly from a withdrawal intake. Water uses can be supplied with purchases, reuse, and off-stream storage.

Reuse refers to water which has been put to one use and is subsequently applied to a different use. Recirculation of water multiple times to the same use in a single enterprise is not considered as an addition to use. By some measures, the effluent water discharged from a waste-water treatment facility can be cleaner than the water in the receiving stream. Effective treatment processes for the removal of well-known pollutants such as pathogens, excess nutrients, and heavy metals have been established for many years, and are continually improving with new technologies. Treated solids can be applied as fertilizer to turf or crops. Treated water is used for irrigation in some locations in SC, and it also can be used for some manufacturing processes. Reused water, however, may not be appropriate for all uses.

1 Accessible online at: https://apps.dhec.sc.gov/GIS/ClearingHouse/

Off-stream water storage does not include in-stream reservoirs or water pumped to an upstream reservoir for hydro-electric power. Any flow of water from off-stream storage is a use, sale, or loss. Water losses can include infiltration and evaporation from off-stream storage. Leaks from water utility distribution systems also are considered as water loss.

In this study, water use is quantified using the following mass balance equation:

Equation 1.1 $$Use = Withdrawal + Purchase + Reuse - Sales - Loss - \Delta Storage$$

Where:

Use	:	Off-stream water use
Withdrawal	:	Total water withdrawal from source water bodies
Purchase	:	Total purchases of water from distributors
Reuse	:	Total reuse of water previously used for a different purpose
Sales	:	Total wholesale transfers of water to another user or distributor
Loss	:	Total losses of water preventing it from being put to use
ΔStorage	:	Net change in off-stream water storage

While withdrawals are recorded in the withdrawal database, there is much less information available to quantify purchases, sales, reuse, loss, and changes in off-stream storage for water users across SC. Some relevant information has been collected through survey responses and telephone interviews. Where information is not available, these terms are generally assumed to be negligible and estimated equal to zero.

1.2.4 Water Demand

Water demand is estimated in terms of water volume per month, independent of availability of source water. Unmet demands are represented by the shortage term in the following equation:

Equation 1.2 $$Demand = Use + Shortage$$

Where:

Demand	:	Water required, and normally used, to meet the objectives of water users
Use	:	Water actually used to meet the objectives of water users
Shortage	:	Water required but not available to meet the objectives of water users

In reality, water demand often varies in relation to water availability. When less water is available, some water users can reduce their demands by adapting, relocating, or ceasing operations. Within the context of this study, such reductions in demand can be understood as increasing water-use efficiency or facing a shortage.

1.2.5 Water Consumption

Water use can be classified as either consumptive or non-consumptive according to the flow of water resulting from the use. Water that is evaporated or transpired to the atmosphere is consumed. Water that becomes part of an economic product also is considered consumed. In some cases, water consumption is simply a percentage of water use and it will be projected as such. In other cases, patterns of consumptive water use are significantly different from patterns of non-consumptive water use and the different kinds of water use are projected independently.

1.2.6 Return Flows

Water that is not consumed is returned to a surface water body, groundwater aquifer, or re-used to meet another demand. Piped discharges to surface water are subject to National Pollutant Discharge Elimination System (NPDES) regulations which require monthly reports of discharge volume. The discharges in the NPDES database often include inflow and infiltration from the environment to the waste-water system in addition to the return flows resulting from non-consumptive water use. The term "Inflow and infiltration" is used in the field of wastewater conveyance and treatment, sometimes denoted as I/I. Quantitative information is not available to reliably separate return flows from I/I. If reported monthly discharge volume is not commensurate with monthly withdrawal volumes for a water user, then the annual minimum monthly discharge will be used as an estimate of return flow.

Equation 1.3 *Return Flow = Discharge – Inflow & Infiltration*

Where:

Return Flow	:	Water returned to the environment after non-consumptive uses
Discharge	:	Concentrated discharges to surface water bodies (NPDES data)
Inflow & Infiltration	:	Waste-water resulting from inflow and infiltration (I/I)

Septic system leach fields and some irrigation practices can return flows to groundwater or as dispersed surface water. Generally, return flows to groundwater and dispersed return flows to surface water are assumed to be negligible unless otherwise noted. While I/I can be a significant portion of discharge volume in some cases, it will not be considered further in these methods. Return flows can be relevant to surface water availability during dry periods, but I/I tends to occur mostly during rainy periods.

1.2.7 Aquifer Storage and Recovery

Aquifer storage and recovery (ASR) is a strategy used by some public suppliers in SC to manage groundwater resources. The concept of ASR is to purposefully add water to an aquifer when water is available from other sources so that the water can be retrieved when supply is less plentiful. Groundwater composition varies by location and depth, but groundwater is typically cleaner (and cheaper to treat) than surface water. ASR could pose a risk of polluting aquifers with contaminants from surface water. To avoid this risk in SC, water is treated to drinking water standards before being used for ASR. Some have argued that drinking water standards should not be applied to ASR due to the impact on the economic viability of this otherwise very useful water management practice.

Some return flows to groundwater for ASR are documented in the water-withdrawal database. In this study, ASR is considered as off-stream storage, and the sum of ASR injections and withdrawals has no net effect on water demand.

1.2.8 Permit Systems and Water-Using Enterprises

Water withdrawals are not always connected to discharges in a simple 1:1 relationship. In some cases, complex water-supply systems are interconnected with multiple suppliers and multiple discharge locations. SCDHEC maintains the Environmental Facilities Information System (EFIS) which contains permit information for drinking water distributors in SC. Many of these distributors have multiple interconnections with different distribution systems. Also, many industrial water users are closely linked to drinking water systems. Together, the withdrawal, discharge, and distribution permits and reports can be used to estimate consumptive and non-consumptive water use in aggregate across an interconnected water system.

In some cases, suppliers have provided sufficient records of water transactions to calculate water use for individual enterprises within interconnected systems. This allows for more precise application of the projection methods when information is available.

1.2.9 Categories

Each intake in the water withdrawal database is labelled as one of the following categories: hydro-electric power, nuclear power, thermo-electric power, water suppliers, industry, agriculture, golf courses, mining, aquaculture, and other. The categories used here are based on those withdrawal permit categories, with some modifications. Nuclear power is considered thermo-electric power generation. Hydro-electric power is considered an in-stream demand, and is not included in these projections methods. Most industry withdrawal permits fall under the more specific label of manufacturing. Thus, Thermo-electric Power, Public Supply, Manufacturing, and Agricultural Irrigation are the labels used here for the major categories of water demand in SC. Golf, Mining, and Aquaculture are among nearly a dozen labelled as Other Categories. Each of these categories is addressed in the chapters that follow. There are important differences between the categories in terms of what information is available, what factors impact demand, and what trends are expected to have impacts in the future.

1.2.10 Drivers

Each major category of water use is associated with a primary driver, as outlined in Table 1.1 Drivers of Water Demand. Projections of the drivers are available in other literature, and those projections will be used to 'drive' the projections developed in this study. In some cases, driver data are available for each permit-holder, in other cases, the driver variable is represented by a local or national average. Driver data and projections are interpolated to a monthly or annual time step and extrapolated to cover the projection time period. More information regarding the driver data is provided in subsequent chapters.

Table 1.1 Drivers of Water Demand

Category	Primary Driver
Thermo-electric power	Electricity production
Public and domestic supply	Population
Manufacturing	Economic production
Agriculture and Golf Courses	Irrigated acres

1.2.11 Kinds of Water Use

The major categories can be subdivided into specific kinds of use: thermo-electric utilities use different fuels, generators, and cooling systems; public water supply includes sales to residential, commercial, and industrial customers; and irrigation practices vary for different crops, soils, and equipment. When such differences are found to have significant effects, the general water demand model described below will be applied separately for each distinct kind of water use.

1.2.12 A General Model of Water Demand

Equations 1.1, 1.2, and 1.3 above represent axioms, statements put forward to define the terms of this study. These axioms provide a quantitative definition of water demand, and they form the basis for estimating past water demand using available records. The above axioms, however, are not sufficient to project future water demand. For that, a hypothetical model is proposed. Equation 1.4, below, represents the generalized water demand model used in this study. This model proposes that water demand is a function of five factors (plus additional error caused by external factors). The generalized water demand model is designed to be flexible enough for all categories and kinds of water demand. It is designed to factor in diverse data sets where a lot of relevant information is available, and it can be reduced to a simplified form if data is unavailable or if some factors are insignificant.

Equation 1.4

$$Demand = \frac{Driver * Rate * Seasonality * Weather}{Efficiency} + Error$$

Where:

Demand	:	Water demand for a given use and time.
Driver	:	Primary driver of the given use at the given time.
Rate	:	Average rate for the given kind of use.
Seasonality	:	Seasonal variation relative to the annual average for the given kind of use.
Weather	:	Weather impact relative to average conditions.
Efficiency	:	Efficiency of the given use relative to others of the same kind.
Error	:	The difference between modelled and actual demand for the given use and time.

There are many more variables affecting water demand than the five factors in Equation 1.4. Every specific water demand is different in some way, but it is not feasible at this time to investigate and develop tailored projections for every specific water demand across SC. Accepting that it is imperfect and incomplete, this hypothetical model is proposed for its usefulness in understanding and projecting water demand.

Here, *kind* refers to the kind of water use, as described in the previous subsection. *Use* refers to water use of a single kind by a single user (or permit system or water-using enterprise). The five factors are distinguished to represent different ways water demand is expected to vary. The value of the Driver factor can vary over time and between different uses of water. The value of the Rate factor is estimated for each kind of water use, and it is generally assumed to stay constant over time. Seasonality factors are also estimated for each kind of water use and further specified for each calendar month of the year. The Seasonality factors for a specific kind of water demand are assumed to remain constant, but the Driver factor may be seasonal and change over time. The Weather factor is calibrated separately for each kind of water use, and it also varies geographically and over time. The value of the Efficiency factor is estimated relative to other water uses of the same kind and under similar conditions. Efficiency factors will be informative if the input data is accurate, but the results of this sort of calculation should not be used to justify strong conclusions regarding the economy of water use (application of this general model cannot substitute for detailed water use efficiency studies). Efficiency is not assumed to change over time in the first draft of projections. More complete documentation of the general water demand model is provided in Appendix A.

Water demand models will be calibrated for each significant use in SC with data representing the historical baseline. The most recent available water use data will be used to validate the calibrated models. Statistical validation provides an unbiased estimate of the accuracy of the projections for the near future. Calibration and validation results will be documented in subsequent reports.

1.2.13 Weather and Climate

Weather can impact water demand in multiple ways. Electricity demand tends to peak when temperatures are most extreme. Temperature, humidity, and surface wind speed impact evaporative cooling and transpiration rates of crops. Insolation and precipitation also impact crop growth and irrigation requirements. The methods described here are intended to represent those weather impacts to the extent that statistically significant effects can be found in the baseline data.

The Gridmet dataset contains daily estimates of precipitation, temperature, and reference crop evapotranspiration on a 4 km grid (Abatzoglou, 2013). Unless another weather dataset is determined to be better suited for a specific water use, daily Gridmet data will be used to calculate monthly weather indices for each water use in this study. If weather indices are found to correlate with a kind of water use, then a weather coefficient will be included for that kind of water use in the baseline model.

The earth's climate is changing, and weather conditions over a recent baseline period might not be representative of future weather conditions. Maximum temperatures in winter and spring have increased across the state (Mizzell et al., 2014). Mean sea level, measured near Charleston, also has increased, and the rate of increase appears to be accelerating (NOAA Tides and Currents – Charleston SC). Summer rainfall has decreased, while autumn rainfall has increased (Mizzell et al., 2014). In a stable climate, short-term trends can be expected to return to the long-term average over time. However, global climate models indicate that these trends may continue, and other unanticipated changes also may occur (USGCRP, 2017). While climate change is not explicitly represented in the water-demand projection methods described here, the two scenarios described below are intended to provide a range of variability covering potential increases in water-demand due to climate change.

1.2.14 Baseline Period

The period of time taken as the baseline for calibration of this water-demand model should be represented by a consistent records with little or no significant external factors affecting water demand. The average rate of use, seasonality, and efficiency of each permit-holder are not assumed to change over the baseline period. In contrast, weather variability over the baseline time period is necessary to estimate weather impacts on water demand. The five-year period from 2013 through 2017 is considered the default baseline, because water withdrawal reporting practices have been relatively stable over this range. While this baseline period does not include some severe droughts from the preceding decade, it does include agricultural droughts such as the summer of 2015. Longer or shorter baseline time periods may be selected on a case-by-case basis for different water users.

1.2.15 Projection Scenarios

The *business-as-usual* scenario assumes moderate weather conditions and no changes to water use efficiency. Driver values for the business-as-usual scenario will be taken from projections published by various sources and extrapolated to the 50-year planning period used here. In some cases, the assumption of no changes to water-use efficiency may not be realistic. While it may be likely that water-use efficiency will continue to increase, that possibility can be understood as a management strategy for stakeholders to consider when evaluating the results of the water-demand projections and water availability assessments in each planning basin.

The *high-demand* scenario applies higher driver growth rates in the range of growth rates in the projections referenced for the business-as-usual scenario. The high-demand scenario also assumes weather conditions with high impacts on water use. If the high-demand driver growth rate for a specific water use is unlikely, then the high-demand scenario for all water uses simultaneously is even less likely. Furthermore, if high-demand weather conditions are unlikely in a given year, then it is even less likely that the high-demand scenario would continue throughout the projected time period. The high-demand scenario is intended to represent an unlikely but possible future condition. The purpose of projecting this scenario is to quantify an upper bound of water demand that is very unlikely to be surpassed.

As described in the following chapters, the high-demand scenario includes the 90^{th} percentile of some factors for some categories of water demand. The 90^{th} percentile statistic can be understood as the 90^{th} figure out of 100, when ranked from lowest to highest. Monthly data is used to estimate the 90^{th} percentile of a factor over the baseline period.

Many additional scenarios can be explored by varying the scenario factors for different kinds of water demand or for different permit holders. The scenarios presented here are based on recommendations from the PPAC. Baseline data and water-demand models will be made available for interested parties to explore different possibilities. Many other scenarios are plausible, and some additional scenarios will likely be explored based on RBC interest.

1.2.16 References

Abatzoglou, J.T. (2013), *Development of gridded surface meteorological data for ecological applications and modelling*, Int. J. Climatol., 33: 121–131 (Available at https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/joc.3413) For more information, see: http://www.climatologylab.org/gridmet.html

Mizzell, Hope; Malsick, Mark; and Abramyan, Ivetta (2014) *South Carolina's Climate Report Card: Understanding South Carolina's Climate Trends and Variability*, Journal of South Carolina Water Resources: Vol. 1 : Iss. 1 , Article 1. Available at: https://tigerprints.clemson.edu/jscwr/vol1/iss1/1

USGCRP, 2017: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp., doi: 10.7930/J0J964J6.

2.0 Thermo-electric Power

Water is used to cool thermo-electric generators throughout SC. Water withdrawal and consumption at a given thermo-electric power plant are related to the type of fuel, prime mover, and cooling system. Fuel types for thermoelectric generation include: coal, oil, natural gas, nuclear, and biomass. Recently, there has been a shift away from coal, with increased use of natural gas to fuel generators.

2.1 Kinds of Thermo-electric Water Use

2.1.1 Prime Movers

Prime movers used in thermo-electric generation can be placed in three classes: gas turbines, steam turbines, and combined cycle. Gas turbines are fueled with natural gas. Combustion heats air, which in turn drives the turbines, using relatively little water per kilowatt hour (kWh).

A variety of fuels can be used to power steam turbines where combustion heats water to create steam that drives the turbines. Compared to gas turbines, much more water is used running steam turbines, mostly to cool and condense the steam exhaust so that it recycles back through the turbine. Water used to generate the steam is often a small fraction compared to cooling water used to condense the steam.

Combined-cycle generators direct excess heat from gas turbines to steam turbines, enabling more efficient fuel use. Water-consumption rates of combined-cycle generators are typically intermediate between gas turbines and steam turbines (NETL, 2010).

2.1.2 Cooling Systems

Cooling systems used in thermo-electric generation can be placed in four classes: once-through, recirculating wet tower, recirculating pond, and dry tower cooling.

In once-through cooling systems, water is passed through a condenser and then discharged back to the environment, warmer but otherwise unchanged. Once-through cooling systems tend to have high withdrawal rates and low consumption rates in the plant boundaries. The discharged water can increase evaporation rates in the receiving water body, but this effect is more difficult to quantify compared to evaporation in the power plant.

The most common type of recirculating cooling system at thermo-electric power plants in SC is wet tower cooling. After passing through the steam condenser, the cooling water is directed to a tower where ambient air is used to reduce the temperature of the cooling water so that the majority of it can be reused in the steam condenser. A portion of the cooling water is lost to evaporation, forming a water vapor plume above the tower. Another portion of the cooling water is discharged back to the environment as 'blowdown' to prevent build-up of minerals and sediment in the cooling system.

Recirculating pond cooling replaces the wet cooling tower with a cooling pond. Recirculating systems tend to have lower withdrawal rates and higher water-consumption rates compared to once-through cooling systems. However, these systems are considered more ecologically friendly overall (Denooyer et al., 2016). The use of recirculating cooling systems has increased as once-through cooling systems have been retired, and this trend is expected to continue (Davies, Kyle, and Edmonds, 2013; Bijl et al., 2016). In SC, recirculating cooling systems are common.

Dry cooling systems operate a closed system without evaporative losses. Dry cooling systems are typically used in arid climates where water is scarce and are uncommon or nonexistent in the US Southeast where high humidity makes these systems less efficient.

2.1.3 Base Load and Peak Generation

Base-load generators can efficiently produce a relatively constant output of electric energy, but such generators may have limited ability to meet short term fluctuations in demand. Peaker generators can vary their output more efficiently and are used to match energy production to daily and hourly changes in demand. Nuclear power is used to meet base load electricity demand, and coal and natural gas can also be used to meet base loads. Peak demands can be met using hydro-power, natural gas, and coal. (NETL, 2010)

Because natural gas prices have declined in recent years, natural gas has taken on more of a role in base-load generation, while coal generators have been shifted to operate during peak loads. As electricity demand increases over the projection horizon, peaker plants can be managed adaptively to meet demand, while base load plants are assumed to continue operating as normal.

2.1.4 Alternative Sources of Electricity

The fastest growing source of electricity in SC in recent years is solar. Solar-electric generation in South Carolina does not require significant amounts of water. Concentrated Solar Power can entail significant water demand, but no such systems are known to operate in the Southeast US. Solar-electric generation is still minor compared with thermo-electric and hydro-electric, and its continued growth may rely on continued support from the government. Faeth et al. (2018) projected continued growth in solar-electric and other renewable sources of electricity, to be as much as 30% of electric power generation by 2060.

2.2 Data Sources

2.2.1 Energy Information

The United States Energy Information Agency (USEIA) publishes reports of monthly electricity generation and water use, nameplate capacities, capacity factors, and planned actions for each electricity generator and cooling system. Nameplate capacity is the maximum capacity which the infrastructure is theoretically capable of producing; the capacity factor is the fraction of the nameplate capacity at which the generator is actually operated. Here, each generator is assumed to operate at the product of its nameplate capacity multiplied by the capacity factor. Planned actions can include increasing or decreasing plant capacity, and decommissioning. No planned actions affecting the generators in this study were found in the USEIA dataset for SC. Thermo-electric plants are not assumed to retire in this study. Projected retirement dates may be provided by stakeholders. River Basin Councils may assess long-term potential retirements.

2.2.2 Water Consumption Rates

Average water consumption rates for different kinds of thermo-electric generators are available from several sources that provide a range of estimates. Estimates from the US Army Corps of Engineers study by Stuart Norvell [CITATION] correspond closely with estimates provided by Duke Energy. Faeth et al. (2018) provide similar numbers for Georgia, and the USEIA dataset includes monthly water consumption rates for cooling systems in each power plant. Estimates from these different sources will be applied on a case-by-case basis for thermo-electric facilities in each basin.

2.3 Projections

2.3.1 Electricity Demand

There are four major power utilities operating in SC: Duke Energy Carolinas, Duke Energy Progress, Santee Cooper, and Dominion Energy South Carolina (formerly SCE&G). Each of these utilities publishes annual or bi-annual Integrated Resource Plans (IRPs) with projections of electricity demand in their service areas. Figure 2.1 shows projected energy demands for each utility. The red and blue lines represent the summer and winter peaks in demand, which may only occur for a few hours each day during the hottest and coldest portions of the year. The IRP projections end at year 2031 or 2032, and they have been extended to year 2070. The projections provided in the IRPs are represented in solid lines, and the dashed lines represent the extended projections for this study. The extended projections were calculated by fitting linear models to each projection from 2028 forward. This projection has the effect of extending the future ends of the lines at a uniform slope.

2.3.2 Water-Demand Scenarios

Because thermo-electric water demand is largely subject to annual planning by the major utilities, specific scenarios will be developed in collaboration with utility representatives as the projections are calculated in each river basin. The default assumption is that increasing average demands are spread evenly across the electricity generation portfolio of each utility. Increases in summer and winter peak demands are assigned preferentially to peaker generators.

2.3.3 References

Bijl, David L. & Bogaart, Patrick W. & Kram, Tom & de Vries, Bert J.M. & van Vuuren, Detlef P., *Long-term water demand for electricity, industry and households*, Environmental Science and Policy, 55 (2016) pp 75-86.

Davies, Evan, Page Kyle, and James Edmonds, *An integrated assessment of global and regional demands for electricity generation to 2095*, Advance in Water Resources, 52 (2013) pp 296-313.

Denooyer, Tyler, Joshua Peschel, Zhenxing, Zheng, and Ashlynn Stillwell, *Integrating water resources and power generation: The energy-water nexus in Illinois*, Applied Energy, 162 (2016) pp 363-371.

Faeth, Paul, Lars Hanson, Kevin Kelly, and Ana Rosner (2018). The Water-Energy Nexus in Georgia: A Detailed Examination of Consumptive Water Use in the Power Sector.

NETL, 2010. *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements: 2010 Update*. DOE/NETL-400/2010/1339. National Energy Technology Laboratory.

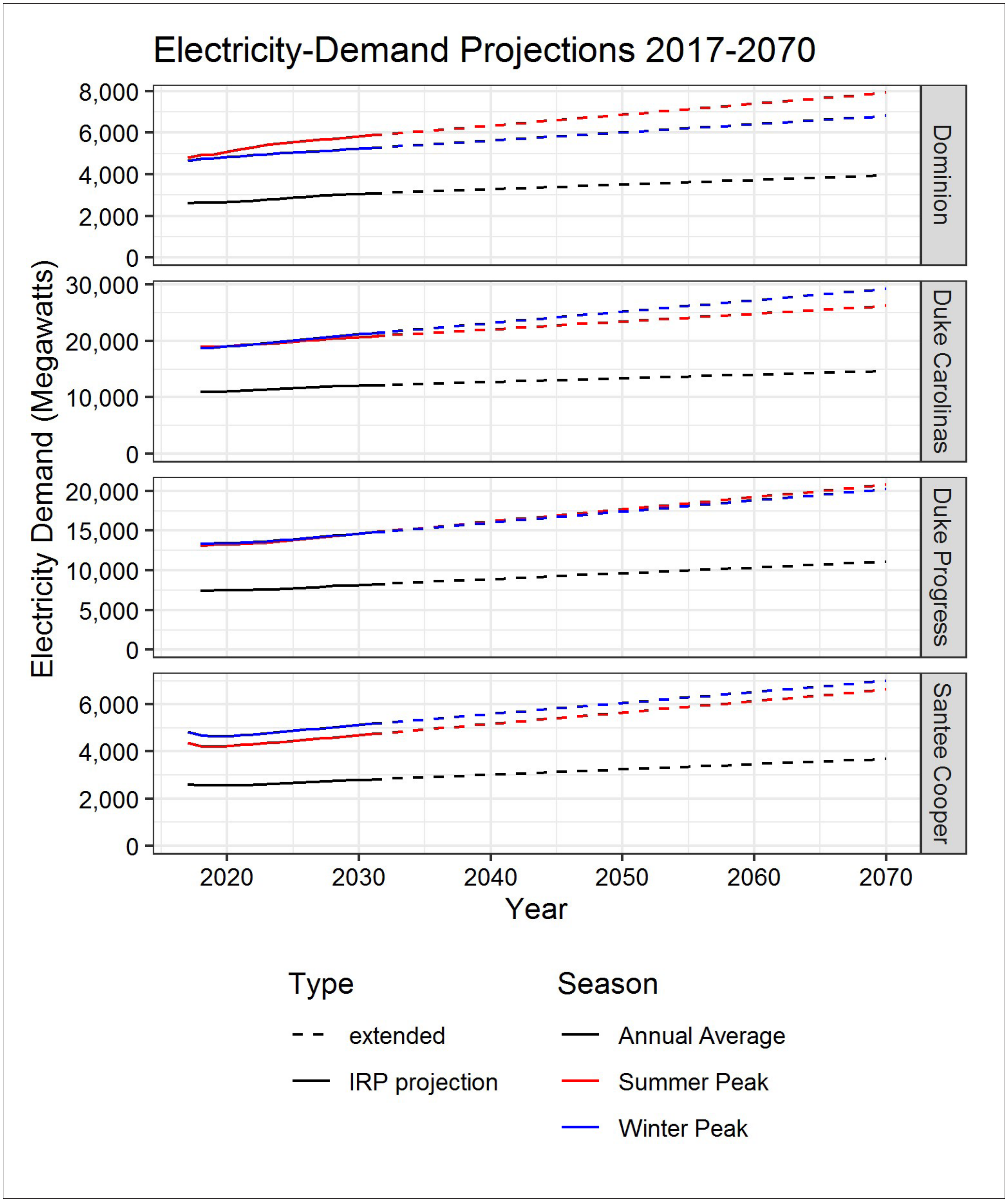

Figure 2.1 Extended Electricity Demand Projections.

3.0 Public Water Supply

Public water supplies include water distributors providing raw or treated water wholesale or retail to other water users. Users purchasing water can include: residential, commercial, industrial, irrigation users, and other public supply distributors. Public supply is the broadest and most diverse category of water use in SC..

3.1 Kinds of Public Water Supply

3.1.1 Public Supply Permits

The United States Environmental Protection Agency (USEPA) defines a public water system as *a system which provides water for human consumption through pipes or other constructed conveyances to at least 15 service connections or serves an average of at least 25 people for at least 60 days a year*. Public water systems are divided into three categories for permitting purposes (Figure 3.1). Type C community water systems supply water to the same population year-round. Type P non-transient non-community water systems supply water to at least 25 of the same people at least six months per year. Some examples are: schools, factories, office buildings, and hospitals which have their own water systems. Type N transient non-community water systems provide water in a place such as a gas station or campground where people do not remain for long periods of time. In addition to the public water systems regulated by USEPA, SCDHEC regulates and issues permits for Type S water supply systems which do not meet the USEPA definition of public water systems. In this study, water demand for type P, N, and S systems is assumed to remain constant. Projection methods described here apply to Type C, Community Water Systems.

The State Drinking Water Database, part of the Environmental Facilities Information System (EFIS), contains information from all of the water supply permits in SC, including the number of commercial and residential taps, wholesale connections, and populations served. Populations served directly are counted as primary populations, and populations served indirectly (through sales of water to another distributor) are counted as secondary populations. This information is updated as permits are renewed every 3 to 5 years, depending on the size of the system. At least some population values in the EFIS database were estimated by multiplication of the number of taps by the average number of residents per household.

3.1.2 Wholesales

The State Drinking Water Database includes some information on system interconnections. Connections are listed, but wholesale volumes are not. The primary population, served directly by a given distributor, is included along with the secondary service population served through a wholesale connection. The secondary population information may represent the total of several wholesale connections. In some cases, water originating from multiple distributors mixes in a single distribution system. Where sufficient information is available, wholesale volumes over the baseline period are subtracted from the seller and added to the buyer to calculate baseline water demand. Where wholesale volumes are not available, multiple interconnected distribution systems are lumped together and considered in aggregate.

Similarly, large industrial purchases of water can skew estimates of per capita water demand for a distribution system. Where sufficient information is available, industrial purchases will be projected separately from public supply using the methods developed for manufacturing water demand.

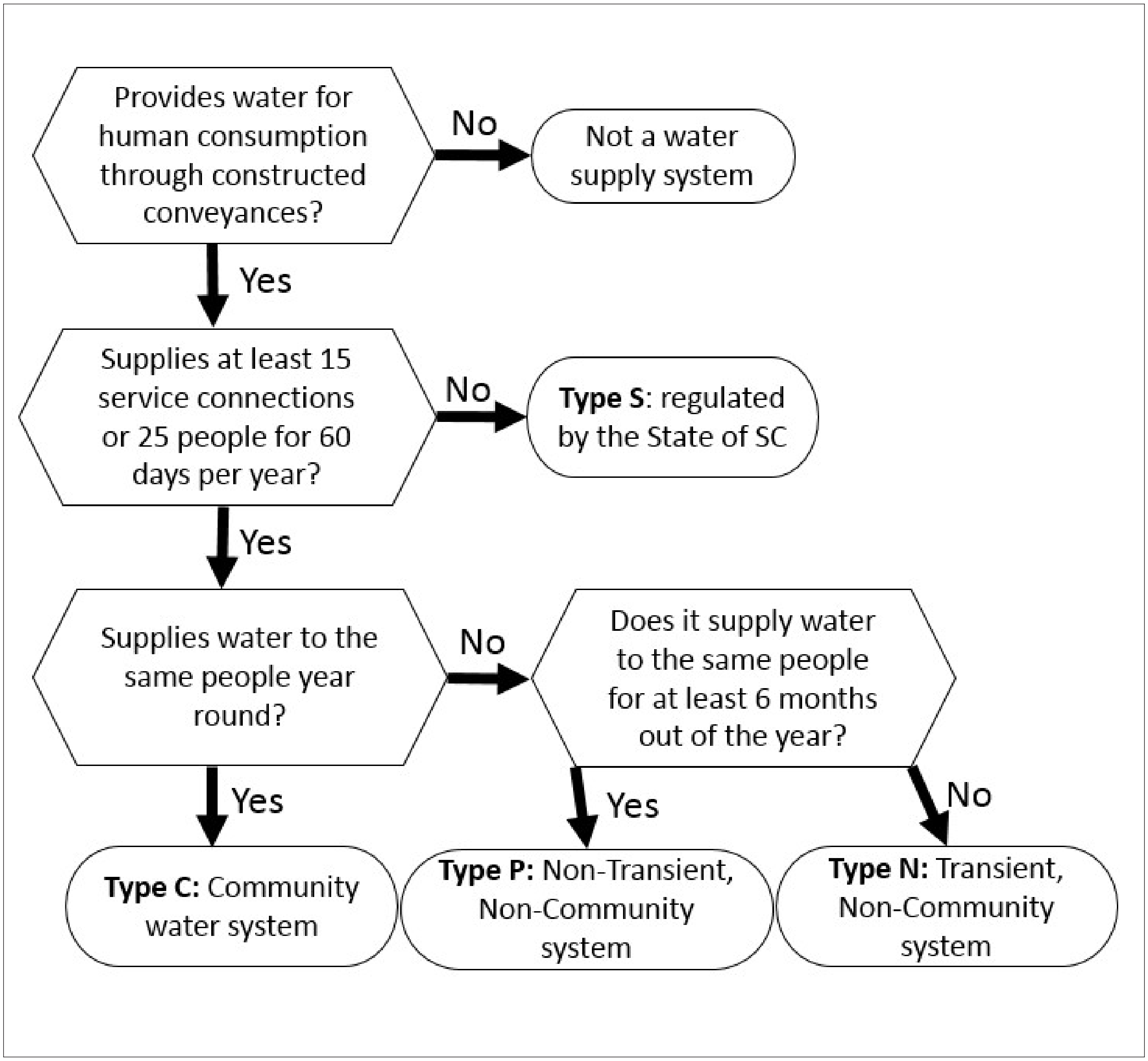

Figure 3.1 Water Supply System Classification.

3.1.3 Septic Systems

SCDHEC maintains a database of permitted septic system drain fields. The database describes the water source of each septic system as either from a public supplier or from a domestic well. Older septic system drain fields may have been installed without a permit, but permit compliance is assumed to be near 100% over the baseline period. The permits often have some geographic information, but the exact address information is not always reliable. In many cases, septic systems were installed prior to home construction, and street names and address numbers may not have been finalized when the permit was granted. The permits, however, do indicate the county where the drain field is located. When sewer collection systems expand, residents may choose to continue to use their pre-existing septic systems instead of joining the sewer network. However, if their septic system fails or faces maintenance issues, homeowners may decide to connect to the sewer system. The septic system drain field permit database is not updated when a septic system is decommissioned. Assuming a life-span of 20 years for a drain field, the number of households purchasing water and on septic is subtracted from the number of residential customers to calculate per capita return flows going to wastewater discharge. Leach field exfiltration is assumed to be negligible compared with other sources of infiltration to the surface water table.

3.2 Data Sources

3.2.1 Service Areas

Some water utilities have provided service area maps. Where such maps are not available, municipal boundaries[2] will be used. Service areas allow for an analysis of geographic data including land cover and demographic survey information. This information will be considered on a case-by-case basis if it has implications for future water demand.

3.2.2 Local Planning

Local (municipal, county, or regional) plans may not coincide exactly with the SCORFA population projections. The SC Code of Laws requires that local comprehensive plans consider water supply, treatment, distribution, sewage system, and wastewater treatment (*Title 6: Chapter 29 Article 3 – Local Planning – The Comprehensive Planning Process*). Local planning documents have been reviewed, and relevant excerpts from the local plans will be included in the basin studies.

3.3 Projections

3.3.1 Population Projections

The SC Office of Revenue and Fiscal Affairs (SCORFA) has developed population projections for each county based on birth, death, and migration rates. The SCORFA population projections are used as the driver factor for public water demand. The SCORFA projections were developed using the cohort component method. Birth, death, and migration rates were estimated for age cohorts in the population of each county. This estimate is based on the assumption that recent birth, death, and migration rates are representative of future rates for each age cohort of the population. The most recent projection available spans the years 2013 to 2035. The populations served by each water supplier in a given county are assumed to grow (or decline) at the same rate as the county population as a whole. Example SCORFA population projections and the modifications used for the water demand scenarios are presented in Figure 3.2. The full SCORFA projections are included in Appendix B.

3.3.2 Business-as-usual

The SCORFA projections represent the business-as-usual scenario, and the projections are extended here to 2070. The average annual change in the population of each county is calculated as the difference between the 2013 and 2035 populations, divided by 22 (2035 minus 2013) increments in the SCORFA projection. If the average annual change is positive, then the business-as-usual scenario is extended to 2070 at the same average annual rate of change. If the average annual rate of change is negative, then the business-as-usual scenario is extended as a flat line to 2070 (no change in population after 2035).

2 Accessible online at http://gis.sc.gov/data.html

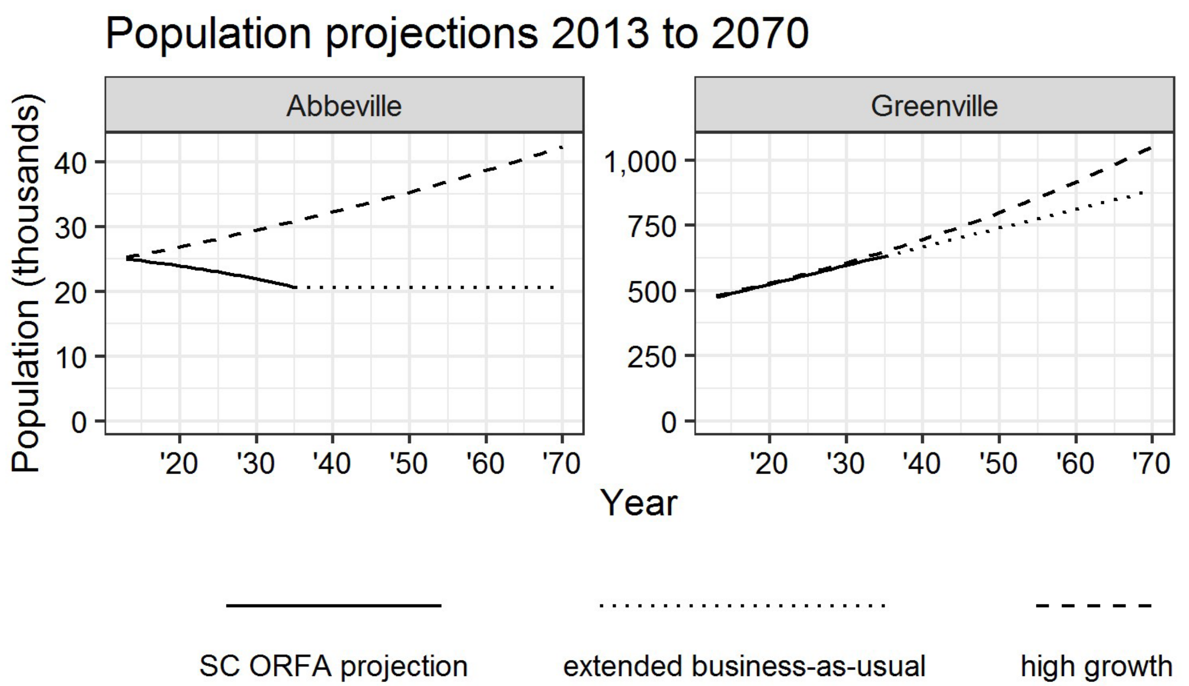

Figure 3.2 Example population projections for the business-as-usual and high-demand scenarios.

3.3.3 High-demand

The high-demand scenario assumes exponential population growth. The average growth rate in the population of each county over the SCORFA projections is calculated as follows:

Equation 3.1

$$\text{growth rate} = \left(\frac{\text{population 2035}}{\text{population 2013}}\right)^{1/23} - 1$$

For counties with a calculated growth rate less than the state average (0.829%), the state average is used. To represent a high-demand scenario, population growth rates for all counties are increased by 10% (for a minimum county growth rate of 0.00829 * 1.1 = 0.00912). 10% was chosen as a reasonable increase after a conversation with SCORFA staff regarding their projection methods and associated uncertainty. The high-demand scenario also includes a multiplier representing the estimated 90th percentile of weather impacts on water demand.

3.3.4 Advanced Methods

Some water distributors have provided more detailed information regarding sales volumes for residential, commercial, industrial, and wholesale water use. Some distributors have provided information regarding indoor and outdoor water use, and some distributors have provided indoor and outdoor water use for the different sales categories. This information can be useful, but at least 3 years of data are needed to apply the seasonal and weather dependent statistical models used here (see Appendix A). When detailed sales data are available, statistical models for the different kinds of water use may be developed on a case-by-case basis.

4.0 Manufacturing

For decades, manufacturing withdrawals have declined as water-use efficiency has increased. A trend in US manufacturing is to increase economic output by producing higher-quality products which often do not require substantially more water to manufacture.

Other studies have modelled water use in the manufacturing sector in terms of gallons per dollar of value produced or gallons per employee. However, these metrics are not generally available for all manufacturing water-use permittees in SC. Therefore, manufacturing water use will not be modelled at specific rates using the driver variable.

4.1 Manufacturing Projections

The US Energy Information Administration (USEIA) provides national level projections of macroeconomic indicators out to 2050, including projected economic growth rates for each subsector. Shorter term projections of employment by subsector and county also are available, but those projections will not be used as the driver variable for this study. Manufacturers withdrawing or discharging more than 1 million gallons per month in SC have been classified to economic subsectors, and projected economic growth rates of each subsector will be applied to the water use of individual permittees.

Growth of individual businesses in SC will inevitably vary from national projections for a subsector. Over the next 50 years, there will likely be openings, closings, and transitions of industrial plants from one sector to another. Those possibilities are not considered explicitly in the scenarios presented here, but should be considered on a case-by-case basis when relevant information is available.

4.2 Business-as-usual

USEIA projected growth rates are adjusted to a minimum of zero. Projected growth rates that are less than zero are replaced with zero; projected growth rates above zero are left unchanged. Average baseline-water withdrawal and consumption for each permitted use are projected using this adjusted USEIA growth rate.

4.3 High-demand

USEIA projected growth rates are adjusted to a minimum equal to the average projected economic growth for all of SC. Projected growth rates less than the SC average are replaced with the SC average; projected growth rates above the SC average are left unchanged. The baseline 90th percentile withdrawal and consumption for each permitted use are projected using this adjusted USEIA growth rate.

5.0 Agricultural Irrigation

Agricultural irrigation includes cultivation of annual crops, orchards, and plant nurseries. While irrigated agricultural land is expanding, most of SC farmland is currently not irrigated. In this study, irrigated area is the primary driver of irrigation volume, but irrigation depth can vary by crop, soil, weather, irrigation method, crop growth stage, and cultivation practices specific to each irrigator. If sufficient data are available to indicate that these factors contribute to significant differences in irrigation depth, then water demand models will be calibrated to represent these different kinds of irrigation.

5.1 Data Sources

5.1.1 Irrigated Acreage

The Census of Agriculture (COA) is considered the most authoritative source of information regarding irrigated acreage per county and crop in the US. The COA is undertaken every 5 years, and the results of the 2017 COA indicate approximately 210,000 acres of irrigated land in SC (USDA-NASS, 2019). These census results are the standard with which other estimates are evaluated.

The US Department of Agriculture Farm Service Agency (USFSA) provides an annual dataset of irrigated and un-irrigated acreage per county per crop[3]. This information comes from farmers registered with the USFSA (not all farms provide this data). It represents an incomplete sample, whereas the COA is statistically corrected with the aim of better representing the entire population of farms. Because USFSA data are not statistically corrected, the reported acreages can be interpreted as a minimum value. USFSA estimates are drafted and updated over several iterations as the data are compiled from local to national offices. The USFSA dataset also includes information regarding crop variety and intended uses. With more details and annual results, the FSA dataset is a good complement to the COA.

5.1.2 Mapping Irrigation

Estimates of irrigated acreage for each county and crop are informative, but mapping irrigated acreage provides additional information regarding the characteristics of irrigated land. Further, by associating water withdrawal reports to mapped irrigation, farm-scale water-demand models will be developed.

With agricultural water withdrawal locations as a guide, 140,000 acres of irrigation have been delineated using high resolution imagery available on the Google Earth Engine online development platform (Gorelick and others, 2017). Irrigation infrastructure (mostly center pivots) has been identified in the imagery, and surrounding irrigated areas have been delineated using the tracks in the field as a guide. The discrepancy between the delineated irrigated acreage and the COA reported acreage could be caused in part by the extension of irrigation beyond the center pivot arm through the use of end guns or the use of irrigation infrastructure which is less evident in satellite and aerial imagery. An estimate of the installation year for the irrigation infrastructure has been assigned to each irrigated area by review of imagery from the National Agriculture Imagery Project (NAIP)[4] over the baseline period. NAIP imagery is available every 2 to 3 years, and

3 https://www.fsa.usda.gov/news-room/efoia/electronic-reading-room/frequently-requested-information/crop-acreage-data/index

4 https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/

identification of irrigation infrastructure was less certain using NAIP imagery compared with the higher resolution images available on Google Earth which were used for initial identification of irrigated areas.

The Landsat program produces satellite images twice a month at a spatial resolution of about 30 meters[5]. The Moderate Resolution Imaging Spectro-radiometer (MODIS) program provides daily images at a spatial resolution of about 250 meters[6]. Both of those datasets include spectral bands beyond the range of the human eye, which can indicate variations in plant stress and surface moisture that may not be apparent otherwise. This information has been used to identify irrigation in other studies. Notably, the MODIS Irrigated Agriculture Dataset for the United States (MIrAD-US) provides estimates of irrigation extent for years 2002, 2007 and 2012 at a spatial resolution of 250 meters[7]. MIrAD-US has been developed with a focus on accuracy in areas where irrigation extent is greatest, and uncertainty is greater in the humid Southeast region of the U.S. (Brown and Pervez, 2014). Comparison with the manual delineations indicates that the current edition of MIrAD-US is not sufficiently accurate, but future editions may provide more accuracy.

The manual delineations of irrigated areas will be used to calibrate an algorithm designed to identify remaining irrigated areas in SC. The resulting algorithm will take satellite data as input to estimate irrigation extent at a high resolution across the state. Depending on the degree of success of the algorithm design and calibration, it may be possible to enhance the delineated irrigation acreage data to include areas for which no infrastructure has been visually identified.

Groundwater withdrawal permits in Capacity Use Areas include the expected irrigated acreage for each withdrawal well. Capacity Use Areas are areas in South Carolina with additional regulatory requirements for groundwater withdrawals. Some irrigators responded to an optional water-use survey developed by SCDNR and distributed by SCDHEC, and some of those survey responses also included details information of irrigated areas and water volumes applied (Pellett and Walker, 2018). This information from permits and surveys will be used to check the accuracy of mapped irrigation.

5.1.3 Irrigation Suitability

Some areas are not considered suitable for irrigation and are excluded from this analysis. Impervious surfaces such as roads and rooftops, as represented in the NLCD, are assumed to remain unirrigated. Public parks and other protected areas in the U.S. have been compiled in an official inventory, the Protected Areas Database (PAD)[8]. Natural areas in the PAD are assumed to remain unirrigated. Parcels smaller than 10 acres are assumed to be unsuitable for irrigation at the scale of mainstream agriculture. Open water and wetlands also are excluded. Slopes greater than 2% are assumed to be unsuitable for center pivot irrigation. These assumptions will be tested using the enhanced delineations of irrigation over the baseline period, described above.

5.1.4 Factors Affecting Irrigation Depth and Timing

Mapping of irrigated areas allows for spatial analysis of other factors which could affect irrigation depth and timing. The Soils Data Layer (SSURGO) includes parameters such as hydraulic conductivity and moisture retention capacity which are relevant for modeling irrigation depth[9].

5 https://landsat.usgs.gov

6 https://modis.gsfc.nasa.gov

7 https://earlywarning.usgs.gov/USirrigation

8 Available online at: https://gapanalysis.usgs.gov/padus

9 https://websoilsurvey.nrcs.usda.gov/

The National Land Cover Dataset (NLCD) has been developed using Landsat data. The NLCD classifies the land in to various categories such as: cultivated land, pasture, wetlands, and developed areas[10]. The NLCD has been published in five-year intervals from 1997-2017. The annual Cropland Data Layer (CDL, a.k.a. Cropscape) is developed using methods adapted from the NLCD. The CDL classifies agricultural lands by crop type and is published annually[11].

Variables such as irrigation type and cultivation practice also can impact irrigation depth and timing. Clemson University Extension has undertaken an ongoing irrigation survey, and the results will summarize a variety of irrigation parameters by county across SC (Sawyer, 2018). Results from a separate Clemson University survey of greenhouses and nurseries also may be informative (Huang and others, 2019). The USDA conducts the Farm and Ranch Irrigation Survey (FRIS) as a follow up to the COA. The FRIS results are extrapolated from a sample of surveyed operations, and the results in SC are published as statewide summary estimates (USDA-NASS, 2013). Some results of the 2013 FRIS could have been skewed by a particularly wet growing season in parts of SC that year. The 2018 FRIS is scheduled for publication in November, 2019.

Each of these surveys provide aggregated estimates for numerous parameters which could be relevant to irrigation depth. Surveys of water withdrawers developed and compiled by SCDNR provide details for individual irrigators, and some additional information has been compiled from telephone interviews. If data available for individual irrigators provides evidence of statistically significant effects on irrigation volume, the resulting effects can be included in the agricultural irrigation water demand model. In the terms laid out in Appendix A, each unique combination of such significant factors would be considered as a different kind of water use. Irrigation of unknown kind can then be estimated using the aggregate data from the surveys described in the preceding paragraph.

5.2 Projections

5.2.1 Agricultural Projections

The United States Department of Agriculture (USDA) publishes 10 year projections of national crop plantings. The land in each county under each crop is projected to grow at the national projected rate from 2017-2027. The relative crop acreages of each county will be held constant for the remainder of the projection horizon. Successfully changing crops on a farm often requires significant investments in additional equipment, as well as knowledge and expertise.

Additional changes in the crop portfolio are likely. For example, the hemp industry is relatively new in SC and is anticipated to continue growing in the near future. Most current hemp production in SC is for Cannabidiol oil, and irrigation is needed for reliable yields. The projected growth and future water demand of this crop in SC is unknown as it is in its infancy. While it is likely that long-term changes in the crop portfolio will impact irrigation water demand, no information has been identified to quantify expected changes.

To project future irrigation for different crops, some stakeholders have recommended the development of an econometric model accounting for crop prices and other economic factors. Such a model could be informed by the assessments described here, but the development of an econometric model is beyond the scope of the resources currently available to the SCDNR for water planning. Instead, projected rates of growth for irrigation from other studies are adopted for the projection scenarios considered here.

10 https://www.mrlc.gov/finddata.php
11 https://nassgeodata.gmu.edu/CropScape

Brown and others (2013) projected a 38% increase in irrigated area from 2020–2070 for Water Resources Region 3, an area extending across the coastal states from North Carolina to Mississippi, including all of SC. That estimate was calculated by fitting a two-parameter non-linear model to historically irrigated acreages rom 1960–2005.

Crane-Droesch and others (2019) combined climate, crop yield, and price models to project the impacts of climate change on irrigated and dryland cultivation of corn, soybeans, and wheat for year 2070. The projected impacts of climate change on irrigated area in SC varied widely between different Representative Climate Pathways and Global Climate Change Models.

5.2.2 Business-as-usual

The business-as-usual scenario assumes that irrigated areas in SC will increase by 38% over the planning horizon. Irrigable areas in each county are constrained by a projection of developed areas with clustered growth (Sanchez, 2018). If irrigation is constrained in some counties, then the projected growth will be shifted to other counties in SC. The baseline average weather conditions are assumed to remain constant.

5.2.3 High-demand

The high-demand scenario assumes that irrigation will expand by 44% over the planning horizon. This assumption could represent a relatively large positive impact of climate change, within the range estimated in the cited work (Crane-Droesch et al., 2019).

Irrigable areas in each county are constrained by a projection of developed areas with spread out growth (Sanchez, 2018). The projection of spread out growth for developed areas represents a high-demand scenario for Public Supply, but it could result lower water demand for agriculture in some parts of SC if development poses a significant constraint on irrigable areas.

Weather impacts are as the 90th percentile weather impact over the baseline period. The weather impact factor is not intended to represent the most extreme drought, but it represents the weather which most increases water demand. Irrigation systems in SC are often designed to supplement rainfall, not replace it. If crop failures are imminent, such as during times of drought, some irrigators cease irrigation. This study does not account for drought-related crop failure in irrigated areas.

5.2.4 References

Brown, J.F. and Pervez, M.S., 2014. Merging remote sensing data and national agricultural statistics to model change in irrigated agriculture, Agricultural Systems, 127; doi:10.1016/j.agsy.2014.01.004.

Brown, Thomas C., Romano Foti, and Jorge A. Ramirez, 2013. Projected freshwater withdrawals in the United States under a changing climate, Water Resources Research, Vol. 49, 1259–1276.

Crane-Droesch, Andrew, Elizabeth Marshall, Stephanie Rosch, Anne Riddle, Joseph Cooper, and Steven Wallander. *Climate Change and Agricultural Risk Management Into the 21st Century*, ERR-266, U.S. Department of Agriculture, Economic Research Service, July 2019.

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*.

Huang, P., A.J. Lamm, L.A. Warner, S.A. White, P. Fisher, 2019 (October publication date). Exploring nursery growers relationships with water to inform water conservation education. Journal of Human Science and Extension.

Pellett, C. Alex, and Walker, Thomas III, 2018. “Water Users’ Perspectives: Summary of Withdrawal Survey Responses and Commentary”, Journal of South Carolina Water Resources: Vol. 5: Iss. 1, Article 3. Available at: https://tigerprints.clemson.edu/jscwr/vol5/iss1/3.

Sanchez., G.M., Terando, A., Smith, J., Garcia, A.M., Wagner, C., & Meentemeyer, R.K. (under review). Forecasting Water Demand for a Rapidly Urbanizing Megaregion. Landscape and Urban Planning.

Sawyer, Cal, 2018. Presentation on South Carolina Irrigation Survey. Presentation at the South Carolina Water Resources Conference, September 2018.

USDA-NASS, 2014. Census of Agriculture: Farm and Ranch Irrigation Survey (2013). Vol. 3. *Special Studies*, Part 1. United States Department of Agriculture – National Agricultural Statistics Service.

USDA-NASS, 2019. Census of Agriculture: United States Summary and State Data (2017). Vol. 1. *Geographic Area Series*, Part 51. United States Department of Agriculture – National Agricultural Statistics Service.

6.0 Other Categories

6.1 Golf Course Irrigation

Golf course managers have reported trends in the market that allow for lower water usage. There is now greater support among the golfing community for less manicured turf and more native plants and wildlife habitat in out-of-play areas in and adjacent to golf courses. There also is a growing preference among some golfers for “firm and fast” turf conditions—closely cropped turf that typically has lower water needs. Turf varieties have been selected for drought tolerance in some areas. Golf course irrigation demand in the business-as-usual scenario is projected to remain stable at the baseline average. In the high-demand scenario, seasonal 90th percentile demands will be used, with no change over time.

6.2 Mining

Mining water demand is projected as the baseline average reported withdrawal with no growth for the business-as-usual scenario and as the 90th percentile with no growth for the high-demand scenario.

6.3 Aquaculture

Aquaculture includes private operations and state-run fish hatcheries which withdraw water for off-stream use. In-stream aquaculture is not considered in this study. Aquaculture water demand is projected as the baseline average reported withdrawal with no growth for the business-as-usual scenario and as the 90th percentile with no growth for the high-demand scenario. The USDA is scheduled to publish the results of the 2018 Census of Aquaculture in December, 2019. The results for SC will be state summary estimates, and may be used to inform the projections of aquaculture water demand.

6.4 Livestock

Locations and capacities of permitted livestock facilities are available from SCDHEC[12]. USDA NASS estimates average water use per head of livestock in each state. Livestock water use in SC is assumed to remain constant at the average rate per head and the 90% of capacity of each facility. The high-demand scenario assumes 100% capacity. Water demand for livestock outside of permitted Confined Animal Feedlot Operations is assumed to be negligible.

6.5 Domestic Wells

The population on domestic supply is estimated by subtracting the populations served by public supply from the total population in each county. That estimate is compared with the number of households listed as domestic supply in the septic drain-field database. A domestic water use rate of 100 gallons per capita per day is assumed, consistent with other studies (Dieter et al., 2018). The county population on domestic supply is projected to grow at the same rate as the county population on public supply, described in chapter 3.

6.6 Data Center Cooling

Water demand for data center cooling is assumed to remain constant.

6.7 Lakefront Irrigation

Lakefront irrigation is assumed to be negligible in this study.

6.8 Emergency Fire Control

Emergency fire control is assumed to be negligible in this study.

6.9 Military Bases

Water use related to military bases and other Federal institutions (including the Savannah River Nuclear Site) is assumed to remain constant.

6.10 Prisons

Water use at prisons is assumed to remain constant.

6.11 References

Dieter, C.A., Maupin, M.A., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2018, Estimated use of water in the United States in 2015: U.S. Geological Survey Circular 1441, 65 p., https://doi.org/10.3133/cir1441. [Supersedes USGS Open-File Report 2017–1131.]

12 http://www.scdhec.gov/HomeAndEnvironment/maps/GIS/GISDataClearinghouse/default.aspx

Appendix A: Formal Methods

Let a water use, *u*, refer to a series of observations of off-stream water use of a specific kind, *k,* over a period of time (t_1, t_2, t_3, ... , t_n). A permittee, water user, or population of water users may direct water to multiple uses of different kinds over a period of time. Each water use is classified as a single kind. The time step used in this study is the calendar month, and each observation is labelled by month, *m*, and year, *y*, to distinguish seasonal effects.

Missing data within the baseline period will be estimated. Daily data will be aggregated to a monthly time-step. Annual data is assumed to remain constant between calendar months.

Table A1. Symbols used in this section

Symbol	Meaning
u	An off-stream water use
k	Kind of water use
t	Time step
y	Year AD
m	Calendar month

Water Use Rate

The monthly rate of water use is calculated by dividing water demand by the value of the driver variable. The average rate for a specific water use ($Rate_u$) is calculated as the average of the monthly rates over each time-step of the baseline period. Water uses of the same kind are expected to have similar average rates of water use, and the average rate for each kind of water use ($Rate_k$) is calculated as an average of each specific water use rate ($Rate_u$) of that kind.

Equation A.1

$$Rate_u = \frac{\sum_{t=t_1}^{t_n} \frac{Demand_{u,t}}{Driver_{u,t}}}{n_t}$$

Where:

$Rate_u$	:	Baseline average rate for use *u* of kind *k.*
t_1 , ... , t_n	:	Baseline time steps for use *u* of kind *k.*
$Demand_{u,t}$	:	Demand at time *t* for use *u* of kind *k.*
$Driver_{u,t}$	:	Driver for use *u* at time *t* of kind *k.*
n_t	:	Number of baseline time steps for use *u.*

Equation A.2

$$Rate_k = \frac{\sum_{u=u_1}^{u_n} Rate_u}{n_u}$$

Where:

$Rate_k$	:	Average rate of demand over the baseline period for all uses of kind *k.*
$u_1, \dots, u_n$	:	Distinct uses of kind *k* in the baseline dataset.
n_u	:	Number of distinct uses of kind *k* in the baseline dataset.

Seasonality

A seasonality term, $Seasonality_{k,m}$, is used to represent seasonal variation in water demand (separate from seasonal variation in the driver variable, if any). Like $Rate_k$, $Seasonality_{k,m}$ is calculated in a two-step process. Baseline average seasonality for a given water use *u* and calendar month *m* is calculated as an average over all of the years in the baseline period. The baseline seasonality term for kind *k* is calculated as the average of the baseline seasonality for all uses *u* of that kind.

Equation A.3

$$Seasonality_{k,m} = \frac{\sum_{u=u_1}^{u_n} \frac{\sum_{y=y_1}^{y_n} \frac{Demand_{u,m,y}}{Driver_{u,m,y} * Rate_u}}{n_y}}{n_u}$$

Where:

$Seasonality_{k,m}$	:	Baseline seasonality coefficient for kind *k* during month *m*, unitless.
$y_1, \dots, y_n$	:	Gregorian calendar years AD in the baseline time period.
$Demand_{u,k,m,y}$	:	Demand for water use *u* during month *m* of year *y.*
$Driver_{u,k,m,y}$	:	Driver for water use *u* during month *m* of year *y.*
n_y	:	Number of years in the baseline period for use *u.*

Efficiency

The efficiency coefficient, as defined here, should not be interpreted as a literal measure of water use efficiency. It is a correction factor which adjusts the general water demand models of each kind to each specific use. Not all uses of the same kind are truly comparable using this general model, and error in either the demand or driver data for any use at any time step in the baseline period could affect the efficiency coefficients of all uses of that kind. Wide-ranging efficiency coefficient values could indicate variation among water uses of the same kind, but ... take it with a grain of salt. Unlike the baseline rate and seasonality, which are calculated as averages across all of the users of each kind, the efficiency coefficient is calculated per use *u*:

Equation A.4

$$Efficiency_u = \frac{\sum_{t=t_1}^{t_n} \frac{Driver_{u,t} * Rate_k * Seasonality_{k,m}}{Demand_{u,t}}}{n_t}$$

Where:

Efficiency$_u$: Baseline efficiency coefficient for use *u*.

Weather

The weather coefficient is calibrated to model variation in reported water use which is not explained by the driver, rate, seasonality, or efficiency variables. The variation in water demand remaining after factoring out the driver, rate, seasonality, and efficiency variables is labelled $\frac{Actual\ Demand}{Expected\ Demand}$. If weather has no impact on water demand, then this term will equal 1 at each time step. In many cases, especially for outdoor water demands, some variation is expected.

Equation A.5

$$\frac{Actual\ Demand}{Expected\ Demand} = \frac{Demand_{u,t} * Efficiency_u}{Driver_{u,t} * Rate_k * Seasonality_{k,m}}$$

Kinds of water demand that show significant variation in $\frac{Actual\ Demand}{Expected\ Demand}$ are assumed to be weather-impacted. One or more weather indices will be developed for each weather-impacted kind of water use. The weather indices will be based on expert knowledge and stakeholder input. Example weather indices include growing degree days, monthly evapotranspiration, and reference crop irrigation requirements. A monthly time series of each weather index will be derived from Gridmet weather data, or other sources as appropriate, for each weather-impacted water use. Each proposed weather index will be evaluated as an explanatory variable for $\frac{Actual\ Demand}{Expected\ Demand}$ using least squares regression. The weather index and regression equation that best fit the observed variation over the baseline period will be selected for each kind of weather-impacted water demand. The weather coefficient, $Weather_{u,t}$, will then be calculated for each weather-impacted use at each time step of the baseline period:

Equation A.6

$$Weather_{u,t} = f_k(Gridmet_{u,t})$$

Where:

$Weather_{u,t}$	:	Weather coefficient for use *u* at time *t*.
f_k	:	Regression derived function for weather-impacted kind *k*.
$Gridmet_{u,t}$	:	Weather index derived from Gridmet or other appropriate data source for use *u* at time *t.*

The use of regression to estimate weather coefficients provides statistical evidence which may or may not support the use of a given weather index. This information can be used to evaluate scenarios beyond the two scenarios prescribed in these methods.

In the *business-as-usual* scenario, all weather coefficients are set equal to 1. In the *high-demand* scenario, the weather impact will be calculated for each use *u* as the 90th percentile observed weather coefficient in the baseline period for each month *m* for that kind *k.*

Water Demand Model

The terms defined above are brought together to model each water use. This model will be fitted to each water use, and the error terms will be assessed by comparison with water use records over the base line period to estimate the accuracy and suitability of the model.

Equation A.7

$$Demand_{u,t} = \frac{Driver_{u,t} * Rate_k * Seasonality_{k,m} * Weather_{u,t}}{Efficiency_u} + Error_{u,t}$$

Where:

$Demand_{u,t}$	:	Water demand for use *u*, expressed in terms of volume per month.
$Driver_{u,t}$	:	Primary driver value for use *u*, units vary by category.
$Rate_k$	:	Normal rate for kind *k* of water demand, expressed per unit of the primary driver.
$Seasonality_{k,m}$	:	Normal seasonality coefficient for kind *k* and calendar month *m*, unitless.
$Efficiency_u$	:	Average efficiency coefficient for use *u*, unitless.
$Weather_{u,t}$	:	Weather coefficient for use *u* at time *t*, unitless.
$Error_{u,t}$	:	The difference between modelled and actual water use *u* at time *t.*

Figures A.1 to A.8 illustrate the calculation of a baseline water demand model for three different water uses (u_1 , u_2 , and u_3) of the same kind. In this example, the kind of water demand can be interpreted as residential public supply. The driver values can be interpreted as population, and the rate can be interpreted in terms of gallons per capita per month. Figures A.1, A.2, and A.3 present the baseline data used in the example. Figures A.4, A.5, A.6, and A.7 illustrate the derivation of the terms in the baseline water demand model.

Figure A.1 illustrates the contrived water demands used in this example. For this example, the demands were calculated to fit the water demand model, with some random error added to each term.

Figure A.2 illustrates the contrived driver data. The driver data for u_3 is seasonal. In the context of this example, that could be a town with a large seasonal tourist population.

Figure A.3 illustrates a contrived weather index. This example weather index could be interpreted as some measure of drought. When these methods are applied across the State, multiple weather indices may be assessed.

In Figure A.4, each box plot represents the distribution of monthly rates of a user over the baseline period. The average rate for each user ($Rate_u$) is labelled in each box plot. Those averages are then averaged among all three uses of this kind to calculate $Rate_k$, labelled on the dashed line.

Figure A.5 represents the individual baseline observations of seasonality for each use and each time step with point icons. Baseline seasonality, $Seasonality_{k,m}$, is depicted with a dashed line.

Figure A.6 shows boxplots labelled with the baseline average efficiency of each example use.

Figure A.7 illustrates a linear model of the weather index (plot C) and $\frac{Actual\ Demand}{Expected\ Demand}$ for each example use. The regression equation is used to calculate a weather coefficient for each use at each time step of the baseline model.

The final modeled baseline flows are compared with the 'observed' baseline flows in Figure A.8. Because Figure A.1 illustrates an example with contrived data, it is no surprise that the model fits quite well. The purpose of this figure is to illustrate the proposed method of fitting baseline models to water demand data for different kinds of uses. Similar figures will be produced for each significant kind of water demand in the State to provide model validation and detailed results for interested stakeholders.

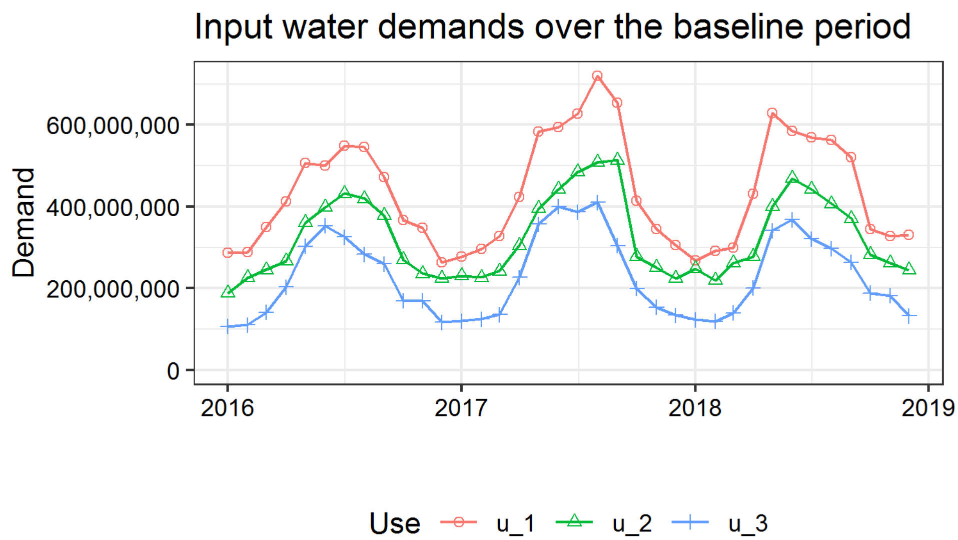

Figure A.1 – Monthly water demands for three uses from 2016 to 2019. These are contrived values generated solely for the purpose of providing an example of how the methods are applied. In this example, there are three uses of the same kind. There is a clear seasonal signal, and a subtle increasing trend. The trend is obscured by small random variations affecting each use individually and by variation that appears to affect all of the uses of this kind (note that the highest demand for each use occurs around the summer of 2017).

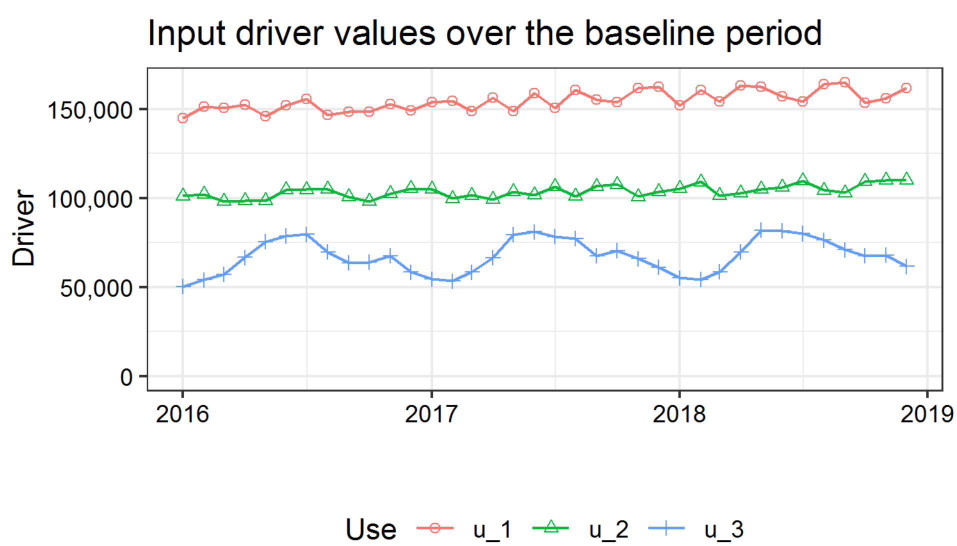

Figure A.2 – Monthly driver values for three uses from 2016 to 2019. The driver values show the increasing trend more clearly than the water demands, though it is still subtle. The driver for u_3 shows seasonality, while the others do not. That is not a problem for this method, and the three uses can still be considered as being of the same kind. Here the driver values also show some random variation.

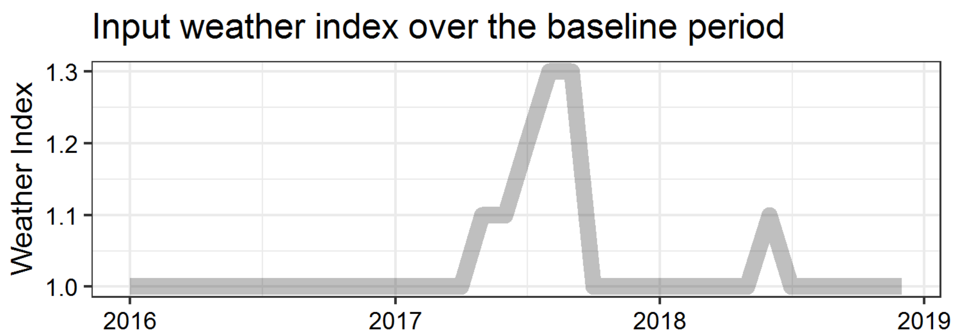

Figure A.3 – Monthly weather index from 2016 to 2019. In this example, each use is affected by the same weather. In reality, weather generally varies somewhat from place to place, and the weather indices will be calculated for each use separately. But what exactly is the weather index? It has not yet been specified for each kind of use. Several candidate weather indices will be assessed, and the weather index which provides the highest correlation over the baseline period will be used. For this example, assume the weather index is a measure of how dry it is. It is clear from the plot that it was driest in the summer of 2017, corresponding to the peak water demands in Figure A.1.

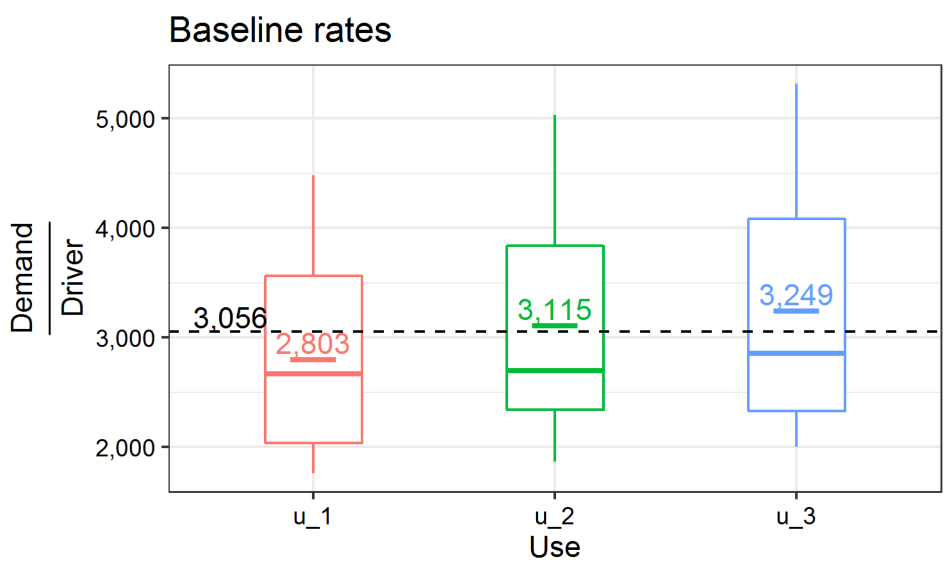

Figure A.4 – Average baseline rate of water demand for each use. The boxplots illustrate the distribution of monthly rate of water demand (demand divided by driver) for each use. Each box spans the interquartile range (25th to 75th percentiles). The 'whiskers' span the highest and lowest values within 1.5 * the interquartile range. In this example, there are no outliers beyond the whiskers. The thick lines crossing the boxes represent the median (50th percentile) values, and the shorter, labelled, thick lines within the boxes represent the mean average rate of demand for each use ($Rate_u$). The dashed, labelled line crossing the entire plot represents the average rate of demand for this kind of use ($Rate_k$).

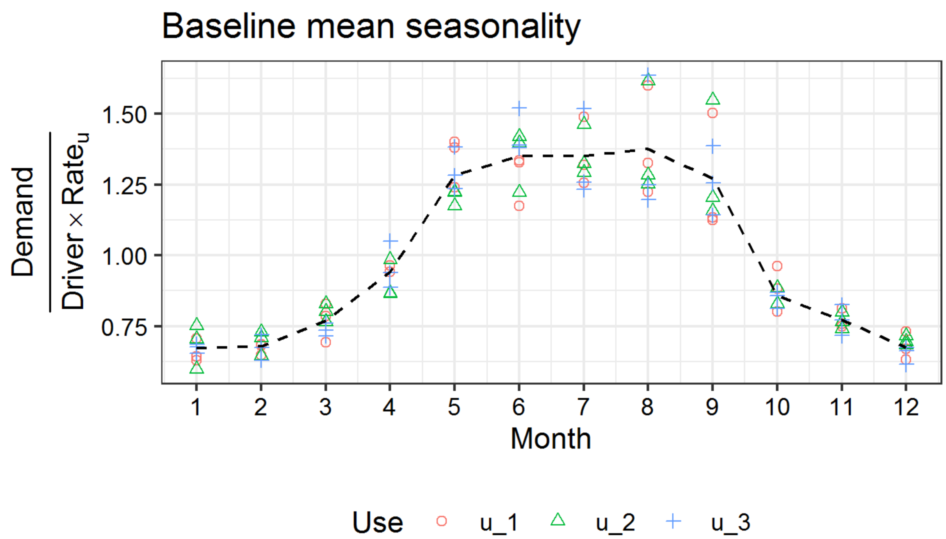

Figure A.5 – Average seasonal factor for each month of the year. Seasonality is calculated for each kind of use as the average effect of each month on all of the uses of that kind. In this example, the points are more tightly clustered during the fall and winter and more dispersed during the summer. That can be attributed to the weather index, which tended to be greater during the summer months (see Figure A.3).

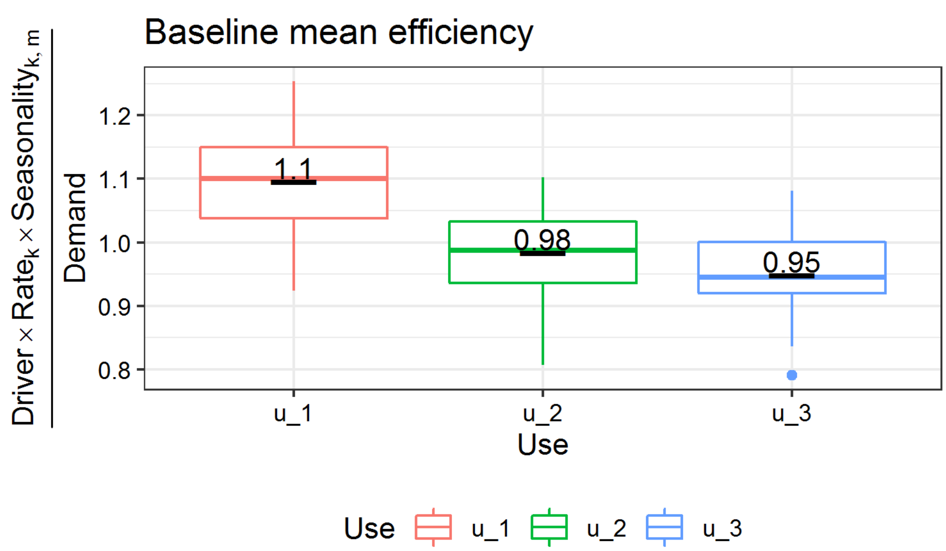

Figure A.6 – Average efficiency of each use. In this context, efficiency is evaluated relative to the average rate for each kind of use. While it might be informative to identify outliers, it should not be interpreted as a value judgement implying that some uses are wasteful. The boxplots here are constructed in the same way as in Figure A.4, and in this case there is a low outlier for u_3. Generally in this study, outliers are not removed from the analysis.

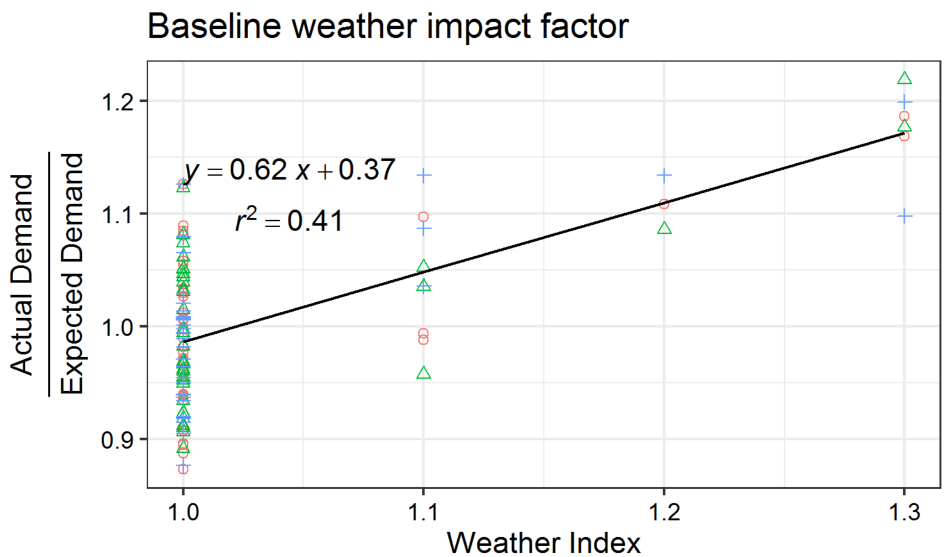

Figure A.7 – Estimated weather impact factor. The weather impact factor is estimated here using linear regression, although non-linear regression may be applied if non-linear effects are apparent. When the projections are developed, the weather indices will be derived from actual data. A weather index might be a measure of soil moisture, cumulative precipitation, potential evapotranspiration, growing degree days, cooling degree days, or some combination of such measures. The weather factor is a transformation of the selected weather index to represent the quantitative impact on water demand. The weather index and the model for calculating the weather factor (linear or non-linear) for each kind of use will be selected based on the ability to explain variation from expected water demand under normal weather conditions. In this example, a small amount of random noise in each variable has compounded to yield a relatively low r-squared value of 0.41 for the linear model and the example weather index.

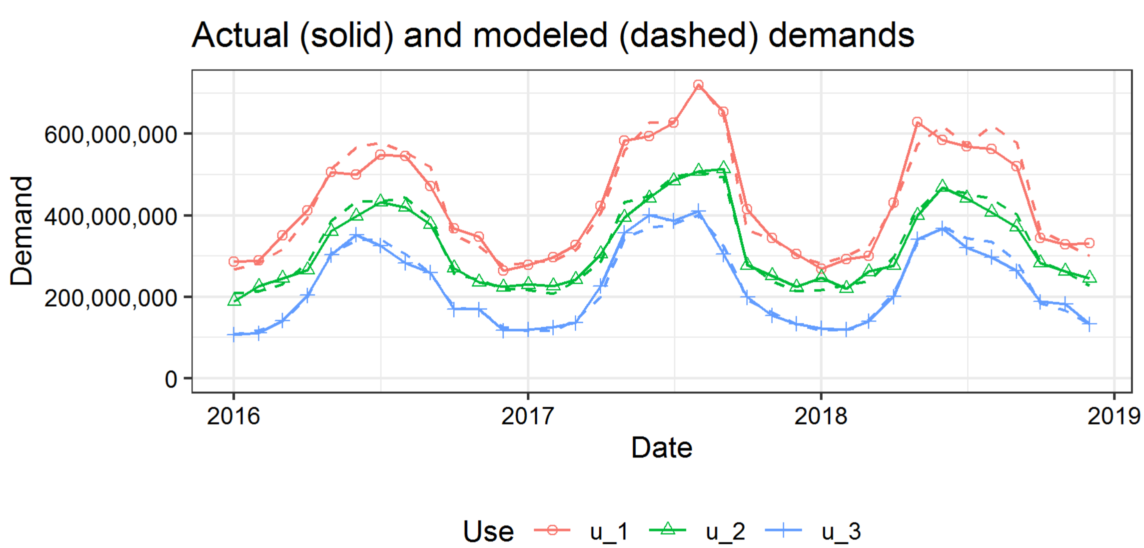

Figure A.8 – Actual and modeled water demand for three example uses. This plot allows comparison of the results of the water demand model to the example data. It looks pretty good, especially the highest and lowest points. Hopefully, similar results will be achieved when the methods are applied across SC.

Appendix B: Projections of Driver Variables

Table B1. Projected Electricity Demand for the Major Utilities in South Carolina

Year	Dominion			Duke Energy Carolinas			Duke Energy Progress			Santee Cooper		
	Average	Summer	Winter	Average	Summer	Winter	Average	Summer	Winter	Average	Summer	Winter
2020	2,664	5,073	4,827	11,113	19,109	19,033	7,479	13,264	13,446	2,561	4,236	4,652
2021	2,690	5,198	4,875	11,223	19,267	19,230	7,516	13,334	13,489	2,573	4,274	4,681
2022	2,739	5,308	4,920	11,292	19,368	19,409	7,572	13,451	13,596	2,592	4,314	4,728
2023	2,788	5,410	4,966	11,410	19,531	19,639	7,579	13,504	13,620	2,617	4,359	4,779
2024	2,835	5,489	5,008	11,534	19,690	19,908	7,682	13,662	13,788	2,648	4,403	4,835
2025	2,881	5,552	5,046	11,639	19,860	20,088	7,762	13,810	13,897	2,668	4,452	4,879
2026	2,927	5,612	5,083	11,747	20,060	20,324	7,847	13,977	14,041	2,693	4,499	4,928
2027	2,974	5,666	5,120	11,849	20,250	20,548	7,932	14,144	14,186	2,717	4,546	4,977
2028	3,024	5,716	5,156	11,946	20,416	20,800	8,025	14,311	14,352	2,747	4,594	5,033
2029	3,039	5,770	5,195	12,017	20,561	21,006	8,098	14,471	14,480	2,769	4,647	5,083
2030	3,053	5,822	5,233	12,078	20,685	21,199	8,168	14,617	14,613	2,790	4,691	5,127
2031	3,093	5,873	5,274	12,141	20,834	21,388	8,241	14,775	14,756	2,814	4,740	5,174
2032	*3,108*	*5,926*	*5,312*	12,208	20,970	21,616	8,318	14,928	14,912	*2,836*	*4,789*	*5,221*
2033	*3,130*	*5,978*	*5,352*	*12,273*	*21,107*	*21,806*	*8,389*	*15,082*	*15,041*	*2,858*	*4,837*	*5,268*
2034	*3,152*	*6,031*	*5,391*	*12,337*	*21,246*	*22,007*	*8,462*	*15,236*	*15,181*	*2,881*	*4,885*	*5,314*
2035	*3,174*	*6,083*	*5,430*	*12,402*	*21,384*	*22,209*	*8,535*	*15,389*	*15,321*	*2,903*	*4,933*	*5,361*
2036	*3,196*	*6,135*	*5,469*	*12,467*	*21,522*	*22,410*	*8,608*	*15,543*	*15,460*	*2,925*	*4,981*	*5,408*
2037	*3,218*	*6,187*	*5,508*	*12,532*	*21,660*	*22,612*	*8,681*	*15,697*	*15,600*	*2,948*	*5,030*	*5,454*
2038	*3,241*	*6,240*	*5,548*	*12,597*	*21,798*	*22,813*	*8,753*	*15,851*	*15,739*	*2,970*	*5,078*	*5,501*
2039	*3,263*	*6,292*	*5,587*	*12,662*	*21,936*	*23,014*	*8,826*	*16,005*	*15,879*	*2,992*	*5,126*	*5,548*
2040	*3,285*	*6,344*	*5,626*	*12,727*	*22,074*	*23,216*	*8,899*	*16,158*	*16,019*	*3,014*	*5,174*	*5,595*
2041	*3,307*	*6,397*	*5,665*	*12,792*	*22,212*	*23,417*	*8,972*	*16,312*	*16,158*	*3,037*	*5,222*	*5,641*
2042	*3,329*	*6,449*	*5,704*	*12,857*	*22,350*	*23,619*	*9,045*	*16,466*	*16,298*	*3,059*	*5,271*	*5,688*
2043	*3,352*	*6,501*	*5,744*	*12,921*	*22,488*	*23,820*	*9,118*	*16,620*	*16,437*	*3,081*	*5,319*	*5,735*
2044	*3,374*	*6,554*	*5,783*	*12,986*	*22,627*	*24,021*	*9,191*	*16,774*	*16,577*	*3,104*	*5,367*	*5,781*
2045	*3,396*	*6,606*	*5,822*	*13,051*	*22,765*	*24,223*	*9,264*	*16,927*	*16,717*	*3,126*	*5,415*	*5,828*
2046	*3,418*	*6,658*	*5,861*	*13,116*	*22,903*	*24,424*	*9,337*	*17,081*	*16,856*	*3,148*	*5,463*	*5,875*
2047	*3,440*	*6,710*	*5,900*	*13,181*	*23,041*	*24,626*	*9,410*	*17,235*	*16,996*	*3,171*	*5,512*	*5,921*
2048	*3,463*	*6,763*	*5,940*	*13,246*	*23,179*	*24,827*	*9,483*	*17,389*	*17,135*	*3,193*	*5,560*	*5,968*
2049	*3,485*	*6,815*	*5,979*	*13,311*	*23,317*	*25,028*	*9,556*	*17,543*	*17,275*	*3,215*	*5,608*	*6,015*
2050	*3,507*	*6,867*	*6,018*	*13,376*	*23,455*	*25,230*	*9,629*	*17,696*	*17,415*	*3,238*	*5,656*	*6,062*
2051	*3,529*	*6,920*	*6,057*	*13,441*	*23,593*	*25,431*	*9,702*	*17,850*	*17,554*	*3,260*	*5,704*	*6,108*
2052	*3,551*	*6,972*	*6,097*	*13,506*	*23,731*	*25,633*	*9,775*	*18,004*	*17,694*	*3,282*	*5,753*	*6,155*
2053	*3,574*	*7,024*	*6,136*	*13,570*	*23,870*	*25,834*	*9,848*	*18,158*	*17,833*	*3,305*	*5,801*	*6,202*
2054	*3,596*	*7,077*	*6,175*	*13,635*	*24,008*	*26,035*	*9,921*	*18,312*	*17,973*	*3,327*	*5,849*	*6,248*
2055	*3,618*	*7,129*	*6,214*	*13,700*	*24,146*	*26,237*	*9,994*	*18,465*	*18,113*	*3,349*	*5,897*	*6,295*
2056	*3,640*	*7,181*	*6,253*	*13,765*	*24,284*	*26,438*	*10,067*	*18,619*	*18,252*	*3,372*	*5,945*	*6,342*
2057	*3,662*	*7,233*	*6,293*	*13,830*	*24,422*	*26,640*	*10,139*	*18,773*	*18,392*	*3,394*	*5,994*	*6,388*
2058	*3,685*	*7,286*	*6,332*	*13,895*	*24,560*	*26,841*	*10,212*	*18,927*	*18,531*	*3,416*	*6,042*	*6,435*
2059	*3,707*	*7,338*	*6,371*	*13,960*	*24,698*	*27,042*	*10,285*	*19,081*	*18,671*	*3,439*	*6,090*	*6,482*
2060	*3,729*	*7,390*	*6,410*	*14,025*	*24,836*	*27,244*	*10,358*	*19,234*	*18,811*	*3,461*	*6,138*	*6,529*
2061	*3,751*	*7,443*	*6,449*	*14,090*	*24,974*	*27,445*	*10,431*	*19,388*	*18,950*	*3,483*	*6,186*	*6,575*
2062	*3,773*	*7,495*	*6,489*	*14,155*	*25,112*	*27,647*	*10,504*	*19,542*	*19,090*	*3,505*	*6,235*	*6,622*
2063	*3,795*	*7,547*	*6,528*	*14,219*	*25,251*	*27,848*	*10,577*	*19,696*	*19,229*	*3,528*	*6,283*	*6,669*
2064	*3,818*	*7,600*	*6,567*	*14,284*	*25,389*	*28,049*	*10,650*	*19,850*	*19,369*	*3,550*	*6,331*	*6,715*
2065	*3,840*	*7,652*	*6,606*	*14,349*	*25,527*	*28,251*	*10,723*	*20,003*	*19,509*	*3,572*	*6,379*	*6,762*
2066	*3,862*	*7,704*	*6,645*	*14,414*	*25,665*	*28,452*	*10,796*	*20,157*	*19,648*	*3,595*	*6,427*	*6,809*
2067	*3,884*	*7,756*	*6,685*	*14,479*	*25,803*	*28,654*	*10,869*	*20,311*	*19,788*	*3,617*	*6,476*	*6,855*
2068	*3,906*	*7,809*	*6,724*	*14,544*	*25,941*	*28,855*	*10,942*	*20,465*	*19,927*	*3,639*	*6,524*	*6,902*
2069	*3,929*	*7,861*	*6,763*	*14,609*	*26,079*	*29,056*	*11,015*	*20,619*	*20,067*	*3,662*	*6,572*	*6,949*
2070	*3,951*	*7,913*	*6,802*	*14,674*	*26,217*	*29,258*	*11,088*	*20,772*	*20,207*	*3,684*	*6,620*	*6,996*

Values from the extended datasets are formatted in italics. Other values are from IRP reports.

Table B2. Population Projections from SCORFA

County	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Abbeville	24.7	24.6	24.4	24.3	24.1	23.9	23.8	23.6	23.4	23.2	23.0	22.8	22.6	22.4	22.1	21.9	21.7	21.4	21.2	20.9	20.6
Aiken	166.9	168.2	169.6	171.0	172.2	173.5	174.7	175.9	177.2	178.2	179.2	180.3	181.3	182.3	183.1	183.9	184.7	185.5	186.3	186.9	187.5
Allendale	9.5	9.4	9.2	9.0	8.9	8.7	8.5	8.4	8.2	8.1	7.9	7.7	7.5	7.4	7.2	7.0	6.8	6.6	6.5	6.3	6.1
Anderson	192.8	193.9	195.0	196.1	197.0	198.0	198.9	199.9	200.8	201.6	202.3	203.1	203.8	204.6	205.1	205.6	206.2	206.7	207.3	207.6	208.0
Bamberg	15.2	15.0	14.9	14.8	14.6	14.4	14.3	14.1	13.9	13.8	13.6	13.5	13.3	13.1	13.0	12.8	12.6	12.4	12.2	12.0	11.8
Barnwell	21.9	21.7	21.6	21.5	21.3	21.2	21.0	20.9	20.8	20.6	20.4	20.3	20.1	20.0	19.8	19.6	19.4	19.3	19.1	18.9	18.7
Beaufort	178.0	181.1	184.2	187.3	190.4	193.4	196.5	199.5	202.6	205.5	208.3	211.2	214.1	217.0	219.7	222.3	225.0	227.6	230.3	232.6	235.0
Berkeley	203.6	208.4	213.2	218.0	223.0	228.0	233.1	238.1	243.2	248.4	253.7	259.0	264.3	269.6	275.1	280.6	286.1	291.6	297.1	302.7	308.4
Calhoun	15.0	14.9	14.9	14.9	14.8	14.8	14.7	14.6	14.6	14.5	14.4	14.3	14.2	14.1	14.0	13.9	13.8	13.6	13.5	13.4	13.2
Charleston	385.1	391.2	397.4	403.5	409.4	415.2	421.1	427.0	432.9	438.3	443.8	449.2	454.7	460.1	465.2	470.2	475.3	480.3	485.4	490.1	494.9
Cherokee	56.2	56.3	56.5	56.7	56.8	56.9	57.0	57.1	57.2	57.2	57.2	57.3	57.3	57.4	57.3	57.3	57.3	57.3	57.3	57.2	57.1
Chester	32.2	32.0	31.8	31.6	31.3	31.1	30.9	30.6	30.4	30.1	29.9	29.6	29.3	29.0	28.7	28.4	28.1	27.8	27.5	27.2	26.9
Chesterfield	46.1	46.0	45.9	45.9	45.7	45.6	45.5	45.4	45.2	45.0	44.8	44.6	44.4	44.2	43.9	43.7	43.4	43.1	42.8	42.5	42.2
Clarendon	34.1	34.0	33.9	33.8	33.6	33.4	33.3	33.1	32.9	32.7	32.4	32.2	32.0	31.7	31.4	31.1	30.8	30.5	30.2	29.9	29.6
Colleton	37.3	37.0	36.8	36.5	36.2	35.9	35.6	35.3	35.0	34.7	34.3	34.0	33.6	33.3	32.9	32.5	32.1	31.7	31.3	30.9	30.5
Darlington	67.5	67.3	67.1	66.9	66.6	66.3	66.0	65.7	65.4	65.0	64.7	64.3	63.9	63.5	63.1	62.6	62.1	61.7	61.2	60.7	60.2
Dillon	31.1	31.0	30.9	30.8	30.7	30.6	30.5	30.4	30.4	30.2	30.1	29.9	29.8	29.7	29.5	29.3	29.2	29.0	28.9	28.7	28.5
Dorchester	151.5	154.6	157.6	160.7	164.0	167.3	170.6	173.9	177.2	180.7	184.1	187.6	191.0	194.5	198.1	201.7	205.2	208.8	212.4	216.1	219.8
Edgefield	26.3	26.2	26.1	26.0	25.9	25.7	25.6	25.5	25.4	25.2	25.0	24.9	24.7	24.5	24.3	24.1	23.9	23.6	23.4	23.1	22.9
Fairfield	22.7	22.5	22.3	22.1	21.9	21.6	21.4	21.2	21.0	20.7	20.4	20.1	19.9	19.6	19.3	19.0	18.7	18.4	18.1	17.7	17.4
Florence	139.5	140.0	140.6	141.2	141.6	142.1	142.5	142.9	143.4	143.6	143.9	144.2	144.5	144.8	145.0	145.1	145.3	145.5	145.7	145.7	145.8
Georgetown	60.2	60.1	60.0	59.9	59.8	59.6	59.4	59.2	59.0	58.6	58.3	57.9	57.6	57.2	56.7	56.2	55.7	55.2	54.7	54.1	53.5
Greenville	488.5	495.6	502.7	509.8	517.1	524.4	531.7	538.9	546.2	553.5	560.8	568.0	575.3	582.6	589.8	596.9	604.1	611.2	618.4	625.4	632.4
Greenwood	70.0	70.1	70.2	70.4	70.4	70.5	70.6	70.6	70.7	70.7	70.7	70.7	70.7	70.7	70.6	70.5	70.5	70.4	70.3	70.2	70.1
Hampton	20.1	19.9	19.8	19.6	19.4	19.3	19.1	18.9	18.7	18.5	18.3	18.1	17.9	17.7	17.5	17.3	17.1	16.8	16.6	16.4	16.1
Horry	301.9	308.1	314.2	320.3	326.7	333.1	339.5	345.9	352.3	358.7	365.1	371.5	378.0	384.4	390.6	396.8	403.0	409.2	415.4	421.2	427.1
Jasper	27.9	28.6	29.2	29.9	30.6	31.4	32.1	32.8	33.6	34.3	35.1	35.9	36.7	37.4	38.3	39.1	39.9	40.7	41.5	42.3	43.1
Kershaw	63.3	63.6	64.0	64.4	64.7	65.0	65.4	65.7	66.0	66.3	66.6	66.8	67.1	67.3	67.5	67.7	67.9	68.0	68.2	68.3	68.5
Lancaster	83.8	85.4	87.1	88.8	90.6	92.4	94.2	96.0	97.8	99.7	101.5	103.4	105.3	107.1	108.9	110.8	112.6	114.4	116.2	118.0	119.7
Laurens	65.7	65.5	65.3	65.0	64.7	64.4	64.1	63.8	63.4	63.1	62.7	62.3	62.0	61.6	61.1	60.7	60.3	59.8	59.4	58.9	58.4
Lee	17.9	17.6	17.4	17.1	16.9	16.6	16.4	16.1	15.9	15.6	15.4	15.1	14.9	14.6	14.3	14.1	13.8	13.5	13.2	12.9	12.6
Lexington	282.0	286.2	290.3	294.4	298.6	302.8	306.9	311.1	315.2	319.3	323.3	327.3	331.4	335.4	339.3	343.1	347.0	350.9	354.7	358.4	362.1
Marion	31.4	31.0	30.7	30.3	30.0	29.6	29.2	28.9	28.5	28.1	27.7	27.3	26.9	26.5	26.1	25.6	25.2	24.8	24.4	23.9	23.5
Marlboro	27.6	27.3	27.1	26.9	26.6	26.4	26.1	25.9	25.6	25.4	25.1	24.8	24.5	24.2	23.9	23.6	23.3	23.0	22.7	22.4	22.1
McCormick	9.9	9.9	9.9	9.8	9.7	9.5	9.3	9.1	9.0	9.1	9.1	9.2	9.3	9.4	8.8	8.2	7.6	7.0	6.4	7.3	8.3
Newberry	37.6	37.7	37.8	37.8	37.8	37.9	37.9	37.9	37.9	37.9	37.9	37.9	37.8	37.8	37.7	37.7	37.6	37.5	37.4	37.3	37.2
Oconee	75.7	76.0	76.3	76.6	76.9	77.1	77.3	77.5	77.7	77.8	77.9	78.0	78.1	78.2	78.2	78.2	78.2	78.2	78.2	78.1	78.0
Orangeburg	90.1	89.6	89.2	88.7	88.1	87.5	86.9	86.3	85.7	85.0	84.3	83.6	82.9	82.3	81.5	80.7	80.0	79.2	78.5	77.6	76.8
Pickens	120.7	121.1	121.5	121.9	122.0	122.0	122.1	122.1	122.2	122.3	122.5	122.6	122.7	122.9	122.6	122.3	122.1	121.8	121.5	121.4	121.3
Richland	410.1	415.6	421.0	426.4	431.7	436.9	442.1	447.4	452.6	457.8	463.1	468.3	473.5	478.7	483.8	488.9	494.0	499.1	504.2	509.2	514.1
Saluda	20.3	20.4	20.5	20.6	20.7	20.8	20.9	21.0	21.0	21.1	21.1	21.2	21.2	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3
Spartanburg	295.2	297.3	299.5	301.6	303.5	305.5	307.5	309.4	311.4	313.1	314.8	316.5	318.2	320.0	321.4	322.8	324.3	325.7	327.2	328.4	329.6
Sumter	108.7	109.0	109.3	109.5	109.7	109.8	109.9	110.1	110.2	110.2	110.2	110.2	110.2	110.2	110.1	109.9	109.8	109.7	109.6	109.4	109.2
Union	27.6	27.3	27.1	26.8	26.6	26.3	26.1	25.8	25.6	25.3	25.0	24.7	24.4	24.1	23.8	23.5	23.2	22.9	22.6	22.3	22.0
Williamsburg	32.3	31.9	31.5	31.1	30.7	30.3	29.8	29.4	29.0	28.6	28.2	27.7	27.3	26.8	26.4	25.9	25.5	25.0	24.6	24.1	23.7
York	248.2	252.6	257.0	261.4	265.9	270.4	274.9	279.4	284.0	288.5	293.0	297.6	302.1	306.7	311.2	315.7	320.2	324.7	329.2	333.7	338.2

Table B3. Projected Growth Rates for Manufacturing Sectors in South Carolina

Projected Annual Growth Rate 2017-2050	
Paper Products	0.7%
Wood Products	1.7%
Chemical Manufacturing	1.7%
Bulk Chemicals	1.6%
Inorganic	-0.1%
Organic	2.1%
Resin	1.6%
Plastics and Rubber Products	2.5%
Other Chemical Products	1.7%
Other Petroleum and Coal Products	-0.8%
Textile Mills and Products	-2.2%
Primary Metals Industry	1.0%
Iron and Steel Mills and Products	0.4%
Alumina and Aluminum Products	1.2%
Other Primary Metal Products	1.5%
Fabricated Metal Products	2.3%
Machinery	2.3%
Cement and Lime	1.9%
Food Products	1.7%
Miscellaneous Manufacturing	2.8%

Source: U.S. Energy Information Administration
https://www.eia.gov/outlooks/aeo/data/browser/#
Accessed Aug 7, 2018

Appendix C: Public Comments on the First Draft

The public comment period for the draft report of the South Carolina water demand projection methodologies was held from May 20, 2019 to June 19, 2019. Excluding ordinary grammar, wording, and formatting suggestions, 95 comments were received from nine stakeholders including members of the water demand TAC. Where the comments include quoted excerpts of the first draft report, those excerpts are written in single quotes and italic. **Author responses are formatted in bold red text**.

General Comments

1. "I was curious how you assume ongoing water supply at boundaries with neighboring states. I suppose the SC-NC-Duke settlement governs the Catawba/Wateree, but I don't know of any particular agreement along the Savannah, Broad, Saluda, or Pee Dee/Lynches/Waccamaw. I don't know that there's a 'right' way to do this without some sort of formal agreement between the states, but was just curious how you'd handled it in the model (both regarding stream flow and projected water demands)."

The projection methods apply only to water demand in South Carolina. Water use in neighboring states is handled differently in the surface and groundwater models.

2. "The report provides a description of many data sources of potential use in making water demand projections. However, only some of these data sources are proposed to be used in the methodology. We recommend that the report explain up front that each section will review background information for each major water use type and potential data sources, but that the methodology will identify the most important variables and data sources for use in making the future projections. Also, after describing each data source, the report should also clearly state if that data source is not proposed for use in making water use demand projections."

Descriptions of several data sources which are not proposed for use in the projections have been removed from the report. The recommended explanatory text has been added to the introduction.

3. "There seems to be some conservatism (i.e., over-estimate of demand) built into the 'business-as-usual' scenario. It would be more transparent to make the 'business-as-usual' scenario as accurate as possible without conservative assumptions (i.e., high estimates of demand). Adding safety factors on top of the 'business-as-usual' projection afterwards for planning or permitting purposes is more transparent."

There is some conservatism in the business-as-usual scenario, in that efficiency is not projected to increase, and populations and businesses are not projected to decline. Those assumptions have been described in the introduction for transparency.

4. "High demand estimates should be used cautiously. Combinations of high demand across multiple major categories of water use should consider the joint probability of the scenario. If the estimates include multiple factors that each are unlikely to occur, then the joint probability of the high demand scenario occurring becomes very small. For example, high demand for both

public water supply and manufacturing would include exponential population growth, drought conditions, and withdrawal and consumption rates by manufacturing equal to 90th percentile historic rates multiplied by an increased growth rate (despite historic rates showing a decreasing trend). The probability of both high demand scenarios occurring is likely exceedingly small. Combinations of high demand across multiple major categories of water use should also consider competing uses of water and reduction in some water uses caused by growth in other water uses. For example, if irrigated acreage is assumed to grow beyond areas presently under cultivation, then does it displace other water demand uses?

"High demand estimates should acknowledge the transient nature of some aspects (e.g., drought conditions)."

These points have been added to the description of the high-demand scenario. The high-demand scenario for agricultural irrigation has been adjusted to reflect future constraints from the expansion of urban and suburban development.

5. "The report should state the need for high-demand estimates and the planned use of these estimates. The need and use should define the methodology for the calculation of high-demand estimates. Typically, an assessment of risk is performed considering frequency of occurrence (e.g., building codes are based on 1%-annual-chance flood risk; water quality permit limits may be based on a 7-day average low flow condition with a 10%-annual-chance risk). The high-demand scenarios will be more useful if they are calculated with an associated risk of occurrence."

A quantitative risk assessment of water demand for each water-use permittee across the state is not feasible to undertake with the resources currently available for state water planning. Such an assessment has not been a part of previous water planning efforts in this state, and many other states publish water demand projections without attempting to quantify risk. The high-demand scenario is meant to provide an upper bound of water demand for planning. Risk assessment is more warranted in cases where demand projections and availability assessments indicate water shortages are possible. River Basin Councils may recommend further analysis and risk assessment if possible water shortages are identified during the planning process.

Chapter 1: Introduction

6. Scope: "States that 'Projections are based on explicit assumptions combined into scenarios spanning a 50-year planning horizon, from 2020 to 2070.' We strongly believe projections 50 years into the future will be highly uncertain, and use of those projections can be very misleading. In our opinion, 15 to 20 year projections will be much more defensible and more valuable for planning and/or permitting purposes."

15 and 20 year projections are included in the 50-year planning horizon. The report has been edited to reflect the uncertainty inherent in long term planning. Water planning efforts can relate to permitting decisions with impacts 50 years in the future. Stakeholders have expressed mixed opinions regarding the value of long term projections, with recommended planning horizons ranging from 10 to 100 years. The 50-year planning horizon is consistent with previous state-wide water planning efforts in SC.

7. Scope: "The report lists a number of variables that are not incorporated to the methodology and are considered 'beyond the scope of the study.' Each of these exclusions highlight the uncertainty in the water demand estimate methodology and call into question the value in projecting as far out as 50 years into the future."

Agreed. These variables are described to highlight some sources of uncertainty in long-term projections. Projection results will be published for years 2025, 2030, 2035, 2040, 2050, 2060, and 2070.

8. Source Water: "Including reuse or reclaimed wastewater as a 'source' of water can have conflicting consequences. This may be especially true if rainfall is not considered a source. Is the State going to allow folks to harvest rain and not control those actions? If so, I believe an argument can be made that all reservoirs are just holding basins for rainwater and therefore should not be considered sources of water."

There are legal and regulatory distinctions between reservoirs/lakes/ponds filled with concentrated surface water and smaller bodies of water filled with dispersed run-off (see SC Code of Laws Title 49, Chapter 4: South Carolina Surface Water Withdrawal, Permitting Use, and Reporting Act). Use of water from many run-off ponds is not subject to the same regulations that pertain to withdrawals from groundwater and other surface water bodies. Rainwater harvesting is assumed to be negligible on a statewide basis.

9. Water Withdrawals: "There are records that go back much farther than the 1980s."

Perhaps, but they are not in the digital SCDHEC water use database as provided. State regulations requiring record keeping went in to effect in the 1980's.

10. Water Use: "I believe the assumption here is that if the water wasn't 'reused' that the same volume of the 'reuse' would have been withdrawn, but I'm not sure that is accurate."

This is an important point, and clarification has been added to the text. No such assumption is necessary. All other components being equal, if reuse declines, then use declines. A decline in use could reflect a shortage, or a decline in water demand.

11. Return Flows: "Shouldn't the equation be Discharge=Return Flow+inflow+infiltration?"

Yes, that could be interpreted as equivalent. However, "Inflow", "Infiltration", and "Inflow & Infiltration" can have distinct meanings in different contexts within water resource management. Text has been added for clarification.

12. Return Flows: Groundwater "Is this stating that there will be no groundwater recharge accounted for?"

The water-demand projections will not calculate groundwater recharge from return flows. In this study, Aquifer Storage and Recovery is considered as a form of off-stream storage, not return flow. Groundwater recharge from deep infiltration/percolation is a component of the natural (albeit human impacted) water cycle, and is not considered in this study as an off-stream water use or return flow. The groundwater availability model for the Coastal Plain does include an infiltration. Seepage from off-stream storage would be included as a "loss" in this study, however quantitative data is not generally available.

13. Drivers of Water Demand Table: “You note that the primary driver for the thermo-electric power category is electricity production. Perhaps I’m splitting hairs, but the primary driver is really cooling for discharge of water from thermo-electric plants. Of course that’s in the service of electricity production, and it’s based on current regulations. It may be worth splitting hairs because it could, perhaps change – for instance, if society decided that consumptive use is more of an issue than heat discharge and/or impingement/entrainment at intakes, or if the state ever wanted to seek some sort of variance for recirculating cooling from the EPA in Washington during a time of severe drought. Other variances have sometimes been granted as particular local needs require, although I don’t think we’ve ever requested one (at least not since I’ve been here).”

Projections must be available for each driver variable, and power utilities provide electricity demand projections in their Integrated Resource Plans. There are quantified correlations between electricity production and cooling water volume for the generator configurations in SC. If the proposed model accurately estimates water demand for each kind of generation system, then a planned or projected switch from one kind to another could be modelled using the methods in the report. Water management strategies that have not been implemented over the baseline period cannot be modeled using the methods described in this report. If a water user or River Basin Council proposes such strategies, the effects can be estimated using other reference material or methods.

14. Drivers of Water Demand Table: “On (Drivers of Water Demand) the report lists ‘irrigated acres’ as the driver for agriculture and golf course. What are the explanatory variables for irrigated acres?”

Probably, some function of the expected value per unit of harvest, the life-cycle costs of irrigation, and the expected increase in yield under irrigation. However, it is not currently feasible for SCDNR to develop projections of those variables, and it is unclear that such a detailed model would improve the accuracy of the water demand projections. Projections of irrigated acreage in the Southeast have been obtained from other sources now cited in the report.

15. Baseline Time Range: “As you noted, I asked about the default baseline period. I can see pluses and minuses to the dates you selected: they’re pretty representative as far as demand goes in our industry (coming after a number of plants were shut down and post-recession), but I wasn’t sure if this was also used for baseline water SUPPLY. i.e., given all the rain (Joaquim ’15, Matthew ’16, Florence ’18), I don’t know how representative these are for at least the Santee and lower Pee-Dee/Waccamaw watersheds. One way or the other, it might be worth beefing this section up a little to describe your rationale.”

The baseline time range as described in this document is specifically for water demand projections. The text has been edited for clarity. The surface and groundwater availability models have been calibrated using methods specific to those studies.

16. Baseline Time Range: “Is this different than the time-period in the PPAC draft framework document?”

Regarding water demand projections, the PPAC draft framework should be consistent with this document. This document and the PPAC framework have been through several drafts and revisions, and there have been inconsistencies within and between the draft documents. This document (including any revisions or addenda) is the authoritative reference for water

demand projection methods for water planning in SC at this time. Efforts will be made to ensure consistency between the Planning Framework and this report.

17. Kinds of Water Use: “It would probably be more correct to say that ‘a thermo-electric utility may have a number of different facilities with different energy sources, intakes, and cooling systems and evolving unit dispatch based on a number of constraints, including price of fuel, environmental constraints, dispatch availability, the nature of the utility service areas’ demands, etc.’ “

The text has been edited for clarity. Energy sources and cooling systems are factors which are expected to distinguish distinct kinds of thermo-electric water demand (with different average rates of water demand). Among many variables which could have some impact on water demand, only the most significant will be explicitly accounted for as distinct kinds water demand.

18. Kinds of Water Use: “It would probably be more correct to say that ‘…an irrigator may provide water at different rates depending on particular crops under cultivation at a given time, differing soil types in a particular location, and crop water needs which vary with weather.’ “

The text has been edited for clarity. Crop and soil type will likely be accounted for in distinguishing different kinds of agricultural irrigation water demand. Weather is a distinct factor in the general water demand model used in these methods.

19. Weather and Climate: “Discusses the Global Historical Climate Network. It would be helpful to include a plot of the station coverage in SC used to develop the meteorological dataset.”

Discussion of the Global Historical Climate Network has been removed from the text.

20. Weather and Climate: “If insolation is going to be included, what about surface winds, which can have a major impact on evaporative cooling and transpiration and that information is readily available.”

The Gridmet dataset includes estimates of insolation and surface winds in the calculation of evapotranspiration.

21. Weather and Climate: Calculating Weather Indices “How are the indices calculated? Are talking about maximum daily temperatures, rainfall, cooling degree days. We used to incorporate variables like these in models via a simple logarithmic regression model. To estimate we would using a logarithmic regression model to get an elasticity. Then we could model different climate scenarios (e.g., hotter, cooler, drier, wetter).”

The specific index will vary by the kind of water use. Indices will be selected based on statistical significance and correlation. This comment constitutes some evidence of stakeholder support for simple regression on log-transformed indices as a statistical method. As such, simple regression on log-transformed indices will be evaluated as the projection methods are applied in each basin.

22. Projection Scenarios: “This is supposed to be ‘worst case’ scenario for highest water use, but the only years considered will be 2013-2017, which weren’t especially dry. This will result in under-estimating the irrigation increases during more severe drought.”

While there have been longer term droughts prior to this time period, there were short term droughts during this time period. Water use often declines in severe long-term droughts as stakeholders increase efforts to conserve water. The PPAC has recommended consideration of short term droughts because they may have a greater impact on water demand. If relevant, reliable data is available, a longer baseline period may be used in some cases.

23. Projection Scenarios: “Please clarify what driver values will be considered. As written, this statement is too vague to evaluate the choice of drivers. The drivers are a significant issue and should be available for review... the choice of drivers is very significant to understanding the value of scenarios for water resources management.”

The text has been edited for clarity. The driver data are included in the appendix.

24. Projection Scenarios: “This says ‘can be explored’. Will other scenarios be explored and how will those scenarios be used.”

The goal is for baseline water demand models to be made available for stakeholders to develop their own scenarios. Model inputs and outputs will be available for download as spreadsheet documents (.csv or .xlsx format). Possibly, an interactive web-based tool will also be provided so that interested stakeholders can explore different alternative scenarios. If a River Basin Council expresses support for an alternative scenario, SCDNR will consider publishing additional model outputs. Revisions and addenda to this report will be published as necessary.

25. Projection Scenarios: “I still think it would be better to rename this scenario as ‘Normal’ or ‘Normal Conditions’ vs. ‘business-as-usual’. In previous documents, I recommended this be renamed since the “business as usual” seems too informal.”

“Normal Conditions” may imply static and unchanging conditions. “Business-as-usual” is meant to represent a continuation of current trends, without further investments in water use efficiency beyond current and confirmed plans.

Chapter 2: Thermo-electric Power

26. Cooling Systems: “We’re not members of EPRI so I can’t really comment on the work they did. But I would note that the date of the report is old in terms of our changing industry (dated 2002). The recession of 2008 killed demand growth since then, followed by increasing regulation and renewables which shuttered older, smaller plants which tended to be mostly once-through. I’d suggest you call EPRI and see if they’ve looked at this more recently and have updated numbers. Or, you could ask all the utilities in SC to provide their recent average consumption (gal/kwh).”

The text has been edited to reflect this comment, and the reference to the EPRI study has been removed. Utilities will be contacted as the methods are applied in each basin.

27. Cooling Systems: “In the first paragraph there’s a sentence indicating that once-through cooling is the predominant practice, siting a pair of studies by Maupin et al and Dieter et al. You’d need to reach out to Duke and Dominion/SCANA/SCE&G to be sure, but that sentence seems incorrect to me. Perhaps we’re the only ones, but our remaining steam-electric plants are all closed-cycle. And any new plants that could be built in the future will certainly be closed cycle. I may be wrong, but my sense is that this is typical in South Carolina – our state grew later than most other states, so the plants that were built to provide power tended to have closed-cycle or nearly-closed cycle as far back as the 1970s. In addition, as they tended to be built in rural areas, there was often sufficient land on plant sites to accommodate closed cycle later. Finally, for many sites that remain, the 316(b) rule will necessitate intake changes in the near future (one or two permit cycles in the future). I think given the small number of power providers in SC, you can get a better estimate by reaching out and asking for different utilities’ expectations.”

Utilities will be contacted as the methods are applied in each basin.

28. Cooling Systems - Dry Cooling Systems: “I can’t think of any air cooled systems in the SE. It’s just too humid.”

The text has been edited accordingly.

29. Cooling Systems: “Discharged as a consumptive use or discharged as returned to the water body?”

Discharge refers to return flows plus Inflow & Infiltration, as defined in the introduction.

30. Peak and Base Load Generation: “It is not clear what point this section is trying to make. There is no discussion of base load generation and no reference to the water demand on peaker generators. Is the point that the natural gas peaker generators create a high water demand during these occasions?”

Yes, peaker plant output varies with short term fluctuations in demand. The text has been added to clarify.

31. Carbon Capture: “What you’ve got is essentially a place holder, properly noting that the impact of unknown, potential future greenhouse gas regulations can’t really be considered. Even so, I think the paragraph is a little too bullish on carbon capture technology as a path forward. You might tamp that down somewhat. You note that consumption is projected to increase by 14-26% due to cooling towers and carbon capture systems. If you’re able to dig into those numbers a little more, I’d expect that recirculating cooling is responsible for most of that increase. If it’s not, you might consider altering the number to make it so.”

This section has been removed from the report.

32. Carbon Capture: “May want to add a sentence to what carbon capture is and why it is creates a water demand.”

This section has been removed from the report.

33. Energy Information: “Is the assumption going to be that all thermo-electric, including nuclear, will be maintained and have their FERC licenses renewed at the current capacity.”

The general assumption is that all plants will continue to operate, but the general assumptions will be modified based on any plans or projections provided by the utilities.

34. Energy Information: “While this study may not assume retirements since it is a general study document, each river basin council will need to assess long-term potential retirements.”

The text has been modified to reflect this.

35. Water Consumption Rates: “So which ones will DNR use?”

The text has been edited for clarity. Water consumption rates for each cooling system will be chosen following discussion of the various estimates with representatives from the electricity utilities.

36. Electricity-Demand Projections: “States that ‘*The IRP projections from 2028 onwards are used to fit linear models for each utility and season to extend the projections to year 2070.*’

“What is the rationale for using only 2028 onward for determining the long-term trend? Doesn’t the longer record provide a better estimate since it incorporates some of the variability shown in the IRP projections? It would be good to explain how the projection varies from the actual trend between 2000 and 2020.”

The electricity demand growth rates in the IRP projections show more variability in the short-term, and projected growth is more linear in the long-term. The extension is based on the growth rate projected in the long-term because the projected short-term variability is not representative of the long-term IRP projection period. The electricity demand projections are now included in Appendix B for stakeholder review. Presumably, the electricity utilities compare their projections to actual data when the IRP reports are updated.

37. Electricity-Demand Projections: “Demand Projections – the last paragraph notes consumption rates increase 15% in high -demand scenario. A few thoughts:

a. “I think you mean high ***water*** demand scenario, right? Not high power demand? You’re estimating future water use by applying current water use to the electricity demand forecast?

Correct

b. “What’s the time period for this projection? Should probably spell that out. The IRP projections extend to year 2031 or 2032; they are extended to 2070.

The text has been edited to make this clear.

c. “See my previous comments on carbon capture probably not playing much of a role.

d. “See my previous comments on recirculating cooling – I’d expect it’s already in place, so this national estimate may not be correct for SC. I’d be curious how the Georgia study you reference (Faeth et al 2018) handled this.”

The report has been edited accordingly. High-demand scenarios for thermo-electric water demand will be developed following discussions with each major electricity utility in SC.

38. Electricity-Demand Projections: “It is not clear if these projections include climate change. The National Climate Assessment indicates that temperatures have risen in the SE and they are projected to rise further increasing demand for cooling. See:

https://science2017.globalchange.gov/chapter/6/ ”

Each utility develops their own electricity demand projections. Refer to the IRP reports for more information on the methods used to develop the electricity demand projections. This comment includes a link to a relevant report on climate change which is now cited in the Introduction chapter of this report.

39. Water-Demand Scenarios: “Our state grew later than most other states, so the plants that were built to provide power tended to have closed-cycle or nearly-closed cycle as far back as the 1970s. In addition, as they tended to be built in rural areas, there was often sufficient land on plant sites to accommodate closed cycle later. Finally, for many sites that remain, the 316(b) rule will necessitate intake changes in the near future (one or two permit cycles in the future).”

The water-demand scenarios for thermo-electric demand have been revised. Instead of projecting a shift to additional carbon capture of addition closed-cycle cooling, the business-as-usual projections are based on continuation of the status quo. A high-demand scenario has not been specified for thermo-electric water demand generally. A high-demand scenario for a specific utility or power plant (or a modification to the business-as-usual scenario) will be developed if utility representatives provide feedback indicating that such a scenario merits consideration.

40. Alternative Sources of Electricity: “States that ‘In this study, increases in solar, wind, and hydro- power relative to thermo-electric generation will not be considered in either the business-as-usual or high-demand scenarios.’

“This is not a realistic assumption given recent historic trends and general popular support for alternative energy sources. The projection would be more accurate to include some estimate of growth in alternative energy sources. To assume no increases in alternative energy will bias the estimate towards higher demand for thermo-electric generation use.”

The quoted statement from the report does not indicate that there will be no increases in alternative energy sources. The statement indicates that alternative energy sources are not projected to increase relative to thermo-electric generation. Alternative energy is assumed to grow at the same rate as thermo-electric. If projections of electricity production by generation type are available, then this assumption can be refined. Power companies may adjust their projected electricity supply portfolios as the methods are applied in each basin.

41. Alternative Sources of Electricity: Solar Power Growth “Actually, Concentrated Solar Power uses a good deal of water. Not sure if CSP would work in SC though. More common out in the desert southwest.”

The report has been edited accordingly.

Chapter 3: Public Water Supply

42. Public Water Supply: "These population numbers have historically been based on county multipliers with residential 'connections' being multiplied by the county population per residence."

The report has been edited accordingly.

43. Public Supply Permits Figure: "I don't think this flow chart is correct... I believe you would need to refer to the governing law the State uses which is the *South Carolina State Safe Drinking Water Act* (Section 44-55-10) and below are the definitions as defined by the State:

(3) "Community water systems" means a public water system which serves at least fifteen service connections used by year-round residents or regularly serves at least twenty-five year-round residents. This may include, but is not limited to, subdivisions, municipalities, mobile home parks, and apartments.

(9) "Noncommunity water system" means a public water system which serves at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least sixty days out of the year and does not meet the definition of a community water system.

(10) "Nontransient noncommunity water system" means a public water system that is not a community water system and that regularly serves at least twenty-five of the same persons over six months per year.

(13) "Public water system" means:

(a) any publicly or privately owned waterworks system which provides water, whether bottled, piped, or delivered through some other constructed conveyance for human consumption, including the source of supply whether the source of supply is of surface or subsurface origin;

(b) all structures and appurtenances used for the collection, treatment, storage, or distribution of water delivered to point of meter of consumer or owner connection;

(c) any part or portion of the system, including any water treatment facility, which in any way alters the physical, chemical, radiological, or bacteriological characteristics of the water; however, a public water system does not include a water system serving a single private residence or dwelling. A separately owned system with its source of supply from another waterworks system must be a separate public water system. A connection to a system that delivers water by a constructed conveyance other than a pipe must not be considered a connection if:

(i) the water is used exclusively for purposes other than residential uses consisting of drinking, bathing, and cooking or other similar uses;

(ii) the department determines that alternative water to achieve the equivalent level of public health protection provided by the applicable State Primary Drinking Water Regulations is provided for residential or similar uses for drinking and cooking; or

(iii) the department determines that the water provided for residential or similar uses for drinking, cooking, and bathing is centrally treated or treated at the point of entry by the provider, a pass-through entity, or the user to achieve the equivalent level of protection provided by the applicable State Primary Drinking Water Regulations.

(14) "State water system" means any water system that serves less than fifteen service connections or regularly serves an average of less than twenty-five individuals daily.

(15) "Transient noncommunity water system" means a noncommunity water system that does not regularly serve at least twenty-five of the same persons over six months a year.
It is unclear (to the author) how these regulations differ from the flow chart.

44. Septic Systems: (*recent years*) "Can this be more specific."
"Recent years" refers to (at least) the baseline period, and the text has been edited for clarity.

45. Septic Systems: (*homeowners typically join the sewer system*) "This is not accurate in my experience."
The word 'typically' has been replaced with 'may'.

46. Septic Systems: "Is a septic system being looked at as a return flow or a consumptive use?"
Septic system drain-field exfiltration is assumed to be negligible (and equal to zero) compared with other sources of infiltration to the surface water table. A use with negligible return flow is equivalent to a consumptive use.

47. Population Projections: "States that the '*SC Office of Revenue and Fiscal Affairs (SC-ORFA) has developed population projections for each county based on birth, death, and migration rates*,' and '*the SC-ORFA projections represent the business-as-usual scenario, and the projections are extended to 2070*.' This section also states that '*where SC-ORFA projections are negative, the business-as-usual scenario is extended as a flat line to 2070 (no change in population after 2035)*.'

"Is this assumption of no negative growth for any county consistent with the projection for SC population growth as a whole? That is, if you sum the county projections using this methodology, how does it compare with the state-wide projection? Does this assumption lead to over-estimating SC population growth because no counties are allowed to exhibit negative growth despite historic trends?"
The business-as-usual scenario uses the SCORFA projections without modification through the period that those projections span. The business-as-usual extension of the SCORFA projections uses a flat line for the counties which the SCORFA projects with negative growth. So, over the course of the SCORFA projection period, the projected population in the business-as-usual scenario is equal to the SCORFA projections.

48. High-Demand: "States that '*the high-demand scenario also includes drought impacts on irrigation demand. Drought impacts for each distribution system are estimated using the 90th percentile monthly per capita water demand in each 3-month season over the baseline period*.'

"Is there a basis for this assumption based on historical use during drought conditions?"
The method has been adjusted to use the 90th percentile of the baseline weather impact multiplier. During prolonged and extreme drought, water use often declines as conservation measures are enacted. The high-demand scenario uses the 90th percentile of estimated historical weather impacts on water demand over the baseline period. As the baseline weather impacts are calculated, high-demand weather patterns are expected to reflect incipient

drought conditions. That expectation is based on anecdotal evidence/professional expertise from stakeholders.

Presumably, the weather impact on public supply water demand is specifically an impact on irrigation of lawns, gardens, athletic fields, etc. However, in many cases, public suppliers have not provided data to distinguish between different kinds of water demand in their systems. If available data provides statistically significant evidence in support of distinct weather impacts on different kinds of use (e.g. indoor vs outdoor, or residential vs commercial), then estimates based on the available sample of data may be generalized to other parts of SC.

49. High-Demand: "States that the high-demand scenario assumes exponential growth, and growth rates are further increased by 10%.

"How do the high-demand growth rates compare to the historic growth rates among SC counties? Will these high-demand growth rates exceed those observed in any county in recent history? If so, is this realistic high-demand estimate?"

Yes, the high-demand growth rates exceed the projections developed by SCORFA. The SCORFA projections are based on historical immigration rates. While birth and death rates may be relatively stable in a population, immigration rates are more dynamic. Following conversation with the developer of the SC-ORFA projections, an increase of 10% over the original population projection was determined to be generally consistent with the underlying assumptions of the high-demand scenario.

In some cases, the high-demand growth rates exceed observed growth in recent history, in some cases observed growth is higher. The methods presented here yield a high-demand growth rate of 2.3% for Jasper County and 1.4% for Greenville County. US Census data (2016-2017) indicates a growth rate of 1.03% for Jasper County and 1.62% for Greenville County (https://datausa.io**). As described in the introduction, adjustments to the general methods will be made to suite specific stakeholders in each basin.**

50. High-Demand: Please clarify – how is per capita demand linked to irrigation demand.

The reference to per capita irrigation demand has been removed.

Chapter 4: Manufacturing

51. Where do data centers fit in? They have high cooling needs. (You'll recall the recent dispute on Google groundwater withdrawal).

Data centers are included in Chapter 6.

52. Manufacturing Projections: "States that 'F*or decades, manufacturing withdrawals have declined as water- use efficiency has increased. There is potential for further efficiency measures which could decrease total withdrawals while increasing consumptive use.*' It also states that '*The US Energy Information Administration (USEIA) provides national level projections of macroeconomic indicators out to 2050, including projected growth rates for each subsector of the economy.*' For the business-as-usual scenario, the report states that '*the average baseline withdrawal and consumption volumes for each permitted use are increased by a growth rate from the USEIA. The USEIA projected growth will be adjusted to a minimum of zero.*'

"Why should the methodology adjust the growth rate to a minimum of zero? Isn't the USEIA projection a more accurate estimate than zero? This may bias the water demand estimate towards over-estimation of manufacturing water use."

Yes, the water demand projection methods are biased towards over-estimation because the costs of under-estimating are potentially much greater. If shortages are found during the planning process, then the estimates of supply and demand can be refined.

53. Business-as-usual: "So what are we using? GDP? Will it vary by manufacturing sector?"

GDP, and it varies by sector. The USEIA projections are now included in the appendix. The text has been edited for clarity.

54. High-Demand: "The manufacturing high demand scenario needs further detail and explanation."

Additional explanation for the high-demand scenario is now included in the introduction. Draft examples will be made available for review before the complete draft results are published.

Chapter 5: Agricultural Irrigation

55. "In general, the Agricultural Irrigation section lists a number of potential data sources, but most are not proposed to be used for the "business-as-usual" or "high demand" scenarios. In the descriptions of the data sources, the report should explain whether each source is proposed for use in the study or not."

References to unused data sources have been removed.

56. "In the Manufacturing section, it is stated that '*a trend in US manufacturing is to increase economic output by producing higher quality products which often do not require substantially more water to manufacture.*' Couldn't the same be said for agriculture?

Nowhere in the Agricultural Irrigation section does it mention the efforts irrigators have gone through in order to conserve water. Low pressure systems, variable rate systems, moisture monitors/sensors, etc. Irrigation methods have greatly improved in efficiency in the last two decades and costs, technology, and awareness have been the driving forces.

Irrigated area as the primary driver of irrigation volume does not take [efficiency] into account."

Brown and others (2013, see Works Cited section of Chapter 5 for full citation) document increasing water use efficiency in the manufacturing sector generally in the U.S. That study projected no increases in water use efficiency for irrigation in the Eastern US. In SC, reported industrial water use has declined, while agricultural water use has tended to increase over the baseline period of record. However, the increasing trend for agriculture may have been driven at least in part by increasing compliance with reporting regulations.

No existing studies have been found which quantify increased water use efficiency for agricultural irrigation in SC. Efficiency practices undertaken over the baseline period are projected to continue over the planning horizon. Additional increases in efficiency, while possible and in many cases likely, are not included in the business-as-usual or high-demand scenario for any water use sector. Projected efficiency improvements will be included for individual water use permittees who provide feedback indicating their plans to increase efficiency.

57. Agricultural Irrigation: “This information on the economic context seems to be a bit tangential to the demand scenarios issue.”

That information has been removed from the report.

58. Agricultural Irrigation: I am unsure why farm income outside of the planning horizon needs to be mentioned.

That information has been removed from the report.

59. Agricultural Irrigation: I am unsure why fertigation and applying pesticides through irrigation needs to be mentioned.

These practices were mentioned to illustrate that irrigation water use can depend on factors beyond crop irrigation requirement. That statement is no longer included in the report.

60. Agricultural Irrigation: “The report lists energy prices, commodity prices, subsidies, and crop insurance as ‘external factors’ not considered. Page 18 also explains that irrigation demand varies by crop, soil, weather, irrigation method, crop growth stage, and cultivation practices specific to each irrigator. All of these are explanatory variables for irrigated acres, and the methodology report should identify the most dominant explanatory variables to be included in the study.”

Energy prices, commodity prices, subsidies, and crop insurance are factors external to the scope of these methods. Agricultural subsidies and crop insurance policies are regulated by federal agencies, such resource management decisions are not the focus of state water planning in SC. If River Basin Councils express interest in management strategies in those policy domains, then further investigation may be warranted.

Prices are subject to short-term market volatility and the long-term business cycle. Lacking a precise and reliable commodities pricing model, the methods presented here rely on two scenarios to encapsulate a range of future conditions. The business-as-usual scenario assumes future conditions will generally be like the baseline period (with the exception of driver variables, as documented in the report). The high-demand scenario assumes future conditions will be favorable for increased exploitation of water resources in SC. For the agricultural irrigation sector, that could be interpreted as low energy prices, and high crop prices.

Reliable data on the specific effects of crop, soil, weather impacts, irrigation method, crop growth stage, and cultivation practices on water demand for agricultural irrigation in SC over the baseline period are not known to be available in existing literature. This report has been amended to include an investigation of these effects. That investigation will be further documented and submitted for academic peer-review. If that investigation results in significant effects, then the significant factors will be quantified as possible with available data. It should be noted that in this study, these variables are understood as factors affecting irrigation depth, not irrigated area.

61. Agricultural Irrigation: “In our opinion, linear extrapolation of irrigated acres is overly simplistic and certainly not a reliable driver for estimating irrigation demand decades into the future. Use of irrigated acres alone as a driver should be limited to a short-term projection, where the uncertainty of the model projection is within a small enough range to be useful.”

The report now references a non-linear extrapolation method for irrigated acres (Brown and others, 2013). Use of irrigated acres as a driver for multi-decade projections is common to

other similar studies (see, for example, the Water and Wastewater Forecasting Technical Memorandum developed by CDM Smith for the Savannah-Upper Ogeechee Regional Water Plan).

The simplicity of projection methods can be regarded as a strength when diverse stakeholder groups seek to review and understand the projection methods. Simple methods were advocated by numerous participants during multiple technical advisory committee conference calls.

Greater model complexity (more factors, more model flexibility) can lead to over-fitting models. If rigorous statistical validation tests are not applied, then choosing the "best fit" calibration out of many possible models (or factors within a model) can lead to less reliable estimates when the model is applied outside of the baseline dataset. This is especially true when the baseline calibration dataset is relatively small.

62. Agricultural Irrigation: "The methodology should consider use of an econometric model for agriculture. USDA long-term projections of crop prices could be used to model changes in irrigated acreage and changes in crop distribution. The Florida Department of Agriculture and Consumer Services used this approach for their 25-year demand projection in *Florida Statewide Agricultural Irrigation Demand; Estimated Agricultural Water Demand, 2015–2040.*"

Water resources stakeholders in SC can learn a lot from the water planning efforts in other states, and many documents regarding water resource management in Florida can be considered as exemplary. Unfortunately, an econometric model of agricultural irrigation is not considered to be feasible with the resources currently available to the SCDNR for water planning. This recommendation will be presented to the River Basin Councils for their consideration, and it is possible that an econometric model could be incorporated in future planning efforts.

It should be noted that econometric models (and most scientific models generally) often rely on an assumption of ceteris paribus or "all other things being equal." This assumption may limit the accuracy of precise econometric models if climate change continues to cause increasing impacts to agriculture globally, and Federal policies change over the short and long term. Of course, unforeseen or unquantified future conditions can limit the applicability of any statistical model. If complex models are unlikely to accurately predict the future, then the benefit of interpretability for simple models may outweigh the cost of imprecision.

63. Irrigation Suitability: "These types of parcels [under 10 acres] could be used by smaller specialty crop growers, greenhouses and nursery growers, which are more likely to use a drip irrigation system."

Agreed. Small scale irrigation (under 3 million gallons per month) is not subject to water withdrawal reporting requirements, and is assumed to be negligible on a state-wide basis. As yet unpublished results of a survey led by Dr. Cal Sawyer and others from Clemson University are expected to test this assumption, and this report may be edited to reflect the results of that study.

64. Agricultural Projections: "While the recent shift to low prices is hindering farmers at the moment, only a few years ago a measurable percentage of recently-timbered forests were being returned to cultivation in SC as their CRP contracts were expiring at a time when prices were good. It's possible this sector could continue its current struggles of course. Also, it's possible that crops previously grown in CA could shift our way as they lose farmland due to water issues

and development. This article from a paper in SF shows an average loss of about 65,000 AC of agricultural land (includes grazing land) per year over a recent 20-yr period in CA."

Several important agricultural regions of the U.S. rely on groundwater resources which may not replenish at the rate they are withdrawn. Additionally, declining snowpack has led to less water availability from snowmelt during the growing season in some areas. If water is not available to support agricultural irrigation in other areas, then there may be greater water demand for irrigation in SC. A comprehensive analysis of water scarcity impacts on global agricultural markets is outside the scope of this report. However, the high-demand scenario is intended to represent increased water demand relative to the baseline trends.

65. Agricultural Projections: "'*Land in each county under each crop is projected to grow at the national projected rate.*' I'm not sure this is a reasonable assumption (see discussion above). If you haven't, it's probably worth inquiring as to whether or not this is a reasonable assumption with Extension, Farm Bureau, and/or Department of Agriculture."

No existing literature has been found which specifies growth rates by county and crop in SC. Revised methods for irrigated area are now included in this report. The method for crop portfolio has not changed: the crops in each county are assumed to grow or decline in relation to each other at the national rate. The methods may be revised further if information becomes available to refine this assumption.

66. Agricultural Projections: "This sentence is confusing. Is it saying all farmers are growing hemp? That does not seem correct."

The text has been edited for clarity.

67. Business-as-Usual: "States that '*the baseline average annual increase in irrigated area per county is calculated from the FSA data. Irrigated areas are projected to continue expanding at the calculated rate until reaching the limit of irrigable land currently under cultivation. The baseline average weather conditions are assumed to remain constant.*'

"Although it is implied, the report should add an explicit statement that "This assumes no growth in acreage under cultivation." Also, this assumption should be evaluated. What are the recent historical trends in acreage under cultivation?

Recently, area cultivation has been rebounding ever since a decline in the 80s and 90s due to conversion to pine plantations. Projections of irrigated acreage in the reference literature appear to be within the bounds of currently cultivated area. Cultivated area may increase in a business-as-usual scenario, but unirrigated cultivated area is not directly relevant to off-stream water demand in the context of this report.

68. High-Demand: "States that '*Irrigation is projected to continue expanding until all irrigable areas are irrigated (including currently forested areas).*'

"This scenario is not realistic, and it does not consider growth in competing land uses. This scenario does not provide any value in planning or permitting if it is highly unlikely to occur."

The methods have been amended so that irrigated area is projected to grow at rates estimated in referenced literature, while constrained by available irrigable land. Forestry is a lower intensity land use which has been in decline in SC after an initial surge motivated by govern-

ment subsidies. The assumption is that forested areas that are otherwise suitable for agricultural irrigation can be converted to irrigated agriculture, although in most or all cases the projected irrigated extent will not encompass the majority of forested area in a county.

69. High-Demand: "There is simply not enough land in this state to have a housing/population boom and an agricultural boom at the same time. One will have to go down for the other to go up. The same could be argued for different uses but this was the most glaring to me."

Constraints to irrigation from developed land uses may be represented using as yet unpublished land cover projections developed by Dr. Georgina Sanchez and others at NC State, in collaboration with USGS. A preliminary analysis of that dataset compared with currently irrigated areas does not indicate that urban and suburban development will impose a significant constraint on agricultural irrigation. A more thorough analysis of constraints on areas which may be irrigated in the future will be conducted as the projection methods are applied in each basin.

70. High-Demand: "…the high demand projection is very unobtainable in my opinion. '*Irrigation is projected to continue expanding until all irrigable areas are irrigated (including currently forested areas).*' I need clarification on the definition of "irrigable areas" as it is written."

The methods now include an analysis of irrigated areas designed to classify irrigable areas in SC. The analysis is intended to test parcel size, land cover, conservation protection status, electric utility lines, slope, and soil as factors which can constrain the potential for agricultural irrigation.

71. High-Demand: "The report states that '*irrigation systems in this region are often designed to supplement rainfall, not replace it. If crop failures are imminent, such as during times of drought, some irrigators cease irrigation. This study does not account for drought-related crop failure in irrigated areas.*'

"Some fraction should be estimated to account for crop failures and the corresponding reduction in irrigation."

Crop failure is not a factor in the business-as-usual or the high-demand scenarios, because it represents a condition that is neither typical nor indicative of high water demand.

Chapter 6: Other Categories

72. Golf Course Irrigation: "Would imagine this is projected to shrink?"

It will be projected to remain constant, with a weather impact in the high-demand scenario.

73. Golf Course Irrigation: "The study should consider growth in number of golf courses and determine if it is a significant factor."

The number of water withdrawal permits for golf courses has not increased significantly over the baseline period.

74. Aquaculture: "Should there be any mention of fish hatcheries although very limited in the state. I do not know if any are utilizing running stream/river water through their facilities and then getting released on the down river side."

Text has been added to reflect this comment.

75. Reuse: "This section does not define what will be used for the 'business-as- usual' and 'high demand' scenarios."

The Reuse subsection has been incorporated into the Water Use subsection of Chapter 1. Reuse is now considered as a potential water input for water users, and not a category of water use.

76. Livestock: "Negligible livestock water use - Someone may questions this. CAFOs (confined animal feeding operations) typically use a lot of water. Not sure how many there are in SC though."

The method has been amended to include livestock water use.

77. Livestock: "USDA Ag Census data can be used to estimate this demand. Is this a significant demand? Even if it is relatively small, the demand for livestock should be included, for completeness. In FL, it is about 2% of the demand from agricultural irrigation (Balmoral Group 2017)."

The method has been amended to include livestock water use.

78. Domestic Wells: "If this is for rural areas (on a well and septic tank) then I believe 80 gpcpd is too low, we use 134 gpcpd for our customers and most of our customers are on septic systems."

The assumption is that people relying on domestic wells use less water on average than public water supply customers. This assumption is consistent with USGS estimates of water use.

79. Aquifer Recharge: "Include a statement that this practice has zero net effect on long-term demand but may affect seasonal demand. How will this be included in the projections?"

This subsection has been moved to the General Concepts section of Chapter 1. ASR is now considered as off-stream storage with no net effect on demand.

80. Prisons: "Do you mean water use per capita?"

Prison water use is assumed to remain the same over the projection period. If prison population remains the same, then per capita water use would be the same. If prison population rises, then perhaps they will become more efficient. In any case, water demand for prisons is assumed to be very minor.

Appendices:

81. Formal Methods: "How will annual data be disaggregated?"

Annual data is assumed to remain constant over the months of the year.

82. Formal Methods: "It is not clear how the average rate for each kind of use is calculated. Does Rate_u needs to be segregated into Rate_u,k, in order to calculate Rate_k? And doesn't this require Demand_u,k, to be known? If so, the equations in this section should show these details."

The text and equations have been edited for clarity. As defined in the text, a water use *u* is of a specific kind *k*. As each use is assigned to a specific kind classification, Demand_u,k is exactly equivalent to Demand_u. An alternative formulation could define a use as possibly consisting of multiple kinds, in which case the additional subscript would be necessary. The formulation represented in the report relies on fewer subscripts, which (hopefully) facilitates interpretation of the methods by stakeholders.

83. Formal Methods: Seasonality "The data should first be inspected to determine if there is a trend. If so, the data should be de-trended prior to calculating seasonality. Ignoring trends may work for a short baseline {2013-2017} but use of a longer baseline might require de-trending first."

The assumption is that demands will be de-trended by dividing by the driver variable. Otherwise, water demand is non-stationary over the baseline period, and the baseline period should be adjusted to reflect a stable water demand.

84. Formal Methods: Weather "This section needs further explanation of the weather index and how it will be calculated."

Further explanation has been added to the text. The weather indices will be based on expert knowledge and stakeholder input. Multiple weather indices can be assessed, and any recommendations are welcome.

85. Formal Methods: Weather "Figure and 'plot' needs to be presented more clearly."

The text has been edited for clarity.