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RIVANNA
WATER & SEWER AUTHORITY

RWSA Urban System Water Demand Forecast Report

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List of Acronyms

Abbreviation	Definition
ACOCD	Albemarle County Office of Community Development
ACSA	Albemarle County Service Authority
ADD	average day demand
DU	dwelling unit
FTE	Full-Time Equivalent (measure of employment)
FW	Finished water (delivered from water treatment plants)
FY	Fiscal Year (July 1 of prior year to June 30^{th} of the indicated year)
GDS	[Albemarle County Office of] Geographic Data Services
GIS	Geographic information system
gpcd	gallons per capita per day
gped	gallons per employee per day
gpd/DU	Gallons per day per dwelling unit
gpd/ksf	Gallons per day per thousand square feet (of building space)
GSF	Gross Square Footage (measure of building space)
ksf	Thousand square feet
LRTP	Long Range Transportation Plan (see TJPDC and MPO)
MDD	maximum day demand
MF	Multi-family
MG	million gallons
mgd	million gallons per day
MPO	Metropolitan Planning Organization
NDS	[City of Charlottesville] Neighborhood Development Services
NR	Non-residential
RDU	Residential dwelling unit
RW	Raw water (withdrawn from reservoirs prior to treatment)
RWSA	Rivanna Water and Sewer Authority
SF	Single-family
TAZ	Traffic Analysis Zone
TJPDC	Thomas Jefferson Planning District Commission
WTP	Water treatment plant

Introduction and Purpose

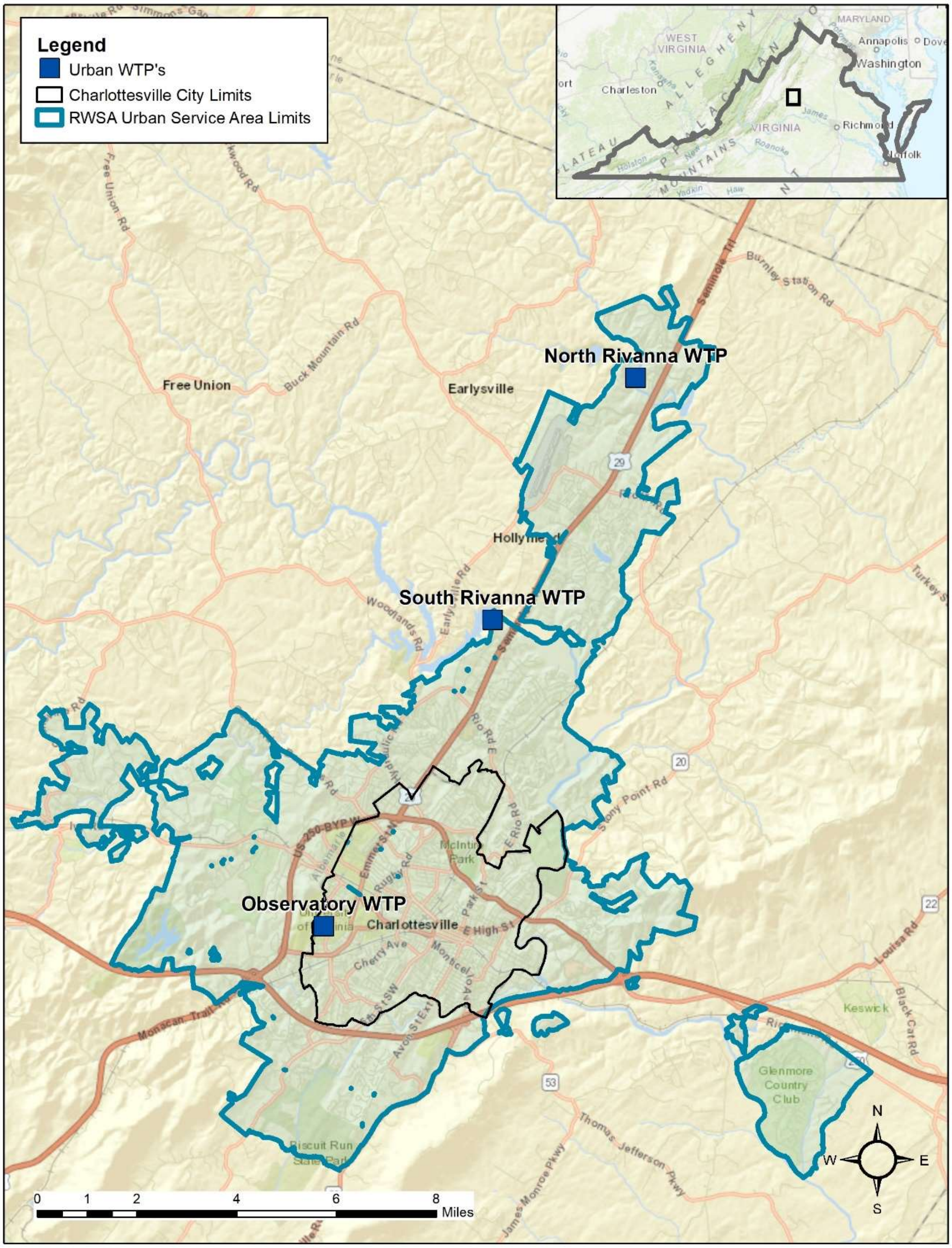
This RWSA Urban System Water Demand Forecast Study was prepared to define the path for implementation of water supply, treatment and distribution improvements necessary to meet the Authority's planning needs for the next 50 years.

Since 1973 the Rivanna Water and Sewer Authority (RWSA) has provided wholesale treated water to several communities in Albemarle County, Virginia as well as the City of Charlottesville. The largest contiguous water system served by RWSA is known as the Urban System or Urban Service Area. The RWSA has two wholesale customers within the Urban Service Area: The Albemarle County Service Authority (ACSA) and City of Charlottesville (City), which is a part of The City of Charlottesville Department of Utilities. Portions of the water distribution system are managed by RWSA with the remainder operated by the ACSA and the City. The RWSA operates three water treatment plants with a combined treatment capacity of 21 mgd that produce treated water (finished water) for the Urban Service Area. The extent of the Urban Service Area is shown in Figure 1.

Since 2008, the Urban Service Area has experienced a steady annual average finished water demand around 9.5 mgd despite a population growth rate averaging 2.2% per year (for a total increase of about 25% since 2008). Aggregate usage per capita has come down as fast as the population has grown leading to near zero growth in demand. Flat or even declining demand trends have taken many water utilities across the country by surprise over the past 10-15 years and a key question facing the RWSA and utilities in similar situations is to determine whether demand growth will resume, when, and at what rate. Looking to the future, the Urban Service Area does have space to accommodate significant population growth, especially within the areas of the County served by the ACSA. There is also potential for further conservation (i.e. continued reduction in per capita demand), but as one of the most water efficient service areas in the nation it would seem reasonable to assume the RWSA may find the limit of the conservation trend as soon or sooner than peer utilities.

This Urban System Water Demand Forecast Study was developed to help RWSA anticipate water demand decades into the future. The foundation of the plan is a series of finished water demand projections developed based on contemporary planning documents, current zoning regulations, finished water production records, and account-level billing data. These projections identify the amount of raw and finished drinking water needed in the Urban Service Area through the year 2070, broken down into five-year increments which will aid in activities planning needed to maintain a high service quality and meet anticipated changes in demand over the planning horizon.

Figure 1: RWSA Urban Service Area Boundaries



1. RWSA Urban Water System Overview

1.1 General Description of the Service Area

The RWSA Urban System lies approximately 65-70 miles to the northwest of Richmond, Virginia and supplies water to all of the City of Charlottesville and rapidly urbanizing portions of Albemarle County surrounding Charlottesville, including the University of Virginia. Its scenic surroundings and the presence of the state's flagship university have contributed to steady employment and population growth for many decades. The County's rural area policies, designed to preserve the scenic nature of most areas of the County not served by RWSA, also drive growth toward areas in and around Charlottesville's urban core and away from surrounding rural areas. The service area's estimated population in 2010 was 97,300, and in 2018 it was approaching 116,000. The Urban System's water supply is derived from the North Fork Rivanna River, South Fork Rivanna River Reservoir, Ragged Mountain Reservoir, and indirectly from Sugar Hollow Reservoir located 15 miles northwest of Charlottesville in the Blue Ridge Mountains. Raw water derived from those sources is then treated at one of three water treatment plants and distributed throughout the service area shown in Figure 1.

1.1.1 Albemarle County Service Authority

The Albemarle County Service Authority (ACSA) distributes treated water and collects sewage for treatment across the portions of the Urban System that lie within the County's jurisdiction. This includes all areas outside of the City of Charlottesville shown on Figure 1, with the exception of the University of Virginia grounds which overlap City-County jurisdictional borders but is served via a connection with the City of Charlottesville. The ACSA purchases treated water from RWSA for distribution to its customer base and pays the RWSA for treatment of the wastewater it collects. The ACSA currently serves a population of approximately 65,000 persons within the Urban Service Area. The majority of the population growth within the Urban Service Area is taking place in areas served by the ACSA.

1.1.2 City of Charlottesville

The City of Charlottesville distributes treated water and collects sewage for its approximately 50,000 residents as well as supplying water to the University of Virginia main grounds. The City purchases treated water from RWSA for distribution to its customer base and pays the RWSA for treatment of the wastewater it collects. Population growth in the City continues despite the fact there is little developable land remaining within City limits. Most future population growth is expected to occur through redevelopment that will allow for greater population density.

1.1.3 University of Virginia

The University of Virginia (UVA) is the region's largest employer and the Urban System's largest water user. Central grounds receive potable water from The City through a 14-inch meter. The University is also a significant property owner of land and buildings within the Urban Service Area that are not contiguous with central grounds. Those buildings receive water service from the City or the ACSA, depending on location and generally have individual accounts per building or per development. UVA is in a continual process of development and redevelopment, adding, on average, over 200,000 square feet of gross building area per year both on-grounds and to its outlying properties.

2. Forecast Goals and Summary of Prior Planning Documents

2.1 Prior Demand Forecasting Reports

Prior to conducting the various analyses required to develop the current demand forecast, the project team reviewed available reports and other documentation associated with prior demand forecasting efforts conducted for the RWSA's Urban System. These documents were reviewed to provide a baseline understanding of the prior projections, the considerations and methods employed, forecast accuracy and therefore the context in which the present report may be received. The Urban Service Area has been the subject of numerous planning studies over the years. The two most recent studies to focus on water demand forecasting for the Urban System are:

1. Demand Analysis for the Urban Service Area, Gannett Fleming, May 2004
2. RWSA Regional Water Demand Forecasts, AECOM, September 2011

The former employed linear and power law (exponential) curve fitting equations and applied them to historical population and demand data for both City and County areas to produce a demand forecast for the Urban Service Area. They also applied an expectation of 5% reduction in aggregate unit demand, via conservation and efficiency improvements, over the 50-year planning period, based on AWWA M50 guidance from that time. Estimated demand forecasts from the study are shown in Table 2-1.

The latter report utilized population and employment projections from the Virginia Employment Commission (VEC) and U. S. Department of Labor Quarterly Census of Employment and Wages (QCEW). Baseline unit demands were developed for the period of 2006 through 2010 and then additional conservation potential was analyzed and estimated at 3.9% over the 50-year planning period.

Table 2-1: Prior Demand Forecasts

Source	2025	2055	2060
Gannett Fleming, 2004	14.5 mgd	18.7 mgd	-
AECOM, 2011	11.9 mgd	16.2 mgd	17.0 mgd

A review of the assumptions in both forecasts shows that the population estimates have, in aggregate, tracked reasonably well with actual population growth since those forecasts were produced. The unit demands, however, have deviated significantly from the assumptions in those reports (implicit in the 2004 forecast and more explicit in the 2011 forecast) and are the principal source of error despite the fact both methods attempted to account for future conservation. Water use intensity (as measured by unit demand metrics) has declined far faster than was imagined at the time those reports were produced.

2.2 Forecast Planning Horizon and Contemporary Urban Planning Documents

2.2.1 Temporal Forecast Horizon

The RWSA Urban Demand Forecast estimates water demand through the year 2070. The 50-year planning horizon exceeds the range for most population and infrastructure planning processes because major water resource infrastructure projects can require a particularly long time to plan, permit, design, construct, and fill. New reservoirs and reservoir expansions can easily require 2-3 decades to move from permitting studies through the construction and filling steps and so it is important to assess needs and plan well in advance of those steps. Other infrastructure such as pipeline and pump stations can also take a long time to plan, permit, and construct.

While the goal of the project is a 50-year forecast, and there are good reasons to select that range, the realities of such a forecast period need to be understood. Regional population and employment forecasts are only available through 2045. Furthermore, the accuracy of forecasts decreases for target dates further into the future. For this reason, the RWSA demand forecasting process is updated approximately every 10 years. Given this understanding, the goal of this forecast is to be as accurate as possible at the 2030 horizon, and to match the regional population and employment forecasts at the 2045 horizon. The forecast at the 2070 horizon involves a lot of assumptions as there are no parallel planning documents (i.e. population and employment forecasts) to support a water demand forecast 50 years into the future, but this information can still be used for appropriate long range planning purposes. Estimates regarding 2070 population for the service area were made based on maximum build-out densities estimated by Albemarle County Office of Community Development (ACOCD) and City Neighborhood Development Services (NDS) department staffs.

2.2.2 Contemporary Planning Documents and Information

The Charlottesville/Albemarle Metropolitan Planning Organization 2045 Long Range Transportation Plan (LRTP), dated May 22, 2019, is based upon the most recent and rigorous urban population and employment forecast data produced for the metropolitan region that includes the RWSA Urban System. The Thomas Jefferson Planning District Commission (TJPDC) produced the LRTP and made available the population and employment projections used for the Demand Forecast Study. The LRTP breaks down population projections and estimates into spatial units known as Traffic Analysis Zones (TAZs). TAZs within the RWSA service area ranged from under 4 acres to just over 2300 acres, with a median size of 72.6 acres and were well-suited to the spatial resolution required for the demand forecast and associated analyses. The population and employment projections in the LRTP closely match those available from UVA’s Weldon Cooper Center for Public Service, shown in Tables 2-2, 2-3, and 2-4, and were used as benchmark population targets for the Demand Forecast Study. The Weldon Cooper Center is the Commonwealth of Virginia’s leading demographic research group and produces the official population projections and estimates for the state’s cities and counties.

Table 2-2: City of Charlottesville Population Projections

	Year	
Projection Source	**2015**	**2045**
Weldon-Cooper	48,210	55,969
TJPDC LRTP[1]	48,326	56,770

1- Population estimates for Charlottesville are based on an area-weighted clip of TAZs matched to Charlottesville boundaries

Table 2-3: ACSA Population Projections[2]

	Year	
Projection Source	**2015**	**2045**
TJPDC LRTP	61,629	95,829

2- Population estimates for the ACSA are based on an area-weighted clip of TAZs matched to the ACSA service area

Table 2-4: Employment Projections from TJPDC LRTP[3]

	Year	
	2015	**2045**
Charlottesville	37,045	47,682
ACSA	37,403	46,293

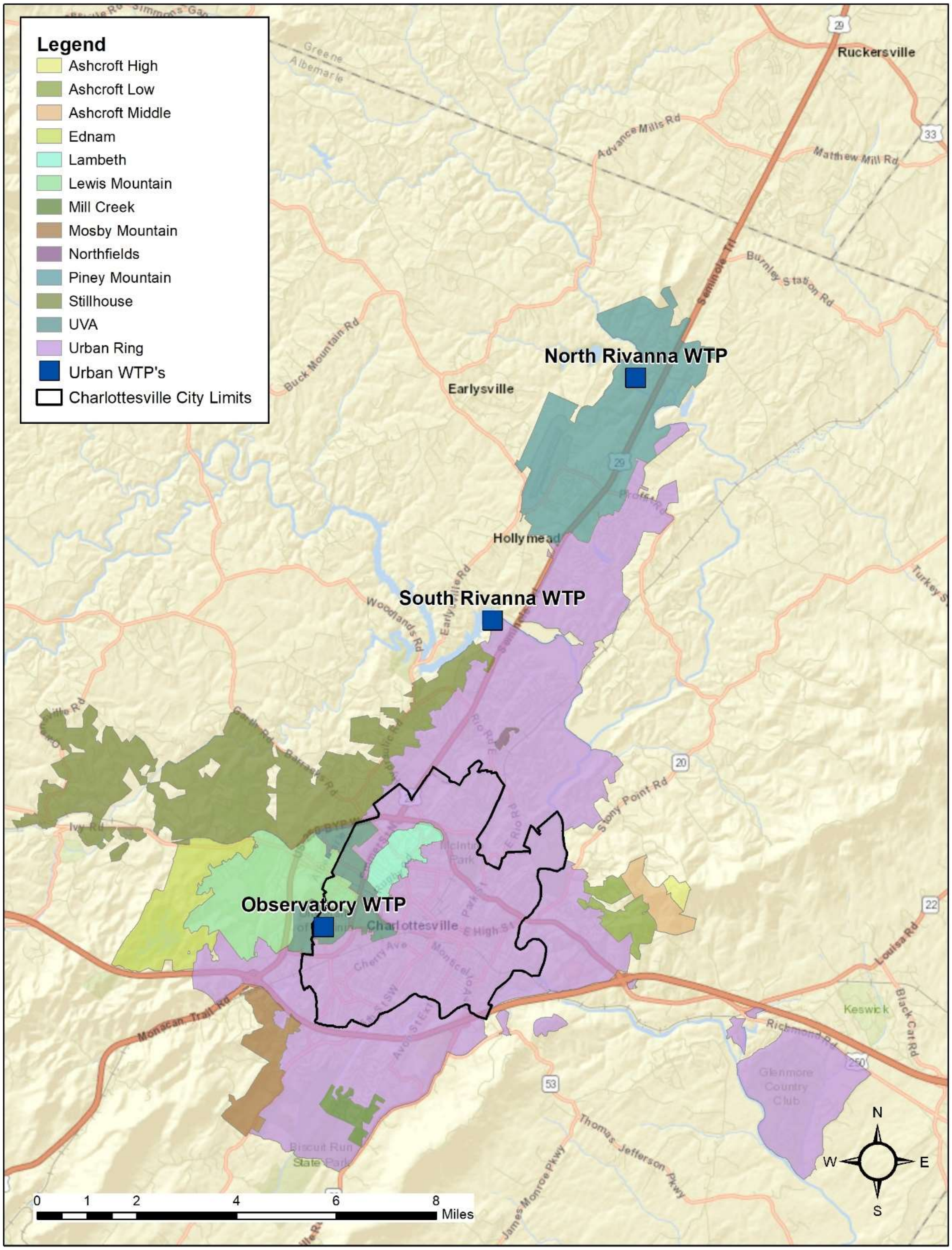
3- Employment estimates for Charlottesville and the ACSA are based on an area-weighted clip of TAZs matched to the ACSA service area

2.3 Geospatial and Water Sectoral Resolution

In addition to developing forecasts for the ACSA, City of Charlottesville, and UVA, the present demand forecasts also allocates the overall demand across twelve distinct pressure zones in the Urban System. The Urban Service Area and demarcations for its 13 pressure zones are illustrated in Figure 2-1 below. For the purposes of the Demand Forecast Study, the small Northfields pressure zone is rolled into the Urban Ring pressure zone forecast. The spatially disaggregate demand forecast was produced using a land use model of development within the Urban Service Area which is described in more detail in Section 3.

In some cases, a demand forecast was developed for specific projects at a finer resolution than the pressure-zone level. Most of these finer scale projections pertain to projects or masterplanned areas owned by the University of Virginia and are described in more detail in Section 3.3. Furthermore, analysis of historical demands and projection of future demands involved assigning billing accounts and future development to one of three water sectors, or class types. Those three class types are single-family residential (SF), multifamily (MF) residential, and non-residential (NR). This is also described in greater detail in Section 3.

Figure 2-1: RWSA Service Area and Associated Pressure Zones

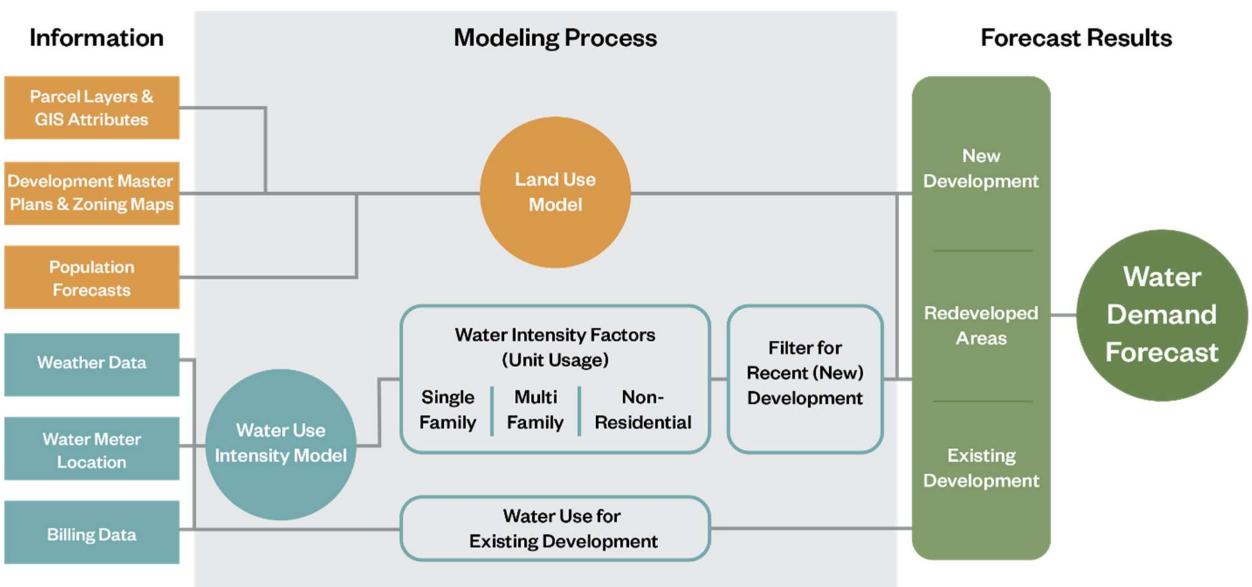


3. Demand Forecast Development

The RWSA Urban System Demand Forecast Study was developed through the application of a land use model and water use intensity model of the service area, together with guidance on population and employment projections from independent agencies to pace the development rate within the land use model. There were many sources of information that went into developing these two models. A simplified schematic, in Figure 3-1, describes the major classes of information and the process flow used to produce the RWSA water demand forecast.

Many of the sources of information used in the modeling process came from local agencies including City Utilities, Charlottesville Open Data, Charlottesville Neighborhood Development Services (NDS), the ACSA, Albemarle County Office of Community Development (ACOCD), Albemarle County Geographic Data Services (GDS), TJPDC, the University of Virginia, the Weldon Cooper Center, and RWSA. The project team held meetings with RWSA, City Utilities, City NDS, ACSA, ACOCD, and UVA during the course of the project to explain the rationale and goals for the project, the proposed forecast development method, request assistance with providing and collecting data, as well as to review the assumptions and results as the demand forecast project began to wrap up.

Figure 3-1: Overview of Demand Forecast Modeling Process



The land use model was used to spatially disaggregate the demands across the RWSA Urban System. Using the general classes of information shown in orange in Figure 3-1, it determines where, how much, and what type of development is likely to occur in the future. The spatially linked information it produces can be used to sum up the number of new single-family homes, multifamily dwellings, and additional non-residential space across a spatial boundary such as a pressure zone. The water intensity model relies on the classes of information shown in blue in Figure 3-1 to determine how much water new single-family homes, multifamily dwellings, and non-residential spaces are likely to use. The information from the two models is combined (along with water demand from existing development) to produce a spatially disaggregate water demand forecast for the Urban Service Area. Sections 3.1 and 3.2 describe the land use and water intensity modeling processes, respectively, in greater detail.

3.1 Land Use Development Model

The purpose behind utilizing a land use model to forecast water demand is to predict the types and densities of development that will take place across the service area and to be able do so in a spatially relevant manner. The type and density of development can then be linked to water demand with the water use intensity model.

The methodology underpinning the land use model involved assigning each parcel to a *partition* according to its pressure zone, zoning or master plan specification, and current development status (built upon or vacant/undeveloped). Together, these characteristics were used to define assumptions about how land will develop in the service area, the assumed rate of development, and the pressure zone to which its water use would be assigned. Partitioning involved grouping parcels into nonoverlapping areas wherein current and future demands were estimated using a consistent set of assumptions within each partition. Thus, each partition in the model represents a group of parcels (an area) within the RWSA Urban Service Area in which the same set of assumptions are applied with respect to the type of development (e.g. residential, non-residential, or mix thereof), timing of development, and density of development expected over the forecast horizon.

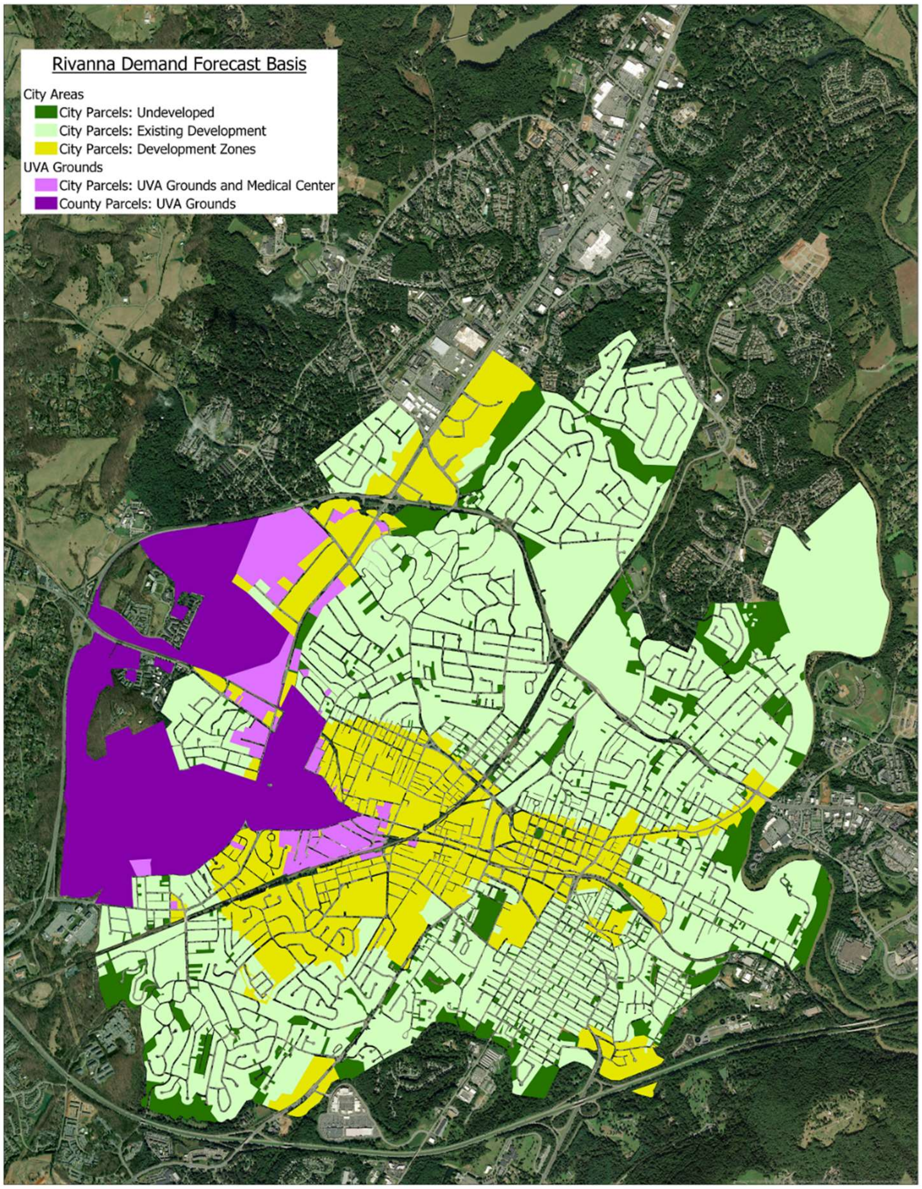
Parcels pertaining to areas of the University grounds that are served by the 14” meter from the City (currently about 90% of the water UVA uses passes through this meter) were excluded from this land use model basis of demand forecasting. The UVA demand forecast was developed independently from the forecast for the City and ACSA service areas. The UVA demand forecast model is described in Section 3.3.

Development within the land model was bounded on the upper end by the maximum densities allowed by current zoning regulations. In the case of the County’s small area masterplans, which cover a significant portion of the ACSA service area, the maximum densities proposed under those masterplans superseded the zoning classifications and were used to define the maximum build-out density. Those densities are enumerated in detail in Appendix A and were acceptable to both the ACSA and ACODC. The model generally assumed no adjustments to the existing zoning and masterplan regulations within Albemarle County. Undeveloped parcels were assumed to develop in accordance with their associated zone or masterplanned densities. Parcels with existing development and water meters were assumed to remain as-is throughout the forecast horizon unless they fell within one of the areas where redevelopment was considered within the model.

Some portions of the ACSA service area were assumed to partially redevelop over the forecast horizon regardless of their existing development status. Areas where redevelopment was assumed in the County are shown in Appendix A Figure A-14 and correspond to areas within the County’s small area masterplans. Those shown in Figure A-12 are currently part of the County’s “development pipeline” and are already slated for development or redevelopment. These assumptions were also met with acceptance by the ACOCD.

Furthermore, some areas within Charlottesville, such as those within a half-mile of the UVA Medical Center and those zoned for mixed use development, were assumed to redevelop to mixed use at higher densities than their zones may currently allow. This assumption is based on the precedence for zoning variances issued in those areas of the City in the recent past. The yellow 'Development Zones' in Figure 3-2 demarcate these areas and City NDS staff reviewed these assumptions.

Figure 3-2: Charlottesville Land Use Forecast Basis



Once the development model was assembled for build-out conditions, the degree of development at target forecast dates was set within the model such that a sufficient number of new housing units and non-residential space would be added to accommodate the anticipated employment growth within the City or ACSA service areas.

Details regarding the partitioning process, build out densities, and other inputs and outputs from the land use model are described in detail in Appendix A.

3.2 Population and Employment Growth

Population growth guidance through 2045 is available from both the UVA Weldon Cooper Center and the Thomas Jefferson Planning District Commission's 2045 Long Range Transportation Plan (LRTP). The projections for both Charlottesville and the ACSA are shown in Tables 3-1 and 3-2, respectively. The values selected for this study for the ACSA represent a growth in population through 2045 equivalent to that projected for the ACSA portion of the service area, but using the ACSA population served estimate from 2015 as a starting point rather than the area-weighted population from the TAZ data for the ACSA. The ACSA's estimate was selected since it was assumed that their estimate based on the number of residential connections might be more accurate than one where TAZs were split to match the service area boundaries, but the two estimates have less than a 1% difference, so they mutually reinforce confidence in the service area population estimate.

The population target for 2070 was based on a rough estimate from City NDS of the maximum population capacity of Charlottesville without any changes to the zoning ordinance, but allowing for redevelopment of currently developed areas. That redevelopment is focused on the portion of Figure 3-2 shaded in yellow and previously discussed in Section 3.1. The 2070 population target for the ACSA is based on the High Development Area Population at buildout from the ACOCD. Figure 3-3 shows these projected populations for the City, ACSA, and total service area.

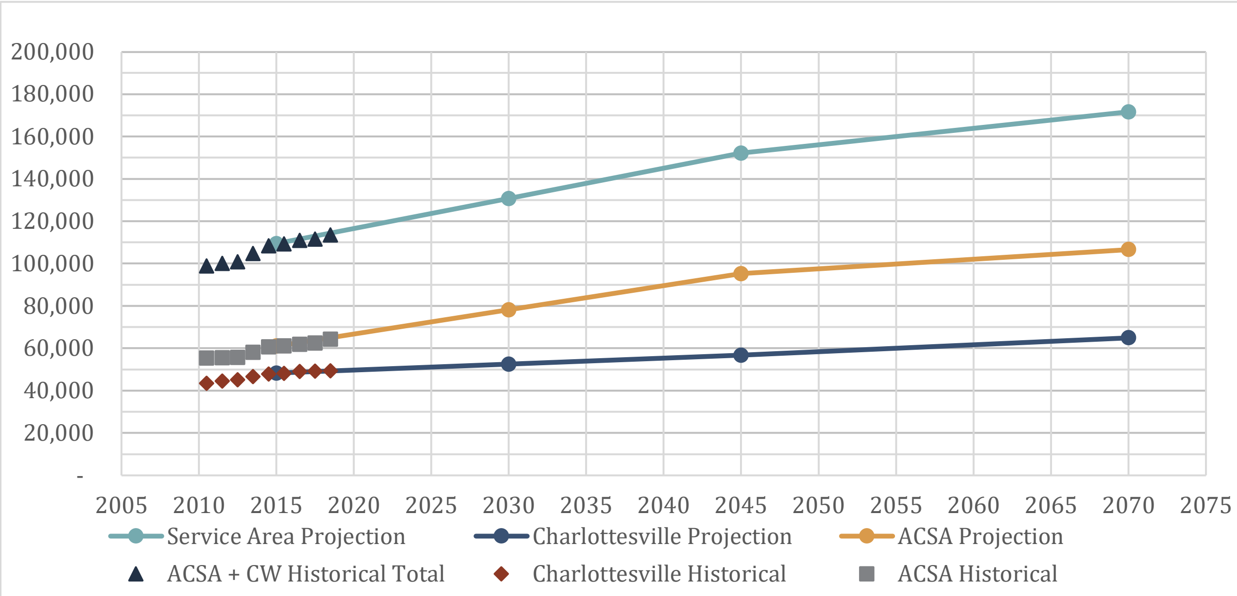
Table 3-1: Charlottesville Population Projections

Source	2015	2045	2070
Weldon-Cooper	48,210	55,969	-
TJPDC LRTP	48,326	56,770 (+17%)	-
This study	48,326	56,770	65,000

Table 3-2: ACSA Population Served Projections

Source	2015	2045	2070
ACSA	61,113	-	-
TJPDC LRTP	61,629	95,829	-
This study	61,113	95,300 (+56%)	106,650

Figure 3-3: Populations Projections for Charlottesville and the ACSA



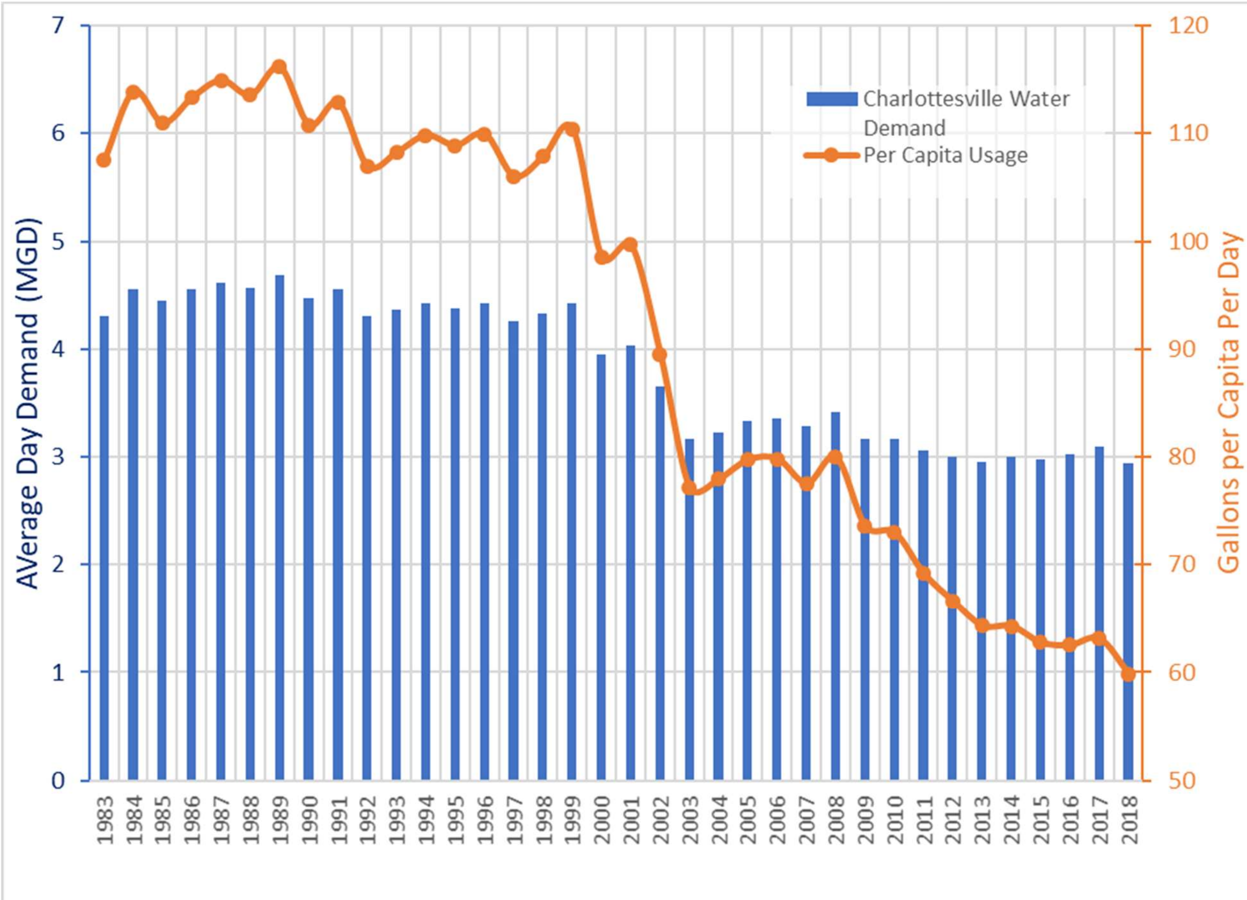
Employment estimates were used as guidance for the addition of new NR space to the service area. At present there is around 500 square feet of NR space in the service area per employee. The amount of new NR space per additional employee through 2045 is closer to 750 square feet, but this figure itself does not account for the replacement or demolition of existing NR space which will often be required to accommodate the new NR structures. There are no employment projections for 2070 available so the ratio of new residential to new NR space was kept fixed after 2045.

3.3 Unit Demand Analysis

Unit demand, also referred to as demand intensity, represents the amount of water used per person, employee, dwelling unit, or per unit area. Developing unit demand profiles is standard practice for water demand forecasting activities[1]. The aggregate per capita unit demand is one water intensity metric often used for comparison. It is calculated as the sum of all water use, not just residentially metered uses, divided by the total service area population. The aggregate per capita unit demand for the Urban Service Area has been declining rapidly over the past two decades as illustrated in Figures 3-4 and 3-5. As shown in Table 3-3, the RWSA service area is among the more efficient in the nation in terms of water use based on this metric.

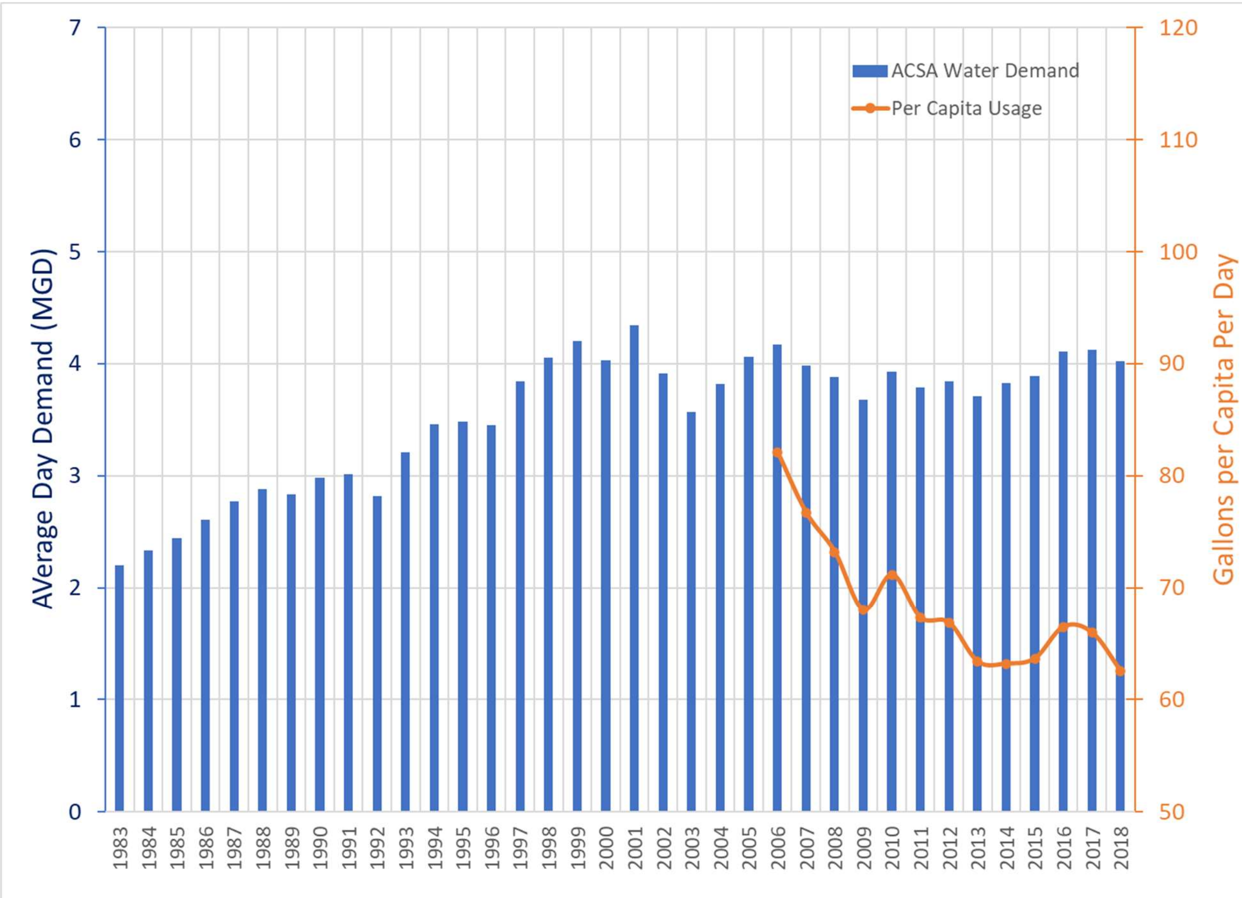
[1] AWWA M50 3rd Edition, Water Resources Planning, Chapter 5, Water Demand Forecasting

Figure 3-4: Charlottesville Average Day and Per Capita Demand Trend[2]



2- University demand removed from Charlottesville totals

Figure 3-5: ACSA Average Day and Per Capita Demand Trend



The unit demands for the City and ACSA portions of the RWSA Urban Service Area have tracked closely as is evident in Figure 3-4 and 3-5, although the population in the ACSA portion of the service area has grown more rapidly than in Charlottesville. The similarities in unit demand profiles provide confidence to support the application of findings from either the City or ACSA to the other in cases where data may be missing from one of the services areas.

Table 3-3: Aggregate Unit Demand Comparison Across Utilities

City / Utility	Aggregate per capita consumption (year)	Raw or Finished Water Basis
RWSA	73 gpcd (2017)[1]	Finished
Loudon Water, VA	80 gpcd	Finished
OWASA (Chapel Hill, Carrboro, UNC)	84 gpcd (2017)	Finished
Raleigh, NC	88 gpcd (2017)	Raw
Durham, NC	105 gpcd (2017)	Raw
Charlotte, NC	120 gpcd (2017)	Raw
Baltimore, MD	109 gpcd (2015)[2]	Unknown
Austin, TX	126 gpcd (2017)[3]	Raw
Santa Cruz, CA	71 gpcd (2015)[4]	Finished
New York City	117 gpcd	Finished

1. Includes UVA consumption and On-grounds population
2. Data from USGS https://waterdata.usgs.gov/md/nwis/wu
3. https://data.austintexas.gov/Utilities-and-City-Services/Austin-Water-Gallons-of-Water-Pumped-per-Capita/wfm8-s7zc
4. http://www.cityofsantacruz.com/home/showdocument?id=55168

The Demand Forecast Study involved further disaggregation of the per capita unit demands among several class types (or use sectors). Each meter or account was assigned to one of three class types. All accounts within a class type were analyzed collectively to develop unit demands for that sector. Of the three class types, two are residential (single-family residential and multifamily residential) and all non-residential (NR) accounts were grouped together into the NR sector. The unit demands for the three sectors were specified as: single-family demand per dwelling unit, multifamily demand per dwelling unit, and nonresidential demand per thousand square feet of building space. The demand intensities in single-family, multifamily, and nonresidential water use sectors were estimated using City and County meter data for FY 2017 and associated information describing structures on parcels from the City from Charlottesville and the Albemarle County Office of Community Development (ACOCD). The results are shown in Table 3-4

Sectoral Classification of Meters. Both the City and the ACSA provided data indicating the type of development (SF, MF, or NR) served by each meter. Visual comparison of meter locations with aerial and street-view imagery indicated that type of development generally agreed with true development characteristics. There were some exceptions, in particular for ACSA meters, that required the accounts to be reclassified for the purposes of this study prior to estimating sectoral unit demands. The account reclassification process used as part of the study is described in detail in Appendix B Section B.1.1.

Single Family Intensity. Following sectoral classification of meters, intensities were estimated for each water use sector using FY 2017 consumption data and estimates of the numbers of dwelling units. Since SF dwelling units (DUs) tend to have their own parcel and also have one account per dwelling unit, the calculation of unit demand for this sector is relatively easy. The average SF unit demand for FY 2017 was estimated to be 120 gal/DU/day. Unit demands were compared across pressure zones and though there were some differences between zones, the dispersion of the data within zones supported the use of a single value for future development across the service area.

Multifamily Intensity. To estimate multifamily (MF) intensity, it was necessary to know the number of dwelling units served by each MF meter used in the estimate. This requirement arises since meters that serve MF structures often serve more than one DU, or even all DUs in those structures. Usually, property appraisers can provide information on the number of dwelling units for MF parcels; then, through a matching of meters to parcels, consumption per MF DU can be estimated. Unfortunately, neither the City nor the ACOCD had this information available for all MF parcels. However, the MF DU count was estimated by working backward from better known quantities. First, the population living in MF DUs was estimated. This was done using the Urban Service Area population estimate (111,600 in FY 2017), the number of SF DUs, and the assumption that 2.54 persons live in the average SF DU. The persons per SF DU figure came from County GDS data and was confirmed with Census Bureau data. The SF population was calculated by multiplying the SF DU count (described in the preceding paragraph) by 2.54. The MF population was then estimated by subtracting the SF population from the service area population. The persons per dwelling unit for MF DUs is 2.01 (also from GDS and Census Bureau) which led to an estimate of 24,934 MF DUs in the service area. The sum of usage across accounts designated as MF divided by this inferred number of MF DUs led to an estimate of 75 gallons per MF DU per day for FY 2017.

Nonresidential Intensity. Nonresidential intensities were estimated from total consumption for NR meters over FY 2017 and then dividing that by total days to produce average gallons per NR sector per day. That number was then divided by the total number of nonresidential building square feet served by those meters. Total building square footage on each parcel was provided by both the City and the ACOCD. The estimated unit demand for the NR sector was 85 gallons per day per thousand square feet (gpd/ksf).

Table 3-4: Estimated FY 2017 Demand Intensity by Sector

Sector	Estimated Intensity
Single-family	120 gal/DU/day
Multifamily	75 gal/DU/day
Nonresidential	85 gal/ksf/day

3.3.1 Demand Intensity Estimates for Future Development

Given the decreasing trend in unit demands across the service area, it became especially important to model how that might change over the forecast horizon. It was assumed that people using future development will use water similarly to newly developed structures compared to older structures. Therefore, an effort was made to discern water use habits of these newer developments. Fortunately, the ACOCD was able to provide parcel-level unit information for housing stock constructed since 2010. These were matched with meter records such that demand intensities for this subset of SF and MF dwellings could be calculated as shown in Table 3-5. These unit demands were assumed reasonable and applied to all future development. Future NR unit demand was estimated at 75 gpd/ksf based on data for University buildings and the expectation of some improvement in efficiency over the present aggregate NR stock (85 gpd/ksf).

Table 3-5: Estimated FY 2017 Demand Intensities for post-2010 Development by Sector

Sector	Estimated Intensity
Single-family	109.4 gal/DU/day
Multifamily	79.5 gal/DU/day
Nonresidential	75.0 gal/ksf/day

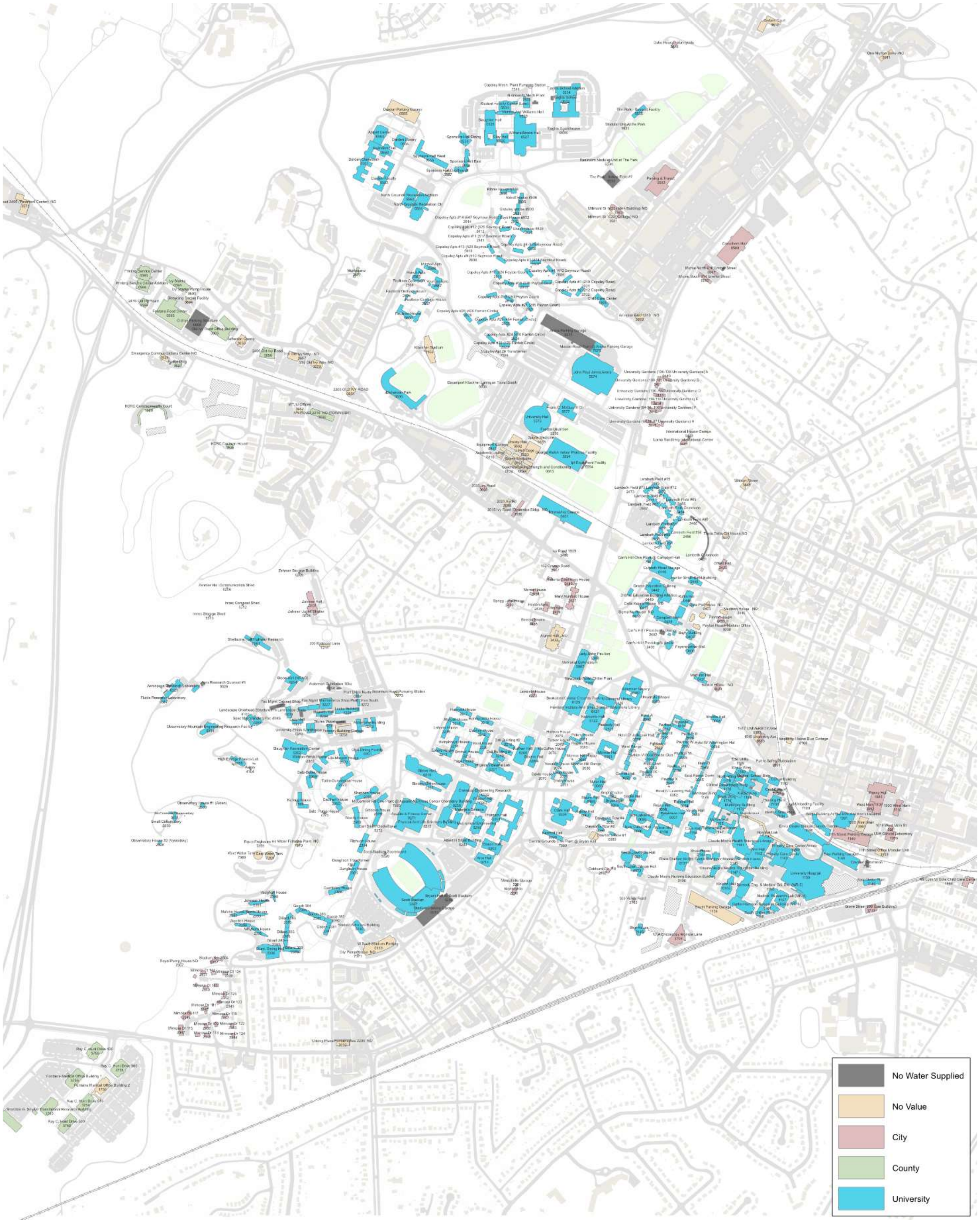
Collectively this set of assumptions produces an aggregate unit demand that continues to decline slightly in the ACSA and remains flat in Charlottesville. These trends are displayed graphically in Section 3.6.2, Figures 3-14 and 3-15.

Details regarding the water intensity modeling covered in this section are described in Appendix B.

3.4 The University of Virginia Demand Forecast

The University of Virginia (UVA) is located on the west side of Charlottesville and has a large influence on water usage in the RWSA service area and is the single largest consumer. UVA has a stated goal of reducing total water use through the year 2035. Currently about 90% of UVA's water is supplied through a single 14-inch meter from the City. UVA buildings not receiving water service via the 14" master meter are supplied by accounts from the ACSA or the City, and are referred to as "direct drops" by University staff. Figure 3-6 is a University produced map and the buildings in blue correspond to those served via the 14-inch line. Predicting demand for UVA using a future land use model would be difficult since the University does not have a comprehensive parcel-based long range plan (not beyond about 10 years), and is not subject to zoning requirements that could guide such a model beyond 10 years into the future. Therefore, a separate forecast method was developed based on University-stated student enrollment projections and historical building development rates together with historical usage data for UVA buildings whose water is supplied by the 14-inch service line. In addition to the demand forecasts for the areas served via the 14-inch service line, forecasts were done for several of the University's masterplanned areas.

Figure 3-6: UVA Building Water Source



Prior to developing the UVA water demand forecast, Hazen reviewed water use data and student enrollment data. In an effort to better understand data sources as well as current planning, Hazen met with University staff in January 2019 to review data and discuss recent trends that could impact Hazen's demand forecasts. The information gathered were used to analyze the University's water use and project water demands for the UVA 14-inch meter area over the 50-year planning horizon. Additionally, Hazen developed specific demand forecasts for UVA masterplanned and several near-term projects and research parks using a similar methodology to that employed for the principal "on-grounds" forecast. The sections below describe the forecast development in more detail.

3.4.1 Determine Building Categories and Demand Drivers for Each Category

The water usage data provided by UVA contained a building use classification which categorized buildings into one of 18 use classifications. The 18 building types were consolidated into four aggregate categories for the areas served by the 14" master meter from the City to simplify the analysis and demand projection. The aggregate categories are University Housing, General University, Care Facilities, and Utilities. Historical water usage for buildings in each aggregate category was correlated with several potential demand drivers for water use and the most well-correlated driver was assumed to remain well-correlated over the forecast horizon. For example, water use within University Housing is well-correlated with the number of students living on grounds while the Utility category is well-correlated with the total university building area since the majority of water usage within this category is from chiller plants which supply the HVAC systems for most of the buildings on grounds. Demand drivers were also assumed to grow and change over time. University staff provided guidance on the expected growth rate of the student body (1% annually) and the growth in building square footage and full-time equivalents for health care facilities were determined from the data provided by staff. University staff reviewed and approved the use of these assumptions in conjunction with this forecast at a meeting on September 16, 2019. Table 3-6 summarizes building types, aggregate categories, water and area footprints, and demand drivers.

Table 3-6: UVA Building Categories and Demand Drivers

Aggregate Building Category	Correlated Water Use Driver	Demand Driver Growth Assumption	Building Use Classification	2018 Water Use (MG)	2018 Area (ksf)
University Housing	Students Housed On-grounds	University will house 1/3 of FT students in on-Grounds housing	Housing	52.8	2178
General University	All students	1% average annual growth until 2070	Athletic	22.2	1430
			Classroom	4.5	484
			Dining	8.9	132
			Landscape	1.1	194
			Library	5.8	817
			Office	35.5	2871
			Public Service	0.1	30
			Research	46.5	2604
			Sports Field	5.2	1247
			Storage	0.3	26
			Support	6.8	601
Care Facilities	Hospital FTE	1% average annual growth until 2070	Child Care	0.4	8
			Patient Care	61.1	1673
Utilities	Total University Building Square Footage	About 190 ksf of net new building square footage per year	Utilities	156.3	91
Not Included in analysis	N/A	N/A	Parking Garage	0.3	1131
			TBD	0.0	0
			Hospital Support (helipad)	0.0	0
Total				**408.0**	**15,518**

3.4.2 Analyze and Project Water Use Intensity, Student Population, and Building Area

After establishing building categories and growth assumptions for the drivers, the historical data were analyzed to determine historical water use intensity for each building category. A water use intensity was calculated by summing the total usage from an aggregate category and dividing by the quantity of each correlated driver (e.g. total students, health care facility FTEs, building GSF). Historical data shows that water use intensity has declined over time for all building types as shown in Figure 3-7. This can be explained by initiatives to reduce water usage and the installation of more water-efficient devices and plumbing fixtures. The rate of decline (i.e. slope) of water use intensities is expected to slow and plateau over time as new water use initiatives and technologies approach their practical efficiency limits, but there is uncertainty with regard to the rate of decline and ultimate efficiency. For this reason, greater efficiency improvement rate and lower efficiency improvement rate scenarios were evaluated for this analysis. The greater efficiency improvement rate results in lower demand and the water use intensity slope from 2018 to 2035 is ½ the historical rate and 1/10 the historical rate after 2035. The lower efficiency improvement rate scenario results in a higher demand and the slope from 2018 to 2035 is ¼ the historical rate and is zero after 2035. Projected water use intensities are shown in Figure 3-8.

Figure 3-7: Historical Water Use Intensity and Trends by Aggregate Building Class

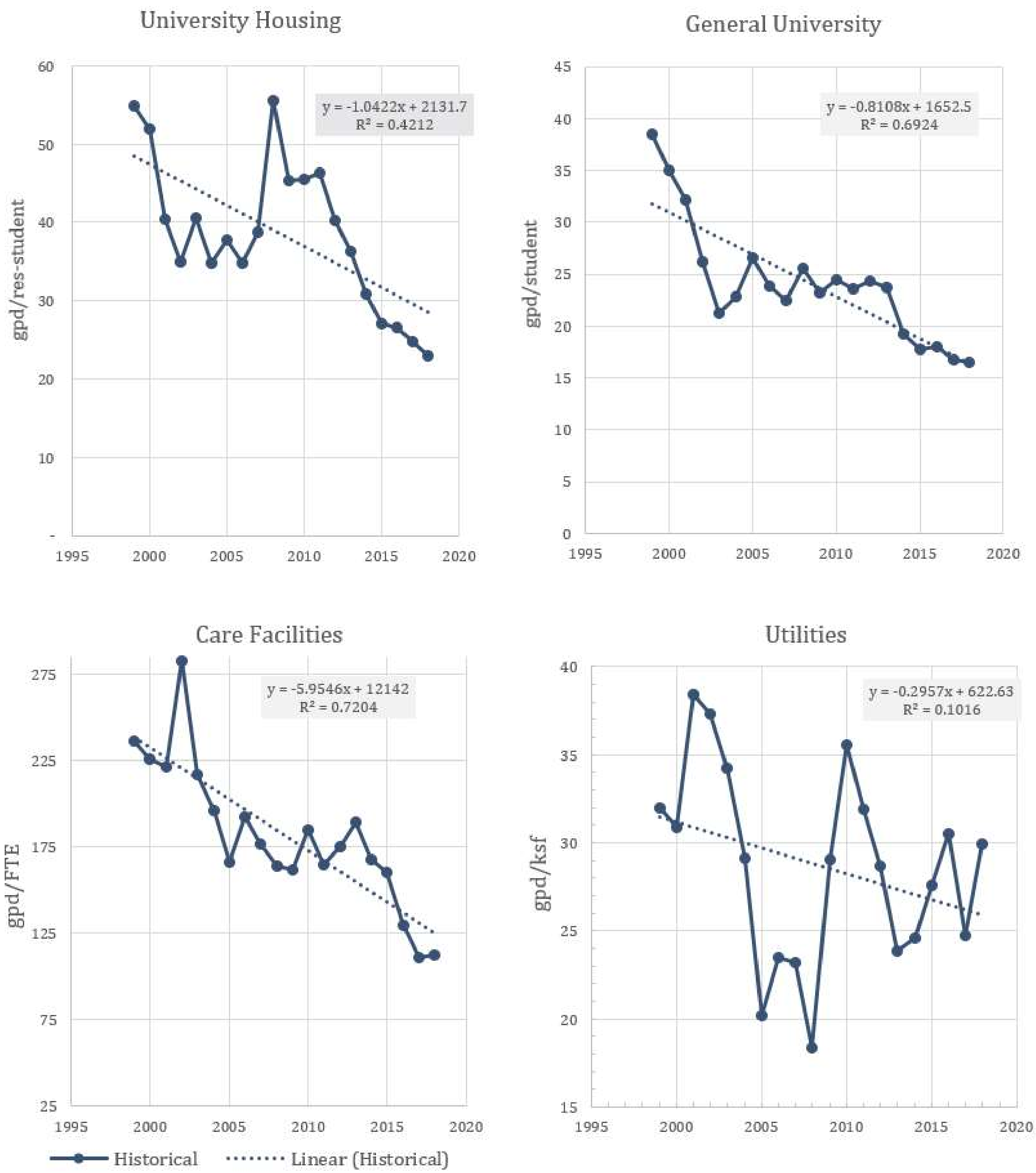
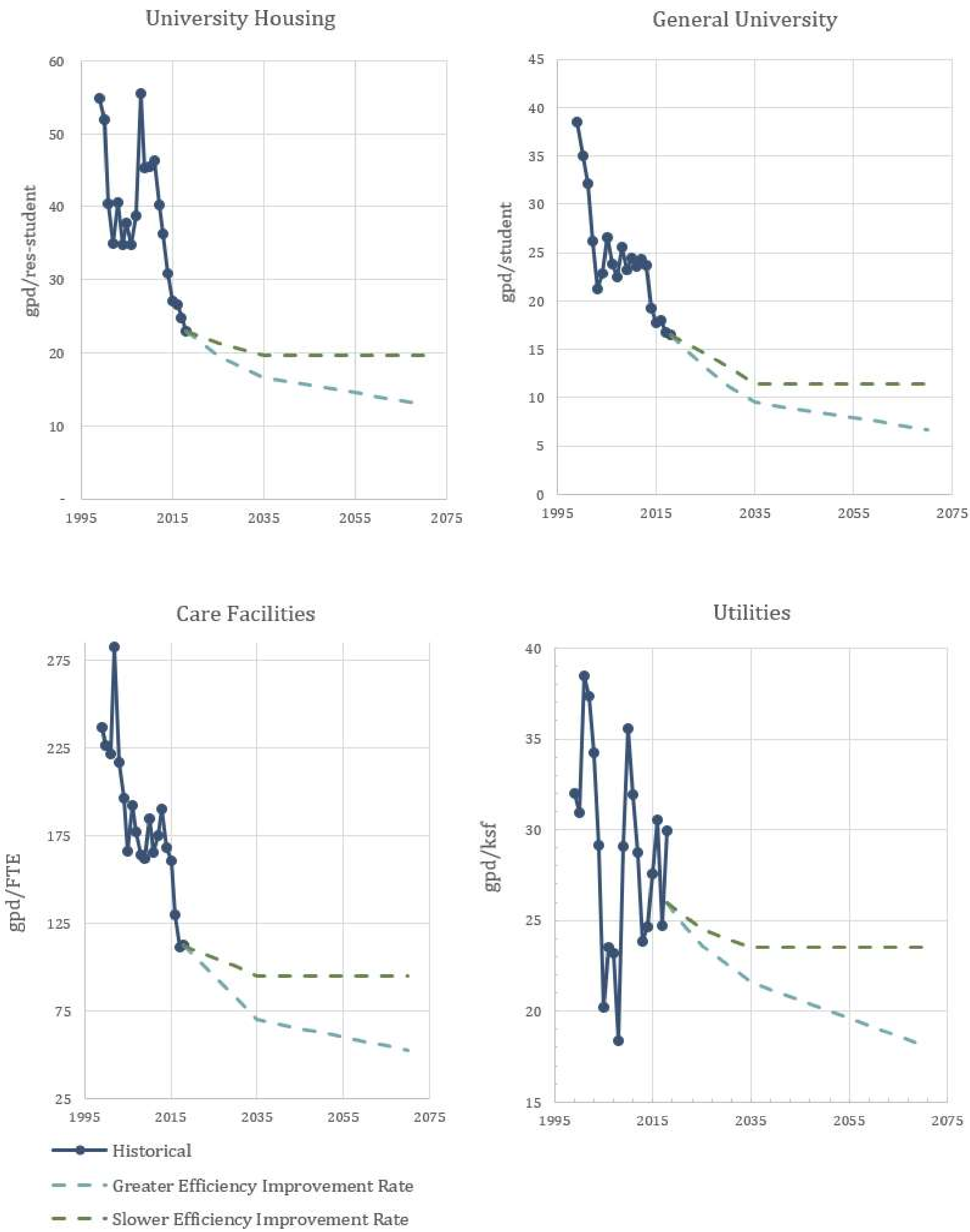
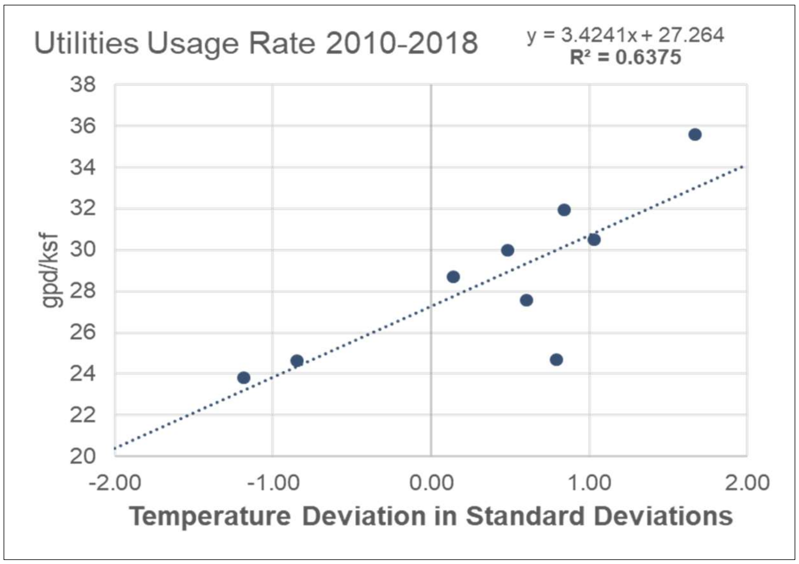


Figure 3-8: Projected Water Use Intensity trends by Building Class



Additionally, it is worth noting that the historical water use intensity for the Utilities category exhibits a dependence on temperature (Figure 3-9). This dependence is expected since the majority of water used in the Utility category is to run water cooled chiller plants which provide cooling for most University buildings on grounds. The utility unit usage rates are also expected to decline and plateau as new buildings with improved thermal efficiency replace older building stock. However, the greater efficiency improvement rate and lower efficiency improvement rate scenarios reflect the usage rate during an average temperature year and do not account for potential variances in temperature. Accounting for weather variation is described in Section 3.6.3 and in Appendix D.

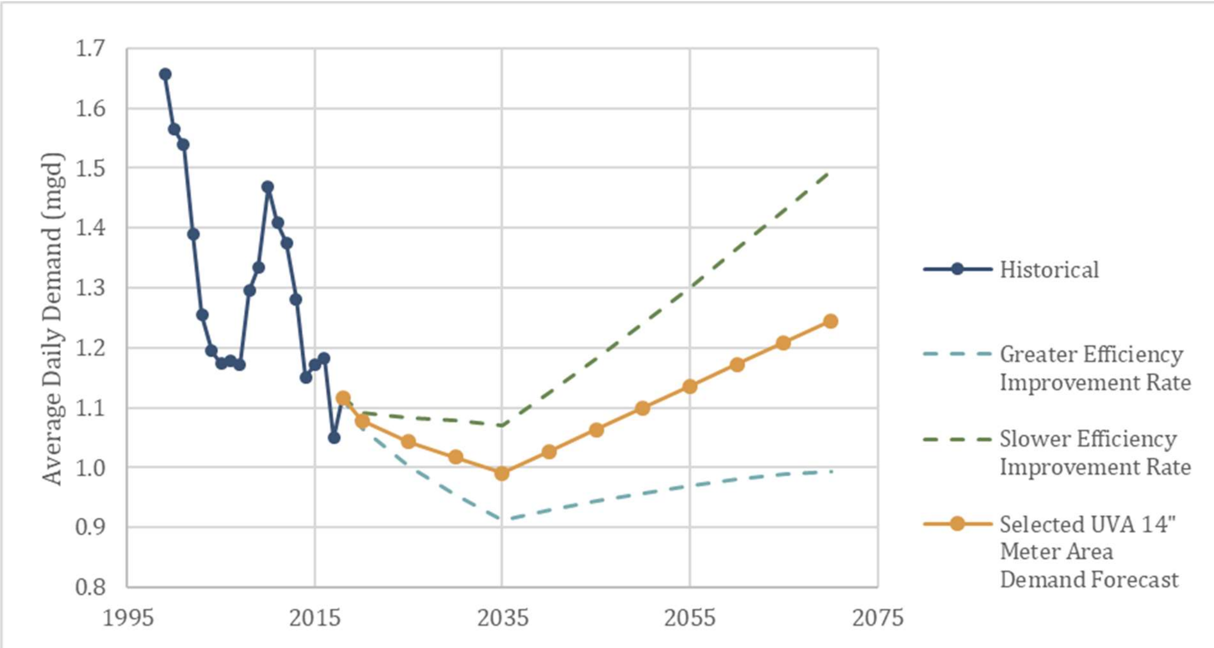
Figure 3-9: Utility Water Use Intensity Temperature Dependence



3.4.3 Project Future UVA Water Use

A water demand forecast for on-grounds areas served by the 14-inch line was developed through 2070 using projected usage rates and projected university growth. Two sensitivity scenarios were developed, one for a greater efficiency improvement rate and another for a lower efficiency improvement rate for each building type. The selected 14-inch meter area demand forecast is an average of the greater efficiency improvement rate and lower efficiency improvement rate projections. As shown in Figure 3-10, the projection predicts that there will be a slight decline (~10%) in UVA water usage until 2035 where demand is forecast to be roughly 1 mgd during an average weather year. Following 2035, a slow increase in demand is projected through 2070. This projection is in line with the UVA planning goal of no increase in water use until 2035. The selected 14-inch meter area demand forecast is incorporated into the RWSA Urban System demand forecast.

Figure 3-10: UVA Demand 14" Meter Area Demand Forecast



3.4.4 Estimates for UVA Masterplanned Areas and Research Parks

Additionally, Hazen provided specific demand forecasts for several UVA masterplanned areas and research parks. Seven (7) future UVA projects were analyzed using a similar methodology as the general UVA projection. First, building categorization and demand drivers were determined through a review of UVA master planning documents. It was determined that three building categories would be considered, a general category, UVA hospital, and research park residential. The general category contains office, research, classroom, and athletic fields. Demand for each category is correlated to planned building square footage.

Second, direct water use intensities (in gpd/ksf) were determined for the general and UVA hospital building types based on historical usage and square footage. Additionally, indirect water use intensities for heating and cooling use were also used for both the general and UVA building categories. Adding the direct and indirect intensities provided a total water use intensity for the new developments. For the research park residential category, water use was estimated by applying the MF water intensity rate that is used in the non-university model described in section 3.3.1, along with the assumption that MF unit size will average 1,000 square feet. The latter assumption was necessary to get a number of dwelling units since the University provided an estimate of residential square footage rather than a count of dwelling units. Table 3-7 below summarizes usage rates used for the demand forecasts for masterplanned areas.

Table 3-7: UVA Masterplanned and Near-term Projects or Special Areas Area Usage Rates

Types	Water Use Intensity
Direct Rate General, gpd/ksf	50
Direct Rate Hospital, gpd/ksf	125
Indirect (Utility/HVAC) Rate, gpd/ksf	25
Research Park Residential, DU/ksf	1
Research Park Residential, gpd/du	79.5

Third, demand projections for the benchmark years 2030, 2045, and 2070 were calculated using the anticipated project square footage and the usage rates stated above. Projected completion time for each project was used to attribute new demand for the benchmark years except for the UVA Research Park project which is assumed to be steadily built over the forecast horizon, building a fixed amount of square footage every year. Table 3-8 summarizes demand projections for the Brandon Avenue, Hospital Bed Expansion, North Grounds / Athletics, Emmet/Ivy Corridor, Ivy Mountain, Fontaine Campus and North Fork (UVA) Research Park Projects. The UVA masterplanned areas and research parks demand forecast is incorporated into the RWSA Urban System demand forecast.

Table 3-8: Demand Forecast for UVA Masterplanned Areas and Research Parks

Assumed Service	Project Name	Total Net Area, ksf	2030 New Use, kgd	2030 Total Use, kgd	2045 New Use, kgd	2045 Total Use, kgd	2070 New Use, kgd	2070 Total Use, kgd
14" Meter Area	Brandon Ave	405	30	30	-	30	-	30
	Hospital Bed Expansion	440	66	66	-	66	-	66
	North Grounds / Athletics	279	21	21	-	21	-	21
	Subtotal	1124	117	117	-	117	-	117
City	Emmet/Ivy Corridor[1]	678	*100*[1]	*100*[1]	-	*100*[1]	-	*100*[1]
ACSA	Ivy Mountain	323	24	24	-	24	-	24
	Fontaine Campus	866	38	38	27	65	-	65
	Near Term Projects	500	38	38	-	38	-	38
	Long Term Projects	366	-	-	27	27	-	27
	UVA Research Park	3150	42	42	61	103	69	172
	Residential	500	9	9	11	21	19	40
	Non-residential	2650	33	33	50	83	50	133
	Subtotal	4339	103	103	89	192	69	261
Total		6141	321	321	97	410	69	479

1 - Based on Table 3-7 and the square footage of the project, the daily average use is projected to be about 50,000 gpd. However, the University of Virginia – Ivy Corridor Redevelopment Phase I Public Realm (issue date September 3, 2019) cited water usage for this site at 248,500 gpd. The latter cited figure is well beyond water usage rates at similar University facilities, but the demand projection for this project was adjusted upward to provide a more conservative estimate.

3.5 Primary Forecast Results by Pressure Zone

Combining the forecast methods used for the ACSA and City as described in Sections 3.1 and 3.2 together with the water demand forecast for the University described above in Section 3.3 produces an overall retail water demand forecast by pressure zone as described in Table 3-9.

Table 3-9: RWSA Retail Demand Forecast by Pressure Zone

Forecast Date Demand in mgd					
Pressure Zone	**2017**	**2030**	**2045**	**2070**	**Demand Change through 2045**
Ashcroft Low	0.045	0.07	0.10	0.12	+ 124%
Ashcroft Middle	0.0044	0.08	0.24	0.34	+ 5300%
Ashcroft High	0.0005	0.002	0.005	0.007	+1050%
Ednam	0.039	0.04	0.04	0.04	-1%
Lambeth	0.184	0.19	0.19	0.20	+3%
Lewis Mountain	0.304	0.45	0.53	0.59	+74%
Mill Creek	0.036	0.04	0.05	0.06	+52%
Mosby Mountain	0.079	0.11	0.16	0.18	+98%
Piney Mountain	0.32	0.52	0.71	0.89	+123%
Stillhouse	0.67	0.70	0.76	0.80	+14%
Urban Ring	5.37	5.96	6.46	7.13	+20%
UVA Pressure Zone (accounts outside 14" meter area)	0.024	0.025	0.026	0.029	+8%
UVA 14" Meter Forecast	1.25	1.13	1.19	1.39	-5%
Total Retail Demand	**8.33**	**9.31**	**10.47**	**11.77**	**+26%**

As can be discerned from the chart, demand growth is not anticipated to be uniform on a percentage basis across pressure zones. Seven of the outlying pressure zones are anticipated to grow faster in their water consumption on a percentage basis than the Urban Zone while four are expected to exhibit little growth (Stillhouse, Ednam, UVA, and Lambeth). Nevertheless, the Urban Ring Pressure Zone demand growth will continue and is expected to account for 60-65% of retail water sales throughout the forecast period.

Table 3-10 summarizes retail, non-revenue, and process water portions of the forecast. It was assumed that non-revenue water will continue to average 12-13% of the retail volume. Non-revenue water refers to water use that does not generate revenue, including that used for line flushing, fire flows, loss to leakage, unauthorized connections, unbilled accounts, or otherwise used at points that are unbilled. While each of these possibilities represent specific ways water can end up in the non-revenue category, not all utilities exhibit each type of non-revenue water and a non-revenue analysis was not conducted for the RWSA as part of the Demand Forecast Study. While it is assumed that non-revenue water will remain a stable fraction of retail demand, there are reasons that it could shift. Some of the more common reasons for changes in the non-revenue fraction include:

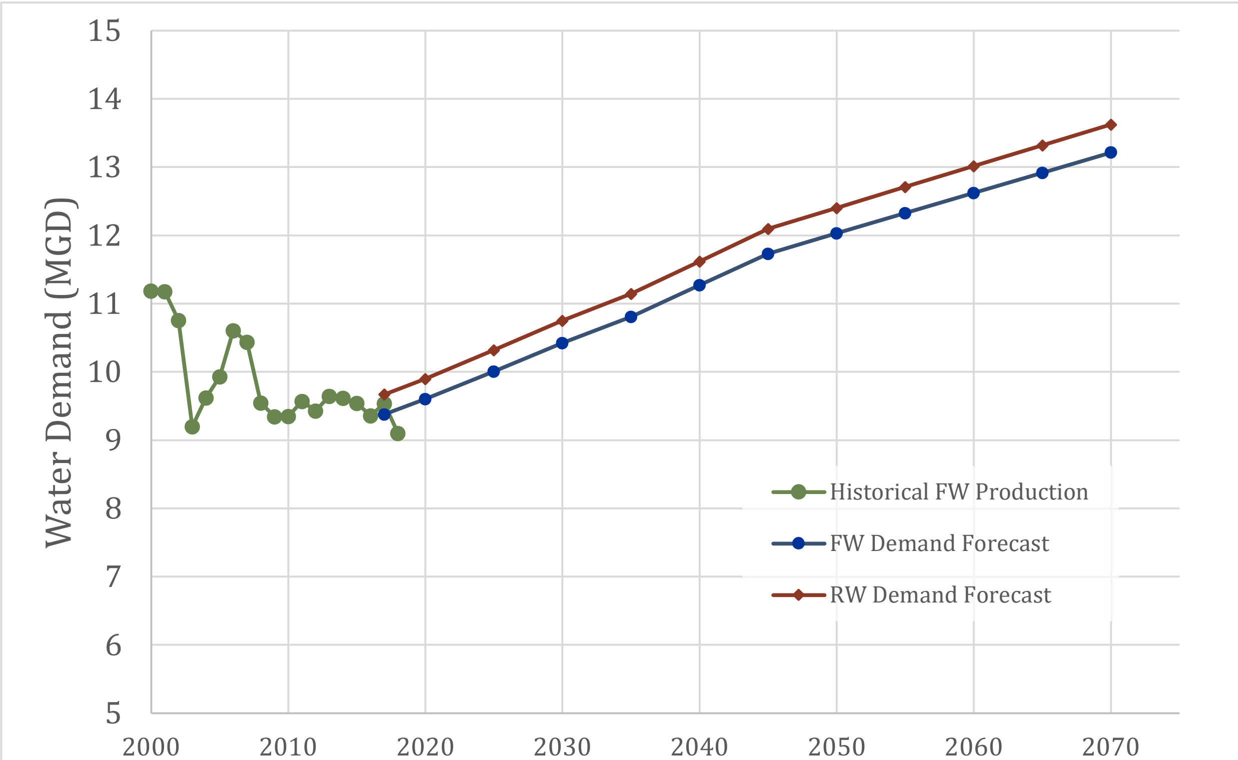
1. Aging infrastructure can result in increasing losses via main breaks and smaller leaks.
2. Leak detection programs are often able to help utilities to noticeably reduce the fraction of non-revenue water.
3. Water quality concerns can force a utility or its customers to increase line flushing to address:
    a. Increased water age in areas of the distribution system with lower demands which, together with reduced retail demand can increase the relative fraction of non-revenue water.
    b. More stringent regulation of disinfection by products or other water quality parameters related to water age.

Process water losses are relatively low system-wide because the South Rivanna WTP, the largest in the system, currently has a very minimal process water loss. Process water loss at South Rivanna WTP is assumed to be 1% for the purpose of calculating raw water demand. Process water losses at Observatory WTP and the North Rivanna WTP are 6% and 3.3% of finished water production, respectively, based on an accounting of the last several years of production data. Figure 3-11 illustrates both raw and finished water demand projections for the primary forecast scenario.

Table 3-10: Raw and Finished Water Forecasts

Forecast Date Demand in mgd					
Demand Component	**2017**	**2030**	**2045**	**2070**	**Change through 2045**
Retail Total	8.33	9.31	10.47	11.77	26%
Non – Revenue Water	1.05	1.17	1.32	1.48	26%
FW Production	9.38	10.49	11.79	13.26	26%
WTP Process Water Loss	0.29	0.33	0.37	0.41	26%
Raw Water Need	9.67	10.82	12.15	13.67	26%

Figure 3-11: RWSA Raw and Finished Water Demand Forecasts



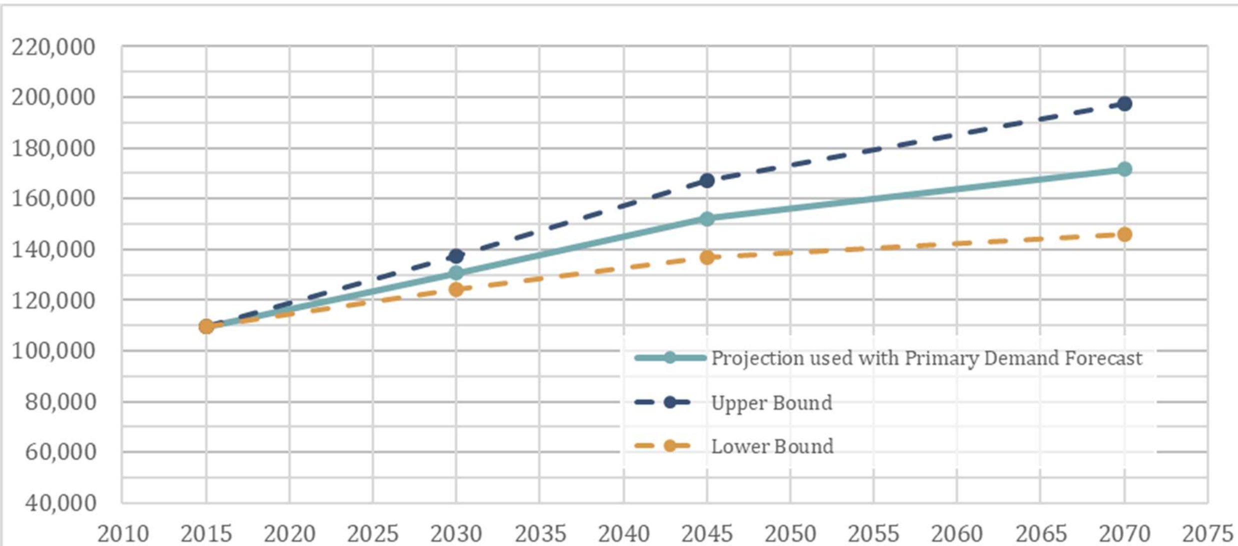
3.6 Forecast Sensitivity Analyses

Prior to about the year 2000, demand forecasting industry wide tended to be a relatively simple exercise that involved calculating a unit demand and multiplying it by a population projection. In many cases even these steps were avoided and a simple linear regression was applied to the historical annual average demand trend to produce the future water demand forecast. Relying on such simple techniques has fallen out of favor as water using behaviors have changed. While urban areas across the country are, in many cases, continuing to exhibit population growth (unlike most rural areas), water demand intensity has been shifting significantly over the past two decades for various reasons. Some of the more commonly cited reasons are that water prices have risen as water utilities shift to full cost-recovery pricing methods, conservation has become more appealing for social and economic reasons, and water using devices have become increasingly efficient. Anticipating the rate of improvement in conservation and efficiency has been difficult for an industry prone to err on the side of caution since a central mission of all water utilities is to provide a high level of supply reliability. However, over-projecting demand can lead to over-investment in infrastructure and associated impacts such as stranding financial resources, water quality concerns, the need to raise customer rates, and higher levels of environmental impact from larger or more infrastructure. Understanding that the primary planning forecast in this report is also intended to be somewhat conservative (more likely to over-project than under-project), some sensitivity analyses were conducted to aid in RWSA's decision making process when facing choices that require anticipating long-range water demands. Many assumptions about future conditions were necessary to produce this forecast. These analyses were conducted to help gauge forecast sensitivity to the principal forecast assumptions which are population growth and water demand intensity (unit demands). In addition, this section also provides an estimate for demand sensitivity to year-to-year fluctuations in weather conditions.

3.6.1 Population Growth

Population growth was assumed to vary by ± 5%, ± 10%, and ± 15%, at the 2030, 2045, and 2070 forecast intervals, respectively. These bounds are less than the full range of potential error in a long-range population forecast according to the Weldon Cooper Center, but were considered sufficient to capture the likely range of forecasting error[2]. The population projection bounds along with the primary projection forecast for the Urban System Service Area are shown in Figure 3-12.

Figure 3-12: Population Forecast Bounds for RWSA Service Area



[2] http://statchatva.org/2017/06/21/how-accurate-are-population-projections/

When the upper and lower bound population projections are factored into the land use and demand forecast model the water demand shifts are somewhat less than the population error bounds on a percentage basis. This is due to the fact that new development (and redeveloped areas) built to accommodate population and employment growth are predicted to be more efficient than the existing building stock. Figure 3-13 illustrates the demand forecast sensitivity to the assumed population range. Table 3-11 contains the demand forecast figures as well.

Figure 3-13: Demand Forecast Sensitivity Range to Population Projection Uncertainty

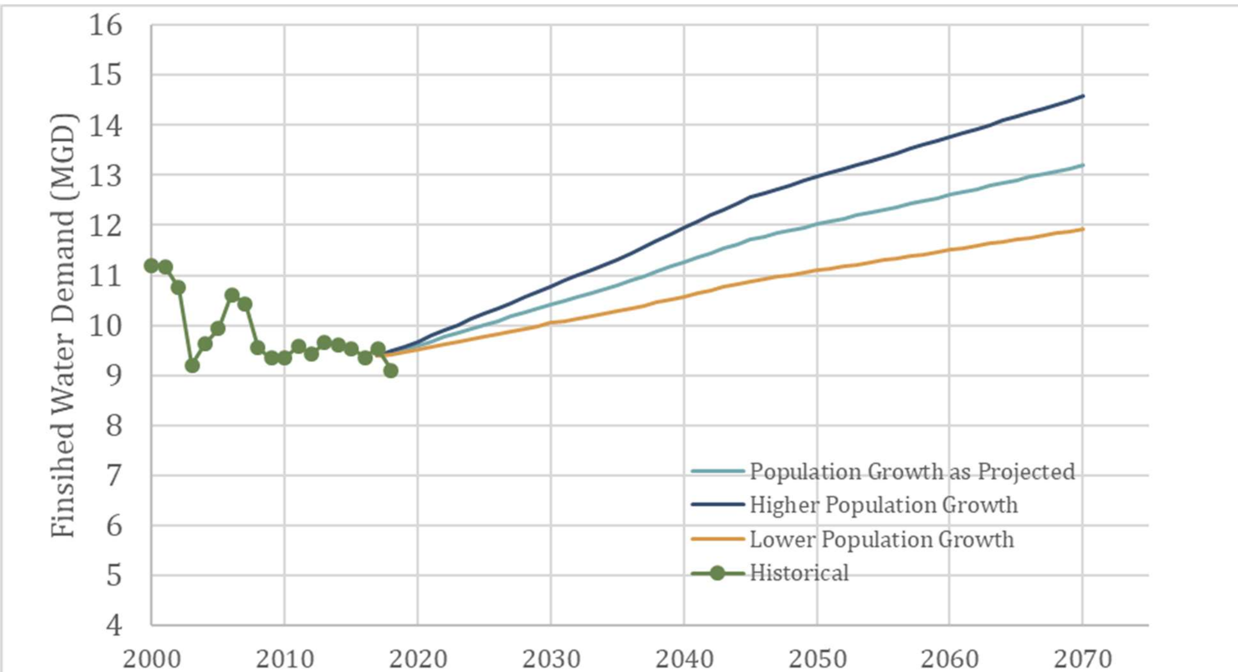


Table 3-11: Demand Forecast by Year and Population Scenario

	Demand in mgd		
	2030	**2045**	**2070**
Lower Bound Population	10.0	10.6	11.9
Primary Population Forecast	10.4	11.3	13.2
Upper Bound Population	10.8	11.9	14.6

3.6.2 Unit Demand Sensitivity

Unit demand assumptions have been the largest source of error in demand forecasts conducted over the past two decades. The primary demand forecast in this report assumes existing structures (other than those on-grounds at UVA) will continue to use water at the same rates as they have historically and that new development will be as efficient as new buildings constructed in the last decade, but no more so. Given the historical trends (see Figures 3-4 and 3-5) in water use intensity within the Urban Service Area, such an assumption is likely to err on the high side of future water use intensity. However, it also seems unlikely that unit demands will continue to fall as rapidly as the have over the past 10-20 years.

A more aggressive conservation scenario was developed under the assumption that per capita unit demand could continue declining at about 0.5 gpcd/yr through 2045, which is about half the rate of decline exhibited in the ACSA since 2007 and about one-third the rate of decline observed in Charlottesville over the same period. These rates were selected knowing that the RWSA Urban Service Area is already amongst the most efficient water using areas in the nation based on the per capita metric, and has probably already achieved much of the readily attainable conservation and efficiency gains given the state of water use technology at present. After 2045 the rate of additional decline in per capita water use is assumed to be 0.15 gpcd/yr. Figures 3-14 and 3-15 illustrate the unit demand rates in the primary forecast, the more aggressive conservation sensitivity scenario described above, as well as illustrating unit demand assume din the 2011 Urban Demand Forecast Study for comparison for both the ACSA and Charlottesville portions of the service area.

Figure 3-14: ACSA Unit Demand Sensitivity Scenarios

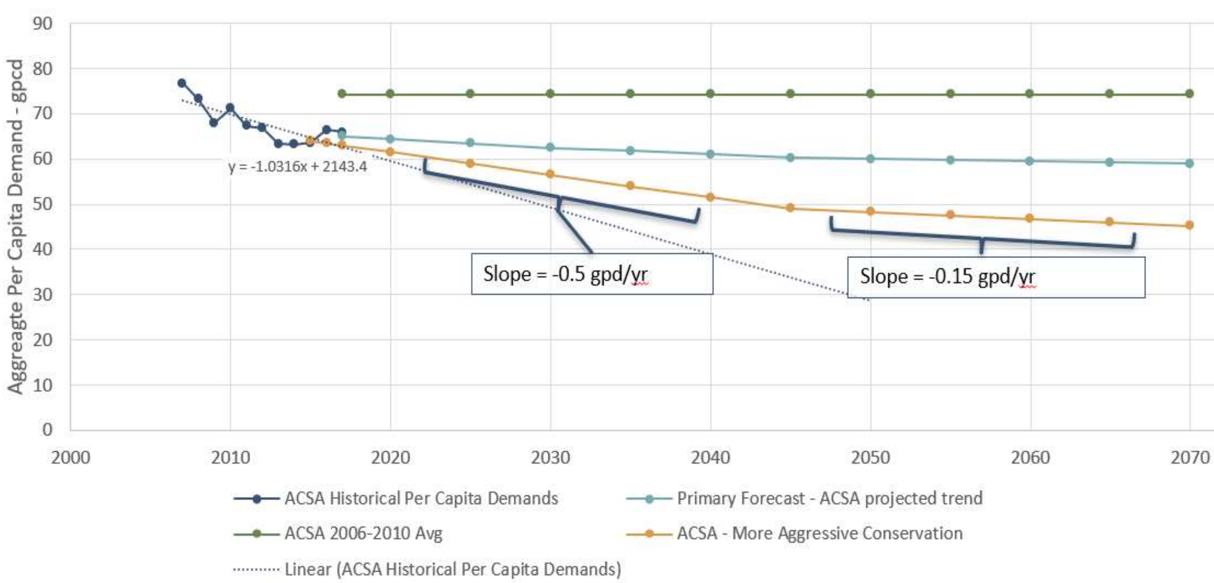
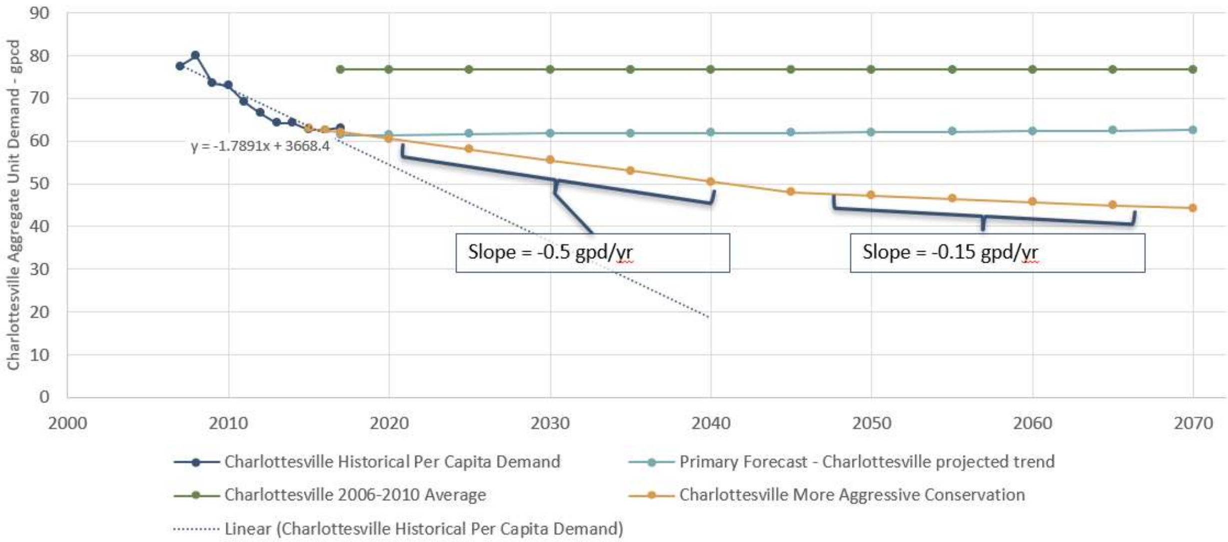


Figure 3-15: Charlottesville Unit Demand Sensitivity Scenarios



When these unit demand scenarios are combined with the primary population forecasts for the City and the ACSA, as well as the UVA demand forecast, the results show an upper and lower bound forecast for unit demand sensitivity. For planning purposes, the Primary Forecast and More Aggressive Conservation scenarios form a plausible upper and lower forecast bound based on uncertainty with respect to future water use intensity (unit demand). The series employing the 2006-2010 average unit demand is shown for comparative purposes to illustrate what water demands might look like if not for the conservation and efficiency measures adopted over the past decade. However, this series is not to be considered a plausible projection bound at present as there is no reason to believe unit demands would revert to pre-2010 usage rates. Table 3-12 contains the demand forecast numbers associated with the scenarios displayed in Figure 3-13. The More Aggressive Conservation scenario includes the Greater Efficiency Improvement forecast demand scenario for UVA whereas the Primary Forecast scenario utilizes the Selected UVA 14" Meter Area Forecast scenario. The respective UVA forecast scenarios for the area served by the 14" meter are described in section 3.4.3 and displayed in Figure 3-10.

Figure 3-16: Demand Forecast Sensitivity Range to Unit Demand Uncertainty

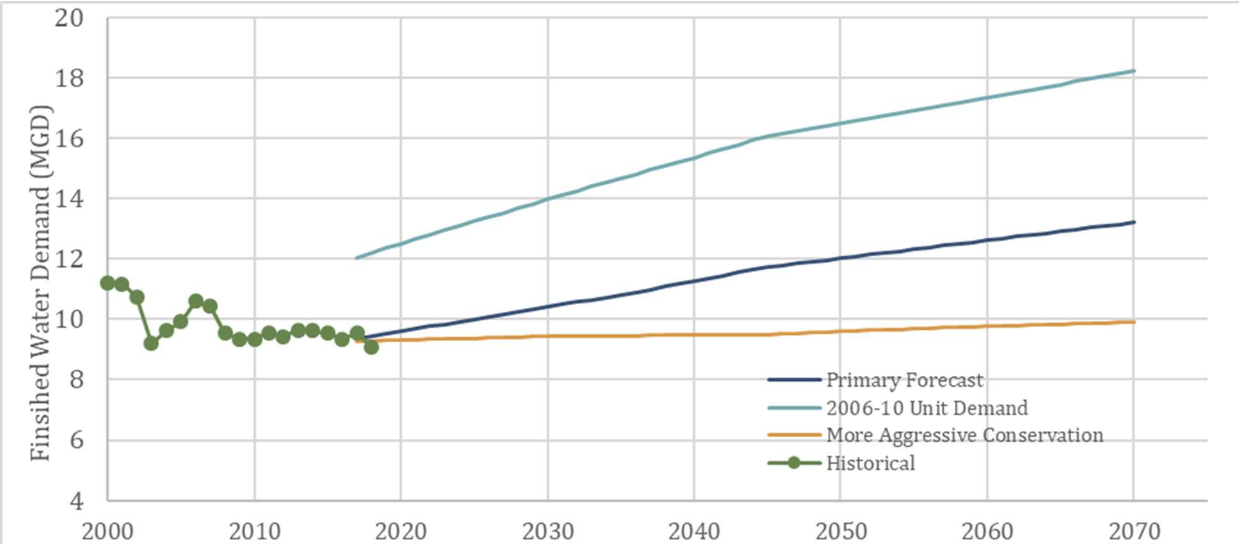


Table 3-12: Demand Forecast by Year and Unit Demand Sensitivity Scenario

Scenario	Demand in mgd		
	2030	2045	2070
2006-2010 Avg. Unit Demand (For comparative purposes only – not a plausible projection)	14.0	16.1	18.2
Primary Forecast	10.4	11.3	13.2
More Aggressive Conservation	9.4	9.5	9.9

3.6.3 Weather Sensitivity (Annual)

Of the manifold influences on water demand, weather is among the most variable over short time scales. Weather can move from one extreme to the opposite in a relatively brief period, though the fluctuations tend to average out over longer periods. Nevertheless, at time scales as long a year, weather can vary enough to noticeably influence water demand and cause it to deviate from that expected under average conditions. Since weather is simultaneously influencing the hydrology of RWSA's reservoir system and water demand, it is important for the purposes of risk management and long-range planning to understand how much demand might increase (or decrease) during these periods. Year-to-year variability in water demand will correspond well with the temporal scale at which RWSA's reservoir system reliability exhibits the greatest sensitivity to weather driven hydrologic variation.

To estimate demand response with respect to annual weather variability, weather data for this region was collected over a 39-year period from 1980-2018. A multiple linear regression model was fit to water demand from 2007 – 2018 (response variable) using annual temperature and precipitation conditions as the explanatory variables. The modeling process was carried out with City, ACSA, and UVA demands considered independently. As expected, the models demonstrate that water demand is positively correlated with temperature and inversely correlated with precipitation. The demand-response coefficients for the three service regions are described in Table 3-13. The coefficients represent the expected demand response per standard deviation from the mean annual temperature and precipitation conditions.

Table 3-13: Expected Demand Response

RWSA Service Region	Temperature Response[1]	Precipitation Response[1]
ACSA	+2.45%	-2.17%
Charlottesville	+0.83%	-0.88%
UVA Grounds (14” meter area)	+3.30%	-2.29%

1 – response per standard deviation from mean, Temperature std dev =1.5°F, Precipitation std dev =7.2 inches

The ACSA portion of the service area exhibits a sensitivity to weather variability that is very typical of the mid-Atlantic region of the United States. Charlottesville’s sensitivity to weather is quite low and may reflect a high ratio of commercial and multi-family residences as compared to single family homes which typically have a greater proportion of outdoor and seasonal water use that is weather dependent. The University of Virginia’s 14” meter area is fairly sensitive to weather fluctuations and is likely due to the use of water-cooled chiller facilities to produce cooling for buildings on grounds. Furthermore, as the University becomes more water efficient in other building categories, the utility category may make up a greater fraction of water use leading to even greater sensitivity to weather in the future.

The demand response coefficients were used to model water demand variability over 5,000 simulated years in which weather conditions were varied using a statistical model based on 1980-2018 weather conditions using a technique known as Monte Carlo Simulation. This number of simulations is more than sufficient to produce a statistical distribution that is both reproducible, unlikely to change significantly with a greater number of simulations and is time-efficient to execute with present computing capabilities. More detail on the weather-demand modeling is provided in Appendix C. The weather bounds used for planning purposes are displayed in Figures 3-17 through 3-20 and show the 99th percentile (upper bound) and 5th percentile (lower bound). The 5th percentile was chosen for the lower bound rather than the 1st percentile because experience indicates that the demand response to weather is attenuated at the low end of the spectrum. This is especially true with respect to precipitation when a threshold is reached such that additional rainfall does not lead to further reduction in demand once turf watering needs are met by sufficient precipitation. At the upper end of the spectrum, it is possible to have events hotter and drier than the 99th percentile conditions. However, imposing mandatory conservation measures is an available tool RWSA can employ to curtail the upper end demand response to such weather events. Furthermore, there is little evidence that the uncurtailed demand response would remain linear beyond the 99th percentile as this type of model assumes.

Figure 3-17: RWSA Finished Water Demand Forecast Sensitivity to Annual Weather Variability

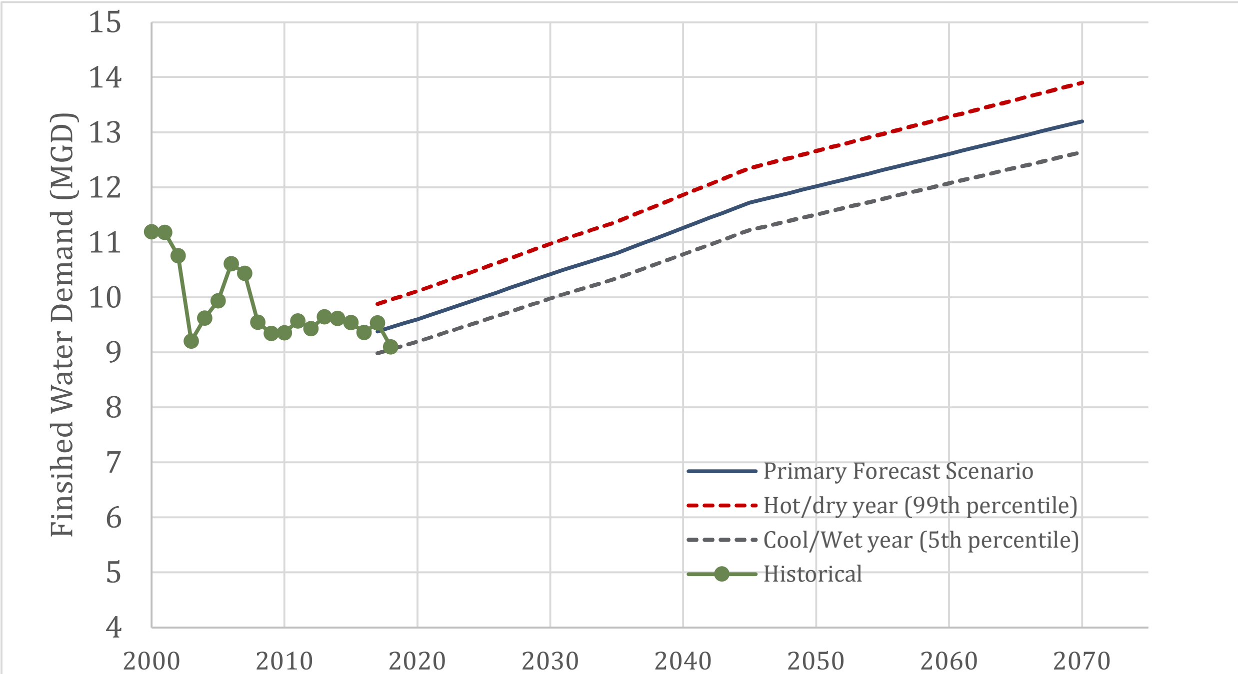


Figure 3-18: ACSA Demand Forecast Sensitivity to Annual Weather Variation

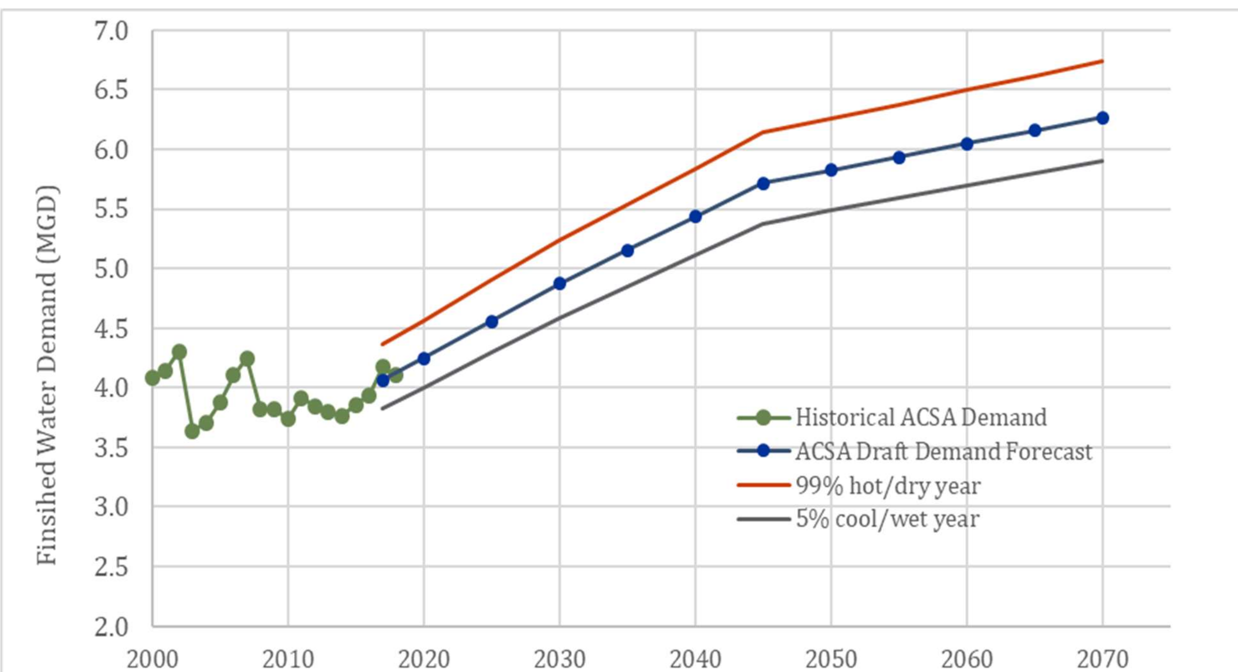


Figure 3-19: Charlottesville Demand Forecast Sensitivity to Annual Weather Variation

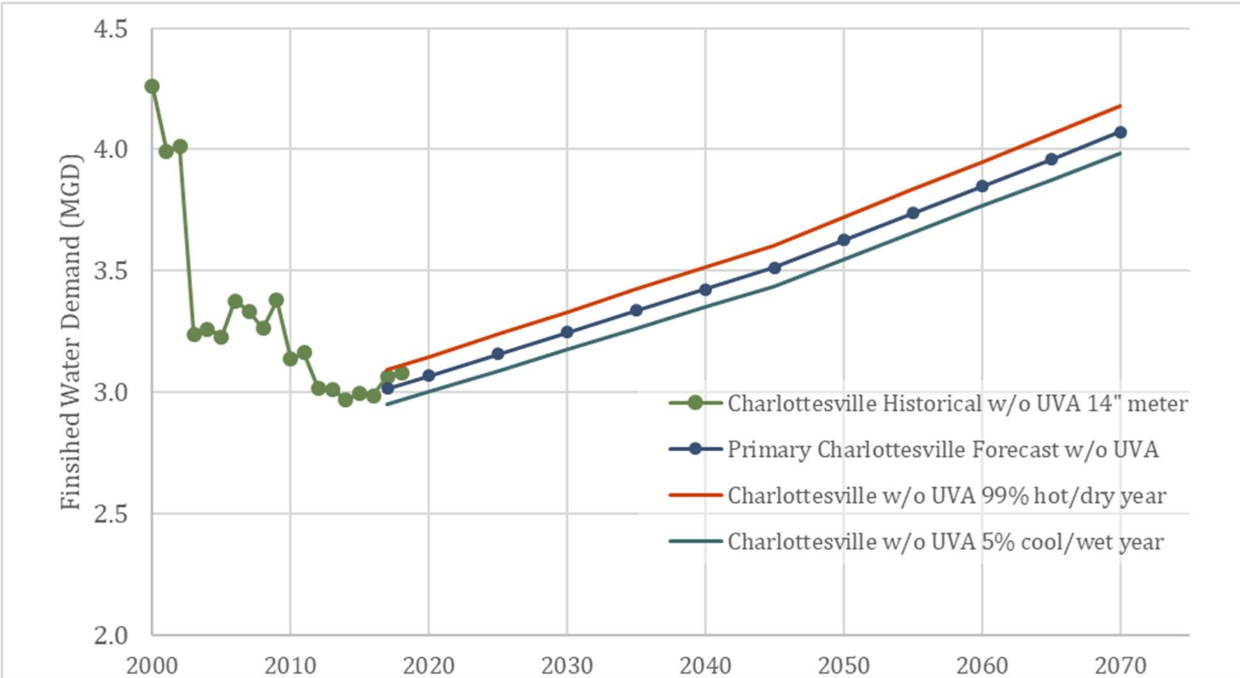


Figure 3-20: University Demand Forecast Sensitivity to Annual Weather Variation

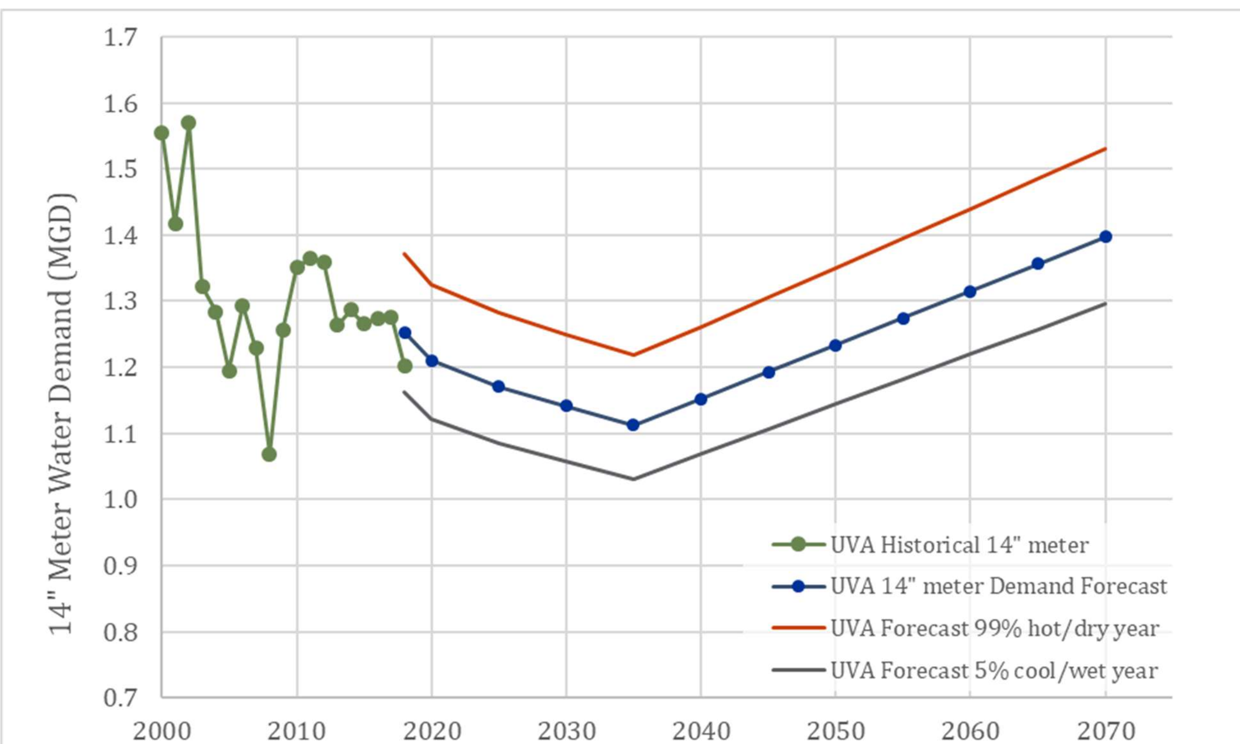


Table 3-14: Finished Water Weather Variability Bounds (mgd)

Forecast Horizon	ACSA		Charlottesville		UVA		RWSA Total[1]	
	5th %tile	99th %tile	5th %tile	99th %tile	5th %tile	99th %tile	5th %tile	99th %tile
2017	3.82	4.36	2.95	3.09	1.16	1.37	8.99	9.88
2030	4.59	5.23	3.18	3.33	1.06	1.25	9.99	10.98
2045	5.38	6.14	3.44	3.61	1.11	1.31	11.24	12.36
2070	5.90	6.74	3.98	4.18	1.30	1.53	12.66	13.92

1 – RWSA Totals also include non-revenue finished water not included in ACSA, Charlottesville and UVA Totals

Finally, one additional feature afforded by the weather variability analysis is that using response described in Table 3-13 to remove the weather influence should make it easier and more reliable to identify the updated direction of the overall unit demand trend (driven by socioeconomic factors).

3.6.4 Compound Sensitivity Bounds

A PowerBI file is provided to navigate the many permutations resulting from the interactions of the three sensitivity analyses described in Sections 3.6.1 through 3.6.3

4. Peak Day Factor Analysis and Maximum Day Demand Forecast

Peak day demand, also referred to as maximum day demand (MDD) is the highest daily demand that occurs in a given year. Water treatment plants, as well as raw and finished water pump stations, are typically sized with peak day criteria in mind and as such it is important to estimate these demands over the water demand forecast horizon. Section 3 described the development of average day demand forecasts and maximum day demand forecasts are typically estimated with a peak to average day ratio (or MDD:ADD ratio).

Two methods were used to approach the peak to average day ratios for RWSA. The primary peak factor analysis (WTP Production Method) estimated peaking factors using RWSA's historical daily finished water pumping data for North Rivanna WTP, South Rivanna WTP, and Observatory WTP (including non-revenue water) for 2010 to 2018. This is the method typically used to determine MDD:ADD ratios. The second method (Mass Balance Method) made use of available distribution pumping records from 2013 to 2018. This method is described in Appendix D.

The primary peak factor analysis used a daily sum of the 3 WTPs' (North Rivanna, South Rivanna, and Observatory) finished water flows from January 2010 through November 2018. The highest day for each year was divided by the average production for that year to get an annual MDD peak factor. Figure 4-1 illustrates the variability in peaking factors over the past nine years. Peaking factors averaged 1.37 over this period. The maximum and minimum peaking factor was 1.50 in 2017 and 1.22 in 2014, respectively. In the last four years the peaking factor has been greater than 1.30.

Figure 4-1: WTP Production Method – Historical Maximum Day Peaking Factors

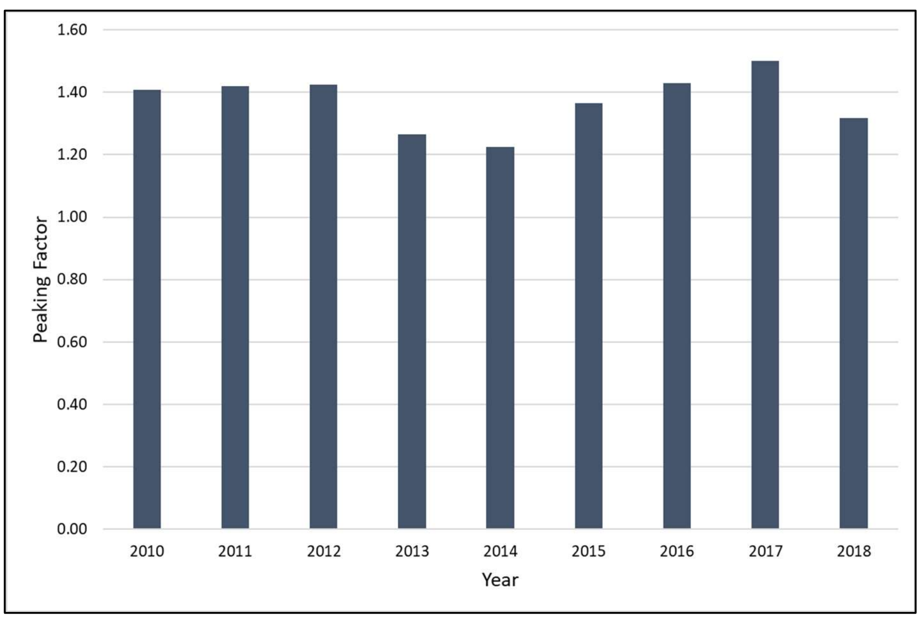
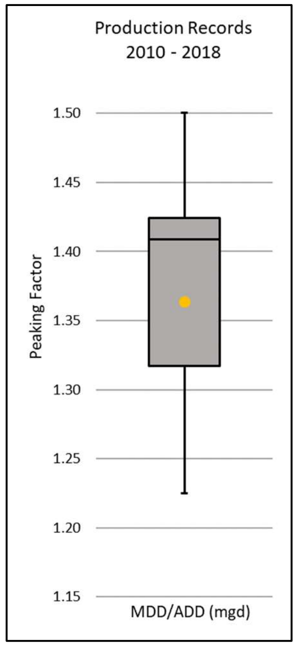


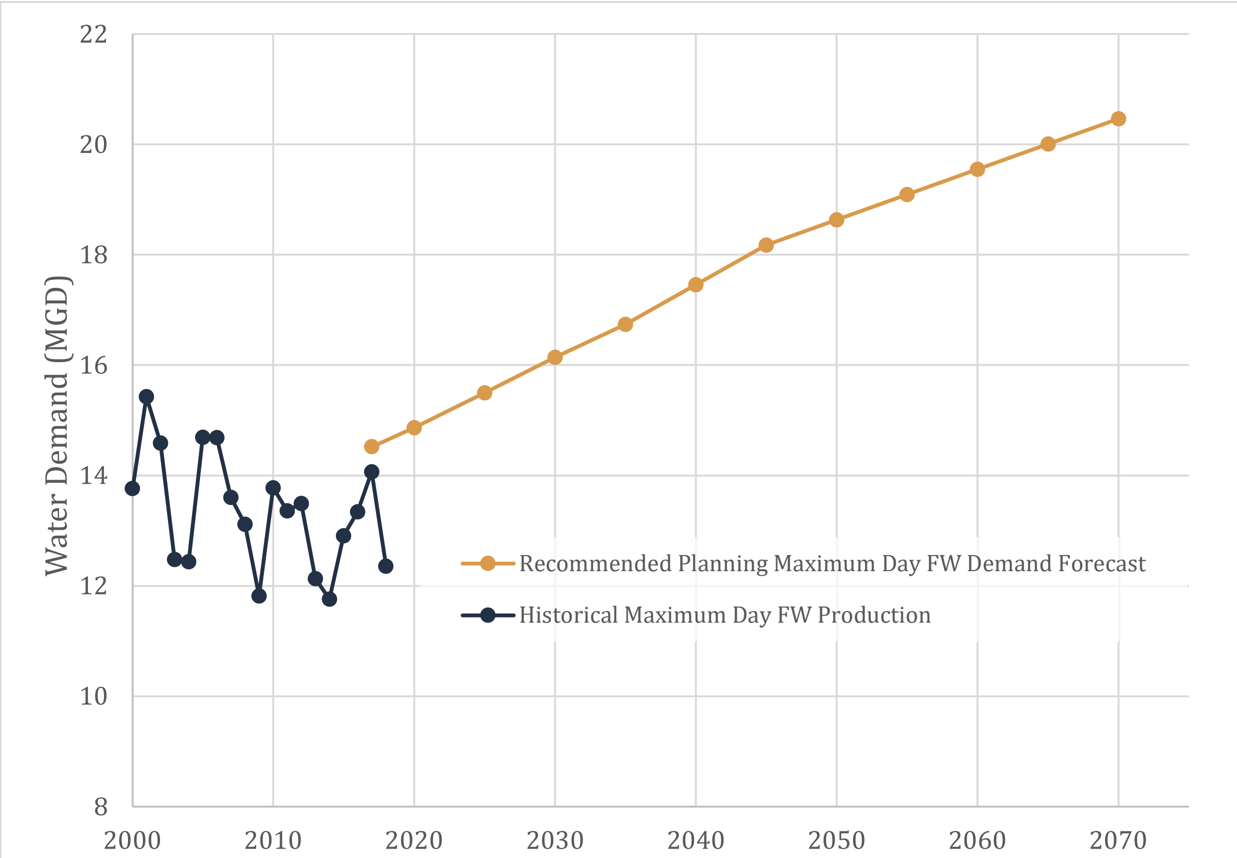
Figure 4-2 illustrates a box and whisker plot of peaking factors for the WTP Production Method. RWSA staff agreed that the 95th percentile of recent historical peaking factors should be used for planning facilities that need to be sized for maximum day demands. The 95th percentile of this dataset was 1.47.

Figure 4-2: Peaking Factors – WTP Production Method



Finally, there was no statistically significant relationship between the average day demand and the annual peak factor in a given year. This means a high (or low) peaking factor is roughly as likely to occur in a year in which the average demand itself is below, near average, or above the trend in annual demands. Therefore, it is recommended that a peaking factor of 1.47 times the hot/dry year average day demand forecast be used as a planning value for infrastructure capacities that are designed to handle maximum day demand within the RWSA Urban System. Figure 4-3 illustrates the maximum day FW demand projection for the Urban Service Area.

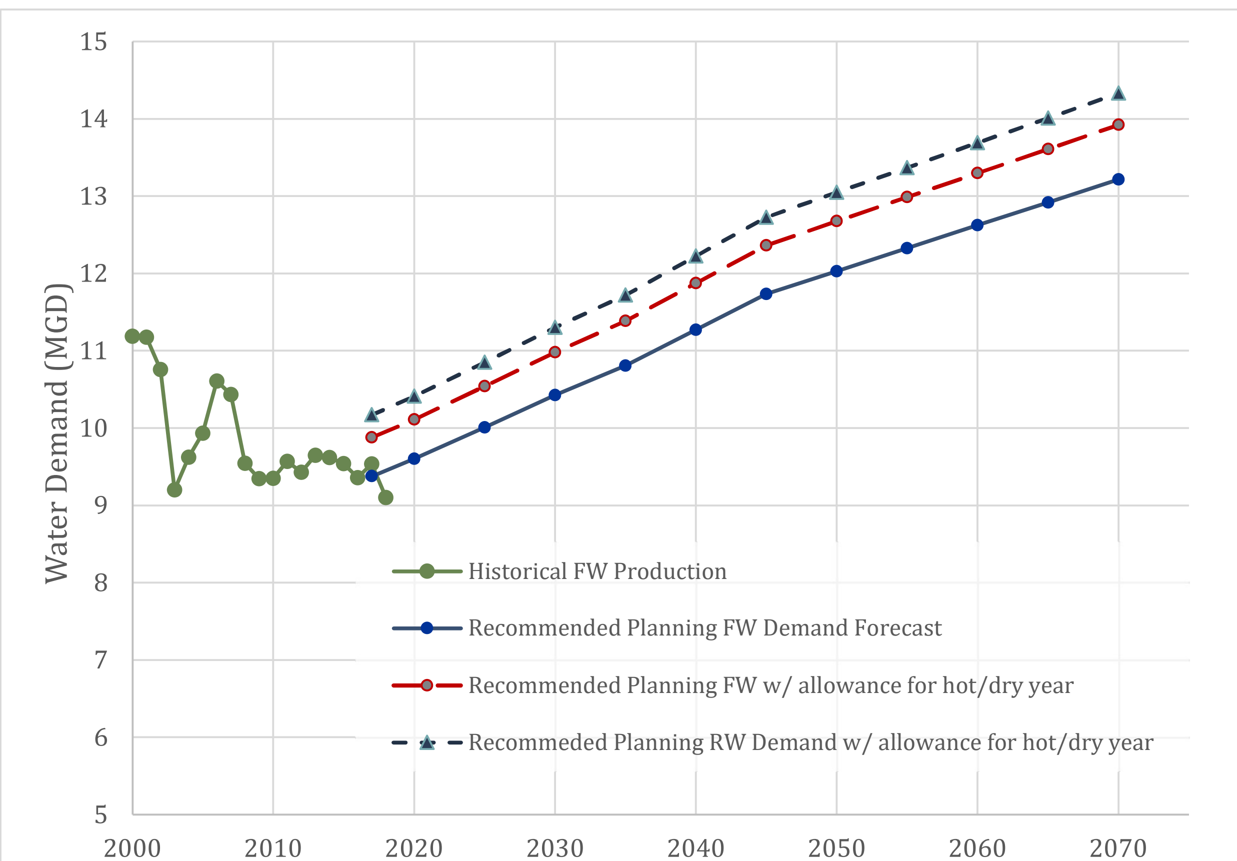
Figure 4-3: Maximum Day Demand Forecast for Primary Demand Forecast



5. Recommendations and Conclusions

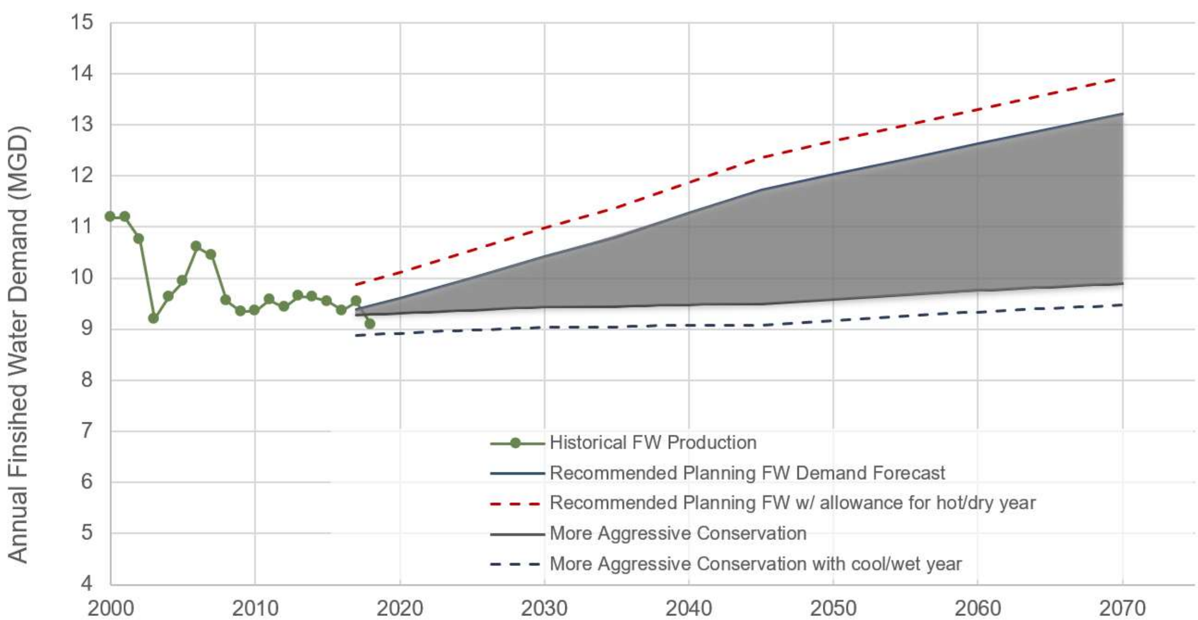
Chapter 780 of the Virginia Administrative Code covers local and regional water supply planning and states that plans shall be designed to "ensure adequate and safe drinking water is available" and to "promote conservation". The primary forecast developed for this report was developed with the principal goal of ensuring that RWSA plans for an adequate supply to meet future needs and is therefore the recommended forecast for infrastructure planning. The primary forecast also assumes that future development will continue to be as efficient as the development over the past 9 years which has led RWSA to be among the most water efficient utilities in the nation. Furthermore, the RWSA should provision for sufficient finished water (FW) to satisfy the increased annual average demand under sustained hot dry conditions that exceed the primary forecast (which assumes near average historical weather conditions) as shown in Figure 5-1. This additional demand may be met by either assuring sufficient additional supply during hot/dry years or imposing mandatory conservation such that demand can be curtailed to a level no greater than the reliable supply, or a combination of the two. Finally, in making these plans, RWSA should also ensure that raw water supplies are not only sufficient and reliable to meet the FW demand, but also account for process water loss, which at present is a low percentage of overall treatment plant production.

Figure 5-1 Recommended Infrastructure Planning Forecasts for Annual Average Demand



Nevertheless, the recommended infrastructure planning forecast is likely to err on the high side. The RWSA Urban Service Area has experienced steadily declining water intensities over the past two decades and this trend may continue for some time into the future until the most efficient plumbing devices and conservation practices fully penetrate the service area. Figure 5-2 illustrates a recommended planning bound, in gray, that the RWSA should prepare for. The lower end of the planning bound is formed using the ‘More Aggressive Conservation’ scenario described in Section 3.5.2. Should demand trend toward this lower bound, revenue from sales will be less than if financial planning is based on the demands from the recommended infrastructure planning forecast. Furthermore, individual years may fall outside of the gray shaded area due to weather variation. Weather bounds extended above and below the recommended planning bounds are indicated by the dashed series outside of the gray shaded planning bound. The expectation is that individual years may fall between the gray planning region and the dashed bounds, but that longer term trends would remain within the gray-shaded region.

Figure 5-2: Recommended Planning Bounds for Annual Trends



The population forecast uncertainty was not included in the planning bounds, though it is a factor that, combined with other uncertainties, could potentially push water demand outside the planning bounds shown in Figure 5-2. However, service area population is a relatively discernable quantity and does not tend to fluctuate rapidly from year to year. If population does track closer to the higher or lower population growth scenarios (described in Section 3.5.1) then the bounds shown in Figure 5-2 can be adjusted by selecting for the appropriate population forecast in the electronic deliverable (PowerBI format) that accompanies this report. Population can be tracked prior to the next water demand forecast by checking in with annually updated population figures provided by the Weldon Cooper Center (for Charlottesville) and by tracking the number of new residential connections for the ACSA multiplied by upcoming 2020 Census estimates for persons per household in the relevant block groups.

Maximum day demands drive the sizing of water treatment plants, which in turn influence supply intakes, raw water pump stations, and to some extent finished water pumping and conveyance pipelines. It is critical that capacity for these facilities is planned for with an appropriate engineering safety factor and are operational ahead of these events to meet expectations for service reliability. However, unlike fluctuations in the average day demand for a year, fluctuations in the peak day (or MDD:ADD ratio) from year to year typically do not have repercussions for utility revenue. Nevertheless, both low and high forecast ranges for maximum day demand are illustrated in Figure 5-3 for both the recommended planning forecast as well the more aggressive conservation scenario. As with the planning bounds for average annual demand described above, peak day sensitivity to population growth is not incorporated into the figure, but variance in service area population should be tracked prior to conducting the next water demand forecast.

Figure 5-3: Maximum Day Demand Ranges for Selected Scenarios

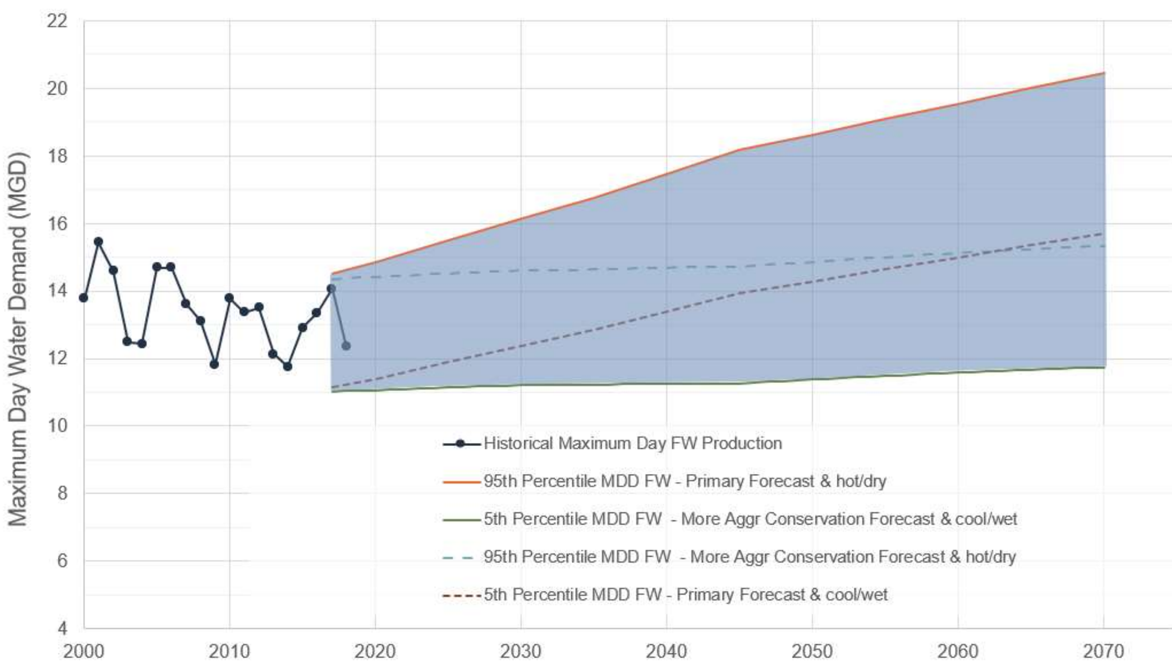


Table 5-1 provides average day demand values for the series shown in Figures 5-1 and 5-2 as well as the higher and lower population growth scenarios described in Section 3.6.1. Unless otherwise indicated, it is assumed the forecast values are for average year weather conditions, the unit demand used with the recommended planning forecast[3], and expected population growth.

Table 5-1: Average Day Demand Forecast for Key Scenarios (mgd)

Forecast Scenario	Year					
	2020	2030	2040	2050	2060	2070
Recommended Planning FW Demand	9.6	10.4	11.3	12.0	12.6	13.2
Recommended Planning FW Demand Hot/Dry Extreme	10.1	11.0	11.9	12.7	13.3	13.9
Recommended Planning RW Demand Hot/Dry Extreme	10.4	11.3	12.2	13.1	13.7	14.3
More Aggressive Conservation FW Demand	9.3	9.4	9.5	9.6	9.8	9.9
More Aggressive Conservation FW Demand Cool/Wet Extreme	8.9	9.0	9.1	9.2	9.3	9.5
Higher Population Growth FW Demand	9.7	10.9	12.0	13.1	14.0	14.9
Lower Population Growth FW Demand	9.5	10.0	10.5	10.9	11.2	11.4

Similarly, Table 5-2 provides maximum day demand values for the recommended planning forecast conditions as well as a set of scenarios that generally form upper and lower bounds for peak day conditions over the forecast horizon. However, in addition to the combination of sensitivity scenarios used above, a low range (5th percentile [1.24 x average day]) and high range (95th percentile [1.47 x average day]) peak day factor was assumed depending on whether a low or high bound would be accentuated under that scenario.

[3] Single-family demand 109.4 gpd/DU; multi-family demand 79.5 gpd/DU; Non-residential 75.0 gpd/ksf from Section 3

Table 5-2: Peak Day Demand Estimates for Key Scenarios (mgd)

Forecast Scenario	Peak Day Factor	Year					
		2020	2030	2040	2050	2060	2070
Recommended Planning FW Demand	1.47	14.1	15.3	16.6	17.7	18.6	19.4
Recommended Planning FW Demand Hot/Dry Extreme	1.47	14.9	16.1	17.5	18.6	19.6	20.5
Recommended Planning RW Demand Hot/Dry Extreme	1.47	15.3	16.6	18.0	19.2	20.1	21.1
More Aggressive Conservation FW Demand	1.47	13.7	13.9	13.9	14.1	14.3	14.5
Higher Population Growth FW Demand Hot/Dry Extreme	1.47	15.0	16.8	18.6	20.3	21.7	23.1
More Aggressive Conservation FW Demand Cool/Wet Extreme	1.24	11.1	11.2	11.3	11.4	11.6	11.7
Lower Population Growth FW Demand Cool/Wet Extreme	1.24	11.3	11.9	12.5	13.0	13.3	13.6

Demand forecasts for each pressure zone are also provided in the PowerBI deliverable for each combination of the sensitivity scenarios described in Section 3.6. However, a note of caution is that there should be an expectation that development by pressure zone is subject to greater variability than is the service area as a whole.

Appendix A: Land Use Model Detail

The principal activities carried out under the land use modeling was the partitioning of the service area and the developing the set of assumptions that tell the model how to treat each partition. This involves assigning each unit of land (in this case the units were property parcels from City and County GIS data) to a partition. Each partition is treated with individual sets of rules based on its jurisdiction (city/county), current development status and zoning or masterplan guidelines. The sections below describe this process, first for the City of Charlottesville and then for the portion of the Urban System served by the ACSA.

A.1 City Partitioning

City land use partitions were based on adjusted zoning attributes of the City parcel layer as well as indicators of occupancy or vacancy for certain zoning classes.

Table A-2 how zoning and occupancy values were used to assign parcels to partitions. Partitions included the following:

- UVA Grounds – omitted from the City forecast
- Medical Center – demand assumed to not change
- Parks and Cemeteries – demand assumed to not change
- Mixed-Use Redevelopment Areas – Neighborhood Plan Zones and an area ½ mile around the Medical Center, all assumed to redevelop towards dense mixed-use characteristics
- Other Areas currently occupied – demand assumed to not change
- Other Areas currently vacant – assumed to develop towards zoned land use

Zoning attribute adjustments. Zoning attributes were contained in the *ZONE* field of the parcel_area_11_06_2018 layer. Prior to partitioning, *ZONE* attributes for some parcels were first adjusted as follows.

- **'MTLP', 'MLTPC', and 'MLTPH' ZONE values**. A total of 57 parcels initially contained 'MLTP', 'MLTPC', or 'MLTPH' in their ZONE fields, neither of which is a true zoning classification defined by the City. By visually cross-referencing the shapes and locations of these parcels in GIS with the City of Charlottesville Zoning District Map, it was established that each of these parcels was partially overlain by multiple zoning districts, though the specific classifications involved in these cases varied. Therefore, for each parcel having an 'MTLP', 'MLTPC', or 'MLTPH' in its ZONE field, that value was replaced to the true zoning classification covering the largest amount of the parcel's area. Figure A-1 shows the parcels having 'MLTP', 'MLTPC', and 'MLTPH' zone values, while Figure A-2 shows an example of an 'MLTP' parcel and its corresponding overlain zoning districts.

Table A-1: Data Source Files for the Demand Forecast

Source	Type	Original Filename	Description
A	Shapefile	*CVL_METERS.shp*	Point layer of retail meters with identifiers for associating consumption records
	Excel	*Water 6-1-16 to 5-31-17.xlsx*	Consumption records by meter (6-1-16 to 5-31-17)
	Excel	*Water Invoicing 7-1-17 to 6-30-18. xlsx*	Consumption records by meter (7-1-17 to 6-30-18)
	Shapefile	*parcel_area_11_06_2018.shp* [H]	Parcel delineations with zoning
	Text	*Real_Estate_Base_Data.csv*	Comma-delimited files containing records, by parcel, of State Tax land use codes, City land use codes, descriptions as well as residential building characteristics
	Text	*Real_Estate_Residential_Details.csv*	
	Text	*Real_Estate_Commercial_Details.csv*	
B	Shapefile	*URbanRingMetersBaker.shp*	Point layer of retail meters with FY 2017 consumption records in attribute table
C	Shapefile	*ParcelsStacked_current.shp* [I]	Polygon layers of parcel delineations with parcel identifiers • ParcelsStacked_current: all parcel shapes including overlapping parcels in same location (e.g. multi-story condominiums) • Parcels_Current: overlapping parcels consolidated into single shapes • Zoning_Current: parcel shapes with identifiers and zoning designations
	Shapefile	*Parcels_Current.shp* [I]	
	Shapefile	*Zoning_Current.shp* [I]	
D	Shapefile	*places29MP_landuse_current.shp* [I]	Polygon layers of development areas from the OCD's neighborhood master plans with future land use designations (these areas are drawn independently of, and do not necessarily align with, parcels)
	Shapefile	*pantopsMP_landuse_current.shp* [I]	
	Shapefile	*village_of_rivannaMP_current.shp* [I]	
	Shapefile	*southern_and_western_urban_ neighborhoods_landuse_current.shp* [I]	
	Shapefile	*Development_RWSA.lpk*	Package of polygon layers for areas currently at various stages of development approval and construction with planned values for SF and MF dwelling units and NR square footage
	Shapefile	*COs_2019_01_02.shp*	Polygon layer of building footprints for new construction since 1991 (mostly since 2000), with certificates of occupancy listing residential type and number of dwelling units in each building.
	Text	*GIS_CardLevelDataNew_20190318.csv*	Comma-delim file containing records, by parcel, of County land use codes and building characteristics
E	Shapefile	*2015_2045_Pop_Empl_Estimates.shp*	Polygon layer of Traffic Analysis Zones with associated 2015 population and employment estimates and 2045 population and employment projections
F	Shapefile	*cb_2017_51_bg_500k.shp* [J]	Block Group polygons covering the entire State of Virginia (subsequently filtered to Albemarle County)
	Excel	*ACS_2015_2017_BG_5YR_B25032.xlsx* [K]	Block Group estimates of total number of housing units in single-unit and multiunit structures.
G	Shapefile	*Pressure_Zones-2016.shp*	Contains city and county pressure zones composing the RWSA service area (including Crozet and Red Hill, both of which were removed before any use of the layer).

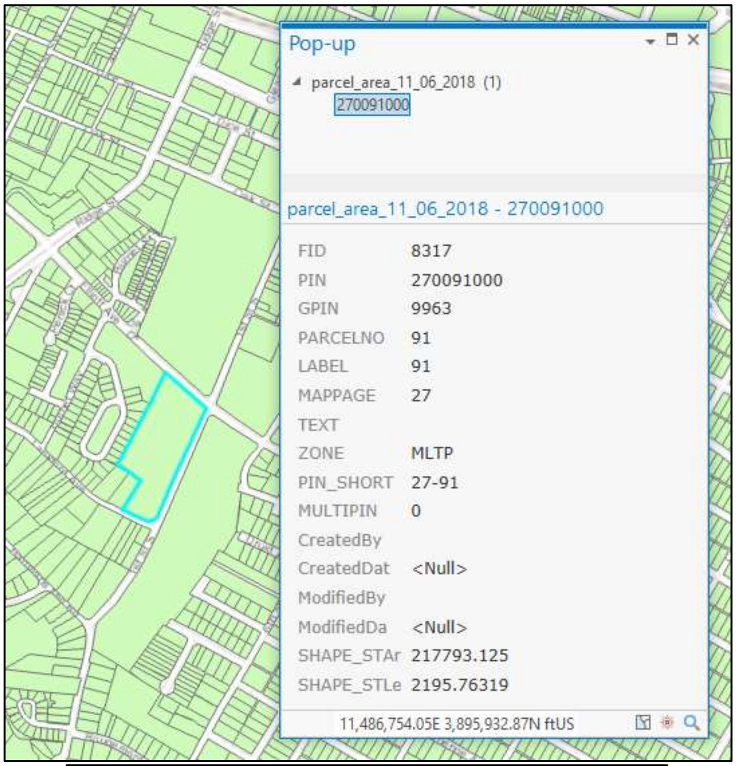
A - City of Charlottesville B – ACSA C - Albemarle County Office of Geographic Data Services D - Albemarle County Office of Community Development E - Thomas Jefferson Planning District Commission
F - US Census Bureau's American Community Survey 5-year Estimates (2013-2017) G – RWSA H - Downloaded from http://www.charlottesville.org/online-services/maps-and-gis-data/download-gis-data
I - Downloaded from https://www.albemarle.org/department.asp?department=gds&relpage=3914 J - Downloaded from https://www2.census.gov/geo/tiger/GENZ2017/shp/
K - Downloaded from US Census American FactFinder: https://factfinder.census.gov/faces/nav/jsf/pages/searchresults.xhtml?refresh=t

Table A-2: Zoning and Occupancy Values Used to Create City Land Use Partitions

Partition Priority Level	Partition(s)	ZONE values	UseCode values	Sub-partitioning?	Future demand
1	UVA Grounds	'UVA Grounds' [A]	NA	Pressure zone only	Forecasted Separately
2	Medical Center	'MedCenterCore' [A]	NA	Pressure zone only	No change from current
3	Parks and Cemeteries	'Park/Cem' [A]	NA	Pressure zone only	No change from current
4	Medical Center Half-Mile	'MedCenterHalfMile' [B]	NA	Pressure zone only	Change with redevelopment towards mixed-use characteristics
5	Neighborhood Plan Zones	'CC', 'CCH', 'CDH', 'CH', 'CHH', 'D', 'DE', 'DEH', 'DH', 'DN', 'DNC', 'DNH', 'HS', 'HSC', 'HW', 'NCC', 'NCCH', 'SSH', 'URB', 'URBH', 'WME', 'WMEH', 'WMNH', 'WMW', 'WMWH', 'WSH'	NA	ZONE value and pressure zone	Change with redevelopment towards mixed-use characteristics.
6	Other Areas currently vacant	All 'B-1', 'B-2', 'B-3' variants All 'R-1', 'R-2', 'R-3' variants 'ES', 'IC', 'ICH', 'M-I', 'MR', 'PUD', 'PUDH', 'U', 'UMD', 'UMDH'	'Vacant Land', 'Vacant Commercial (B1-B3)', 'Vacant Industrial (M1,M3,PMD)'	ZONE value and pressure zone	Change with new development towards residential or nonresidential characteristics specific to each ZONE type.
7	Other Areas currently occupied		Any other than those above	Pressure zone only	No change from current

A – Parcels identified visually and initial *ZONE* values changed to 'UVA Grounds', 'MedCenterCore', or 'Park/Cem'
B – Parcels identified in GIS as all those within ½ mile of 'MedCenterCore' parcels that were not already assigned to 'UVA Grounds', 'MedCenterCore', or 'Park'

Figure A-1: Locations of City Parcels with ZONE = 'MLTP', 'MLTPC', or 'MLTPH'



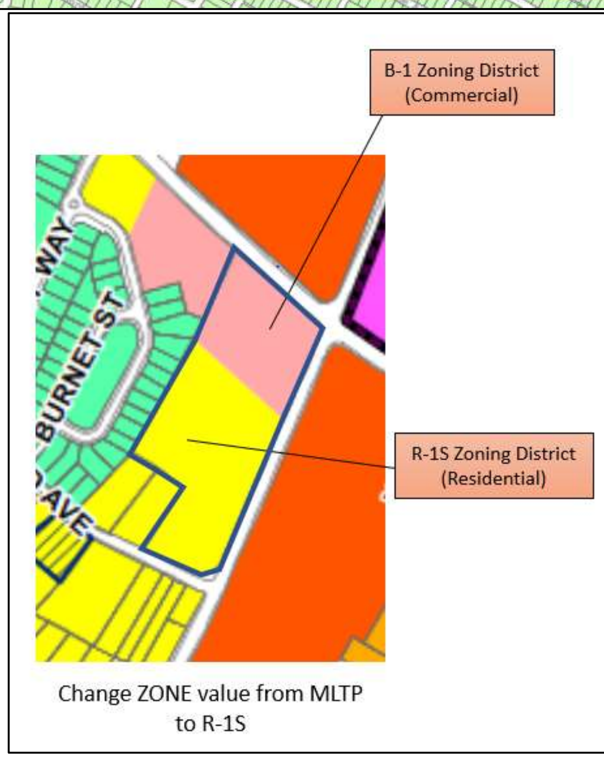


**Figure A-2: Example of parcel with original *ZONE* = 'MLTP'
(reassigned to *ZONE* = 'R-1S': larger proportion of area than 'B-1')**

- **Parks and Cemeteries.** It was desired to ensure that the forecast would never imply redevelopment of current parks and cemeteries in any way. Nevertheless, most parcels containing parks and cemeteries (identified by comparing parcel boundaries to the World Street Map basemap in ArcGIS Pro) had *ZONE* values reflecting some sort of residential, commercial, or neighborhood development plan. To denote that these parcels were ineligible for development in the forecast, a special *ZONE* classification of 'Park/Cem' was assigned to these parcels. Figure A-3 shows an example of a parcel containing a cemetery and the corresponding parcel in GIS with its original *ZONE* value.

- **Medical Center and UVA Grounds.** It was also desired to ensure that the forecast would never imply redevelopment of UVA Grounds by the City. Online maps showing UVA boundaries[4] generally aligned closely with parcel boundaries, such that parcels contained within UVA Grounds could be identified clearly by visual inspection. Furthermore, many of these parcels contained buildings that are part of UVA as indicated by the *UVA_Buildings* layer. Nevertheless, these parcels generally had *ZONE* values reflecting some sort of residential, commercial, or neighborhood development designation by the City. To denote that these parcels were ineligible for development in the forecast, a special *ZONE* classification of 'UVA Grounds' was assigned to these parcels. In addition, ten parcels were visually identified as containing major buildings for the UVA Medical Center. To denote ineligibility for redevelopment, these parcels were given a special *ZONE* classification of 'MedCenterCore'. Figure A-4 shows the locations of 'UVA Grounds' and 'MedCenterCore' parcels.

- **Half-Mile Medical Center.** Discussions with stakeholders including RWSA Staff and City staff indicated that, regardless of zoning or neighborhood plans, the area around the Medical Center (not including UVA Grounds) is valuable real estate and a portion of it could reasonably be expected to redevelop into mixed-commercial-residential uses over the forecast horizon. To explicitly include this redevelopment potential in the forecast, all parcels located within a half-mile distance of 'Medical Center' parcels (excluding 'UVA Grounds' parcels) were given a special *ZONE* classification of 'MedCenterHalfMile'. Figure A-5 shows the locations of 'MedCenterHalfMile' parcels. The MedCenterHalfMile was treated as an additional Mixed-Use Redevelopment Area along with Neighborhood Plan areas.

Occupancy and Vacancy. Following the above adjustments to the *ZONE* field, all City parcels were joined with their corresponding land use codes (the column *UseCode* in the real estate attribute tables *Real_Estate_Residential_Details.csv* and *Real_Estate_Commercial_Details.csv*). Parcels were then flagged as "Vacant" if their *UseCode* value was either 'Vacant Land', 'Vacant Commercial (B1-B3)', or 'Vacant Industrial (M1,M3,PMD)' and their updated *ZONE* value was anything but 'Park/Cem'; parcels that did not meet these criteria were flagged as "Nonvacant".

[4] For example, the UVA SMART Transportation map - https://www.fm.virginia.edu/docs/ges/Bike_Map.pdf

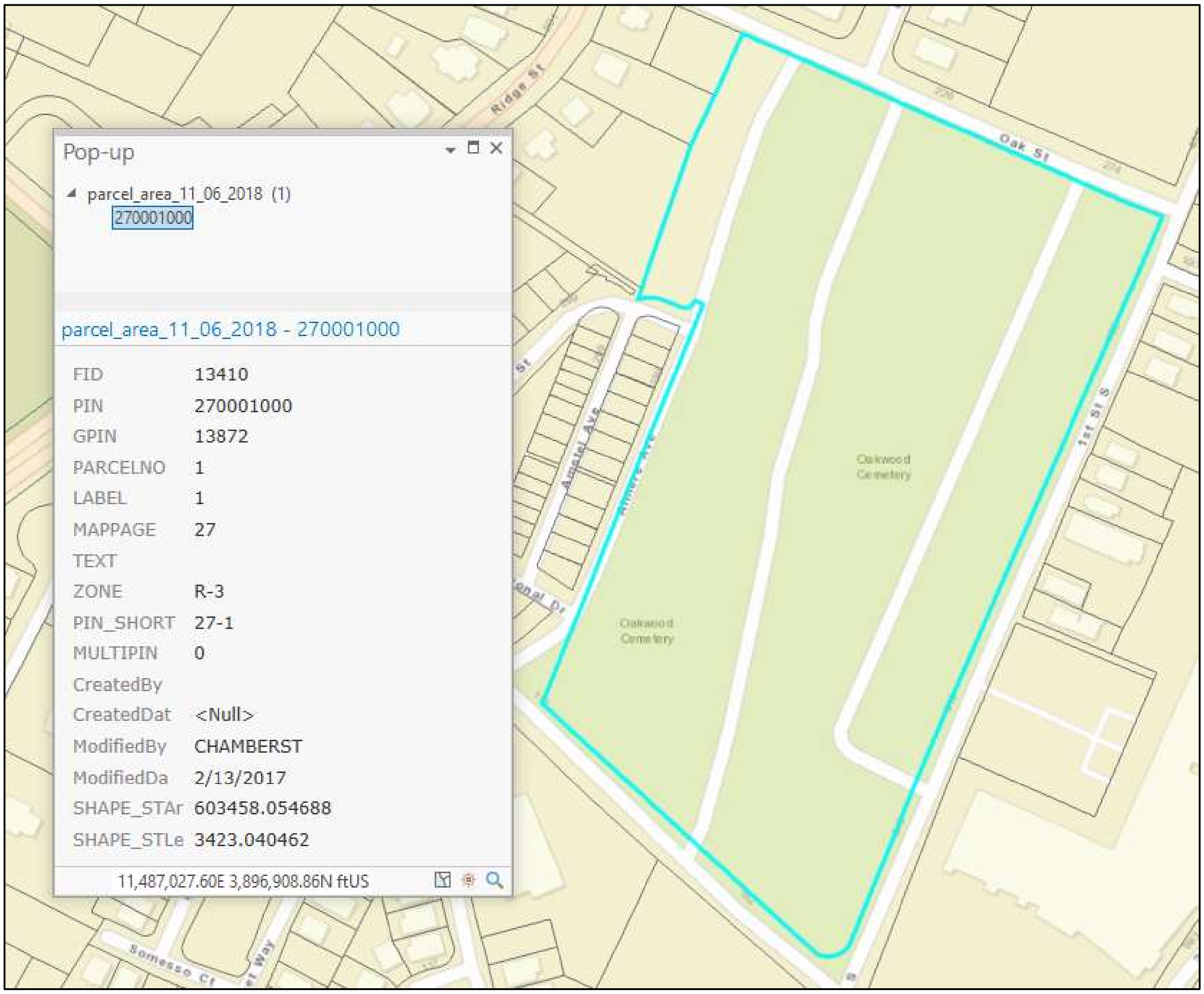


**Figure A-3: Example of parcel containing a cemetery with *ZONE* = 'R-3'
(Oakwood Cemetery, reassigned to *ZONE* = 'Park/Cem')**

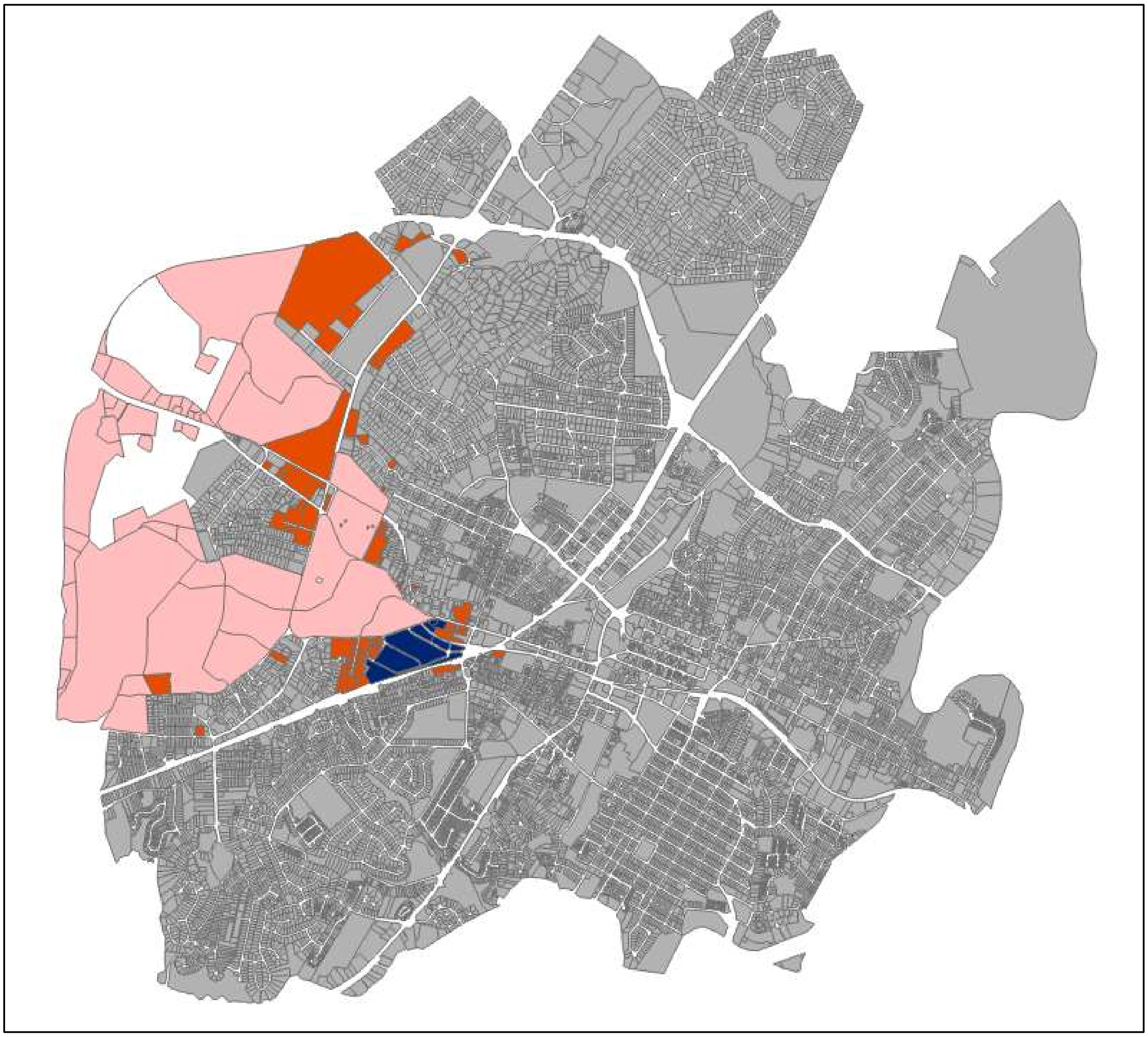


Figure A-4: Locations of City parcels within UVA Grounds (orange) and the Medical Center Core (navy blue). Also shown are Albemarle County parcels within UVA grounds (pink).

Figure A-5: Locations of City parcels within the Medical Center Core (navy blue) and within ½ mile of the Medical Center (teal).

Land Use Partitions. After land use and occupancy classifications were determined, parcels were assigned to land use partitions as shown in Table A-2. Partitions were defined in a priority order (the order is noted in the first column of Table A-2), where parcels assigned to a higher-priority partition were not further considered when defining lower-priority partitions. Figures A-4 and A-5 showed the UVA/Medical Center and Half-Mile Medical Center partitions. Figures A-6 through A-9 show partitions for parks and cemeteries, mixed-use redevelopment areas including neighborhood planning zones and the Half-Mile Medical Center, vacant parcels outside other partitions, and occupied parcels outside other partitions, respectively. Note that for neighborhood planning zones (Figure A-7) and for vacant parcels outside other partitions (Figure A-8), a separate partition is defined for each *ZONE* value.

Pressure Zone Partitions. Parcels were also partitioned by pressure zone using GIS (Figure A-10). First, the centroid of each parcel was determined. Then, these centroids were spatially joined (intersected) with pressure zone polygons in the *Pressure_Zones-2016* layer, associating each centroid with exactly one polygon. Pressure zone designations associated with each centroid were then assigned back to the parcel polygons from which the centroids were derived. Therefore, each parcel was associated with exactly one pressure zone based on the location of its centroid relative to pressure zone boundaries. Note that city parcels almost precisely align with pressure zone boundaries; it is apparent that pressure zones were originally defined using parcel geographic data from the City.

Combined Partitions. In the forecast, land use and pressure zone partitions were used simultaneously, such that each forecast partition corresponded to a specific combination of future land use and pressure zone. While these represent too many combinations to sensibly display on a map, Figure A-11 provides an indication of the associated partition granularity.

Assumed Development Factors for Partitions. Estimates were formed for number of SF and MF dwelling units and NR square feet at maximum buildout density in City partitions assumed to undergo some form of development (Medical Center Half-Mile, Neighborhood Plan, and Other Vacant partitions). Development factors, in terms of future SF units/acre. MF units/acre, and NR sq. ft/acre, were specified for each *ZONE* value. These factors were multiplied by total acreage in each corresponding partition to estimate buildout development. Development factors were derived from zoning and neighborhood plan specifications; current values are shown in Table A-3. These factors can be adjusted as needed within the forecast spreadsheet to create forecast scenarios.

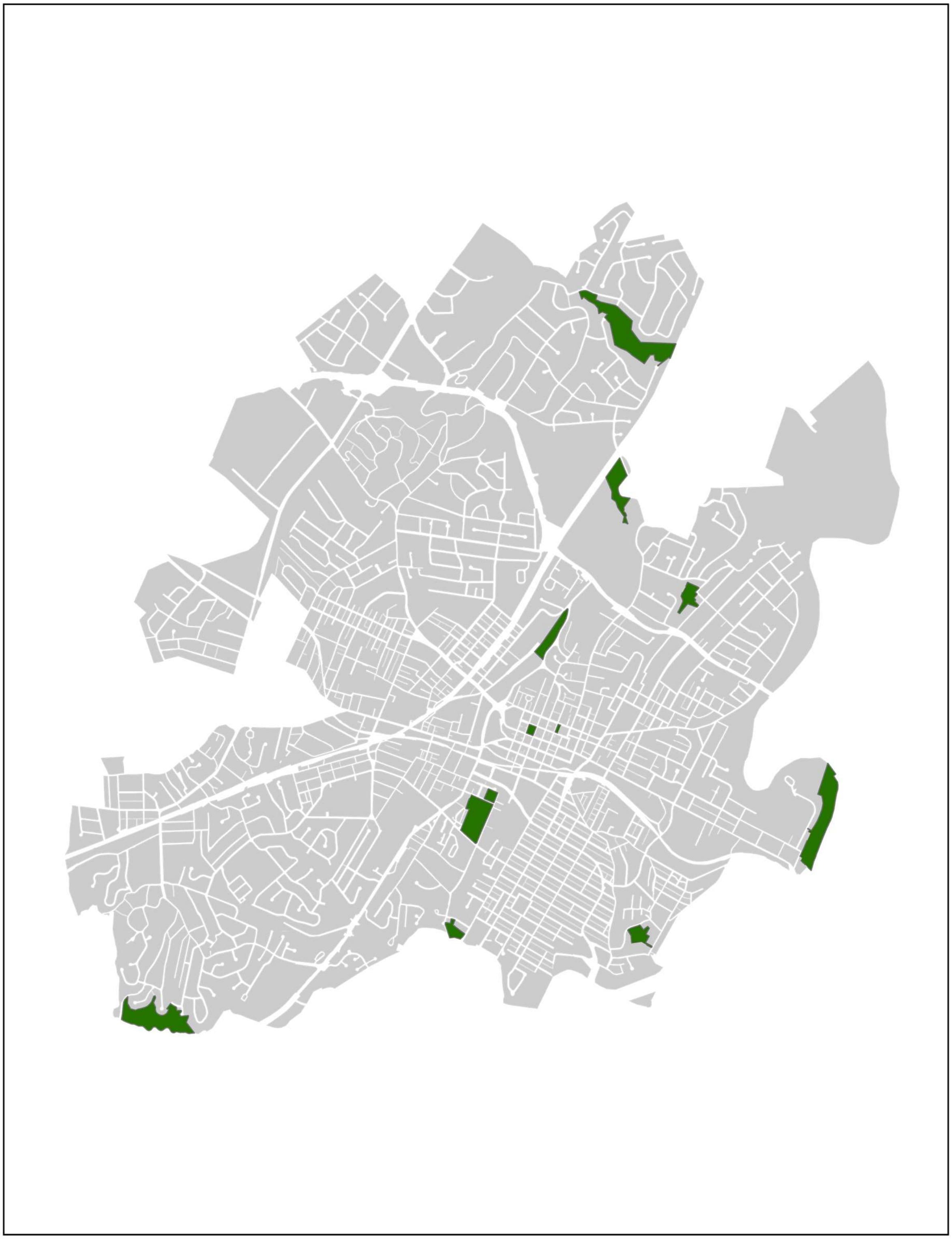


Figure A-6: City Land Use Partitions: Parks and Cemeteries.

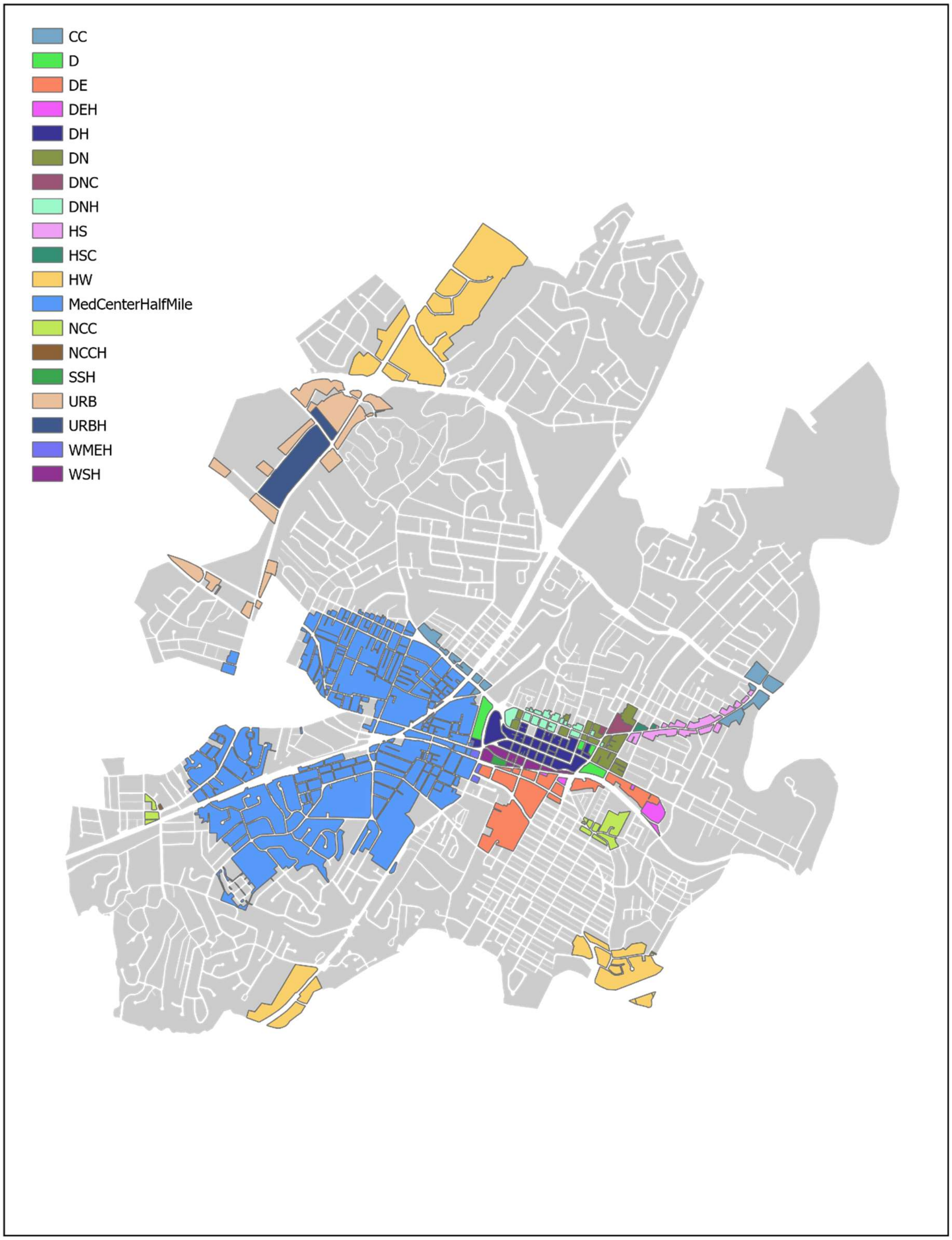


Figure A-7: City Land Use Partitions: Neighborhood Planning Zones and the Medical Center Half-Mile.

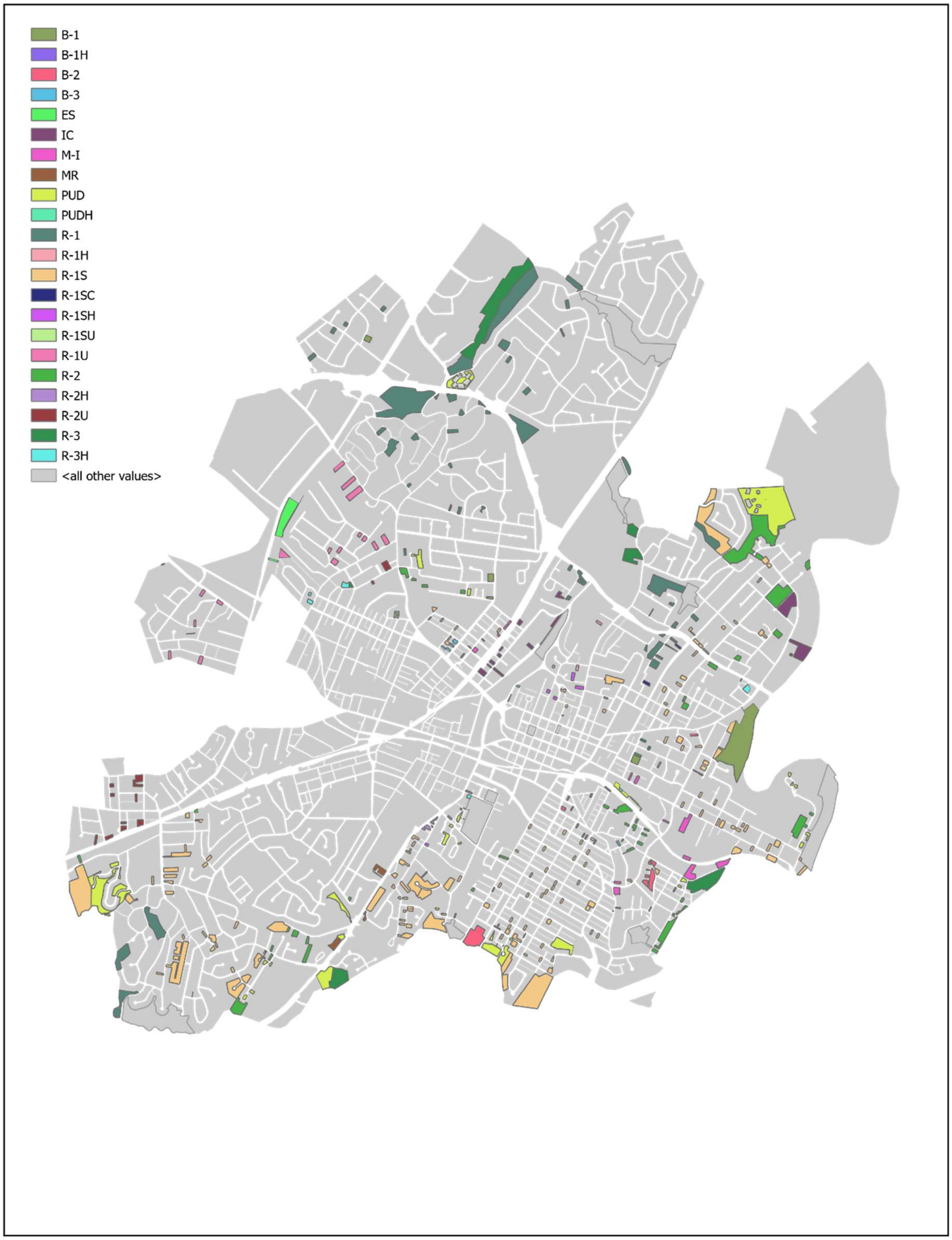


Figure A-8: City Land Use Partitions: Vacant Parcels Outside Earlier Partitions.

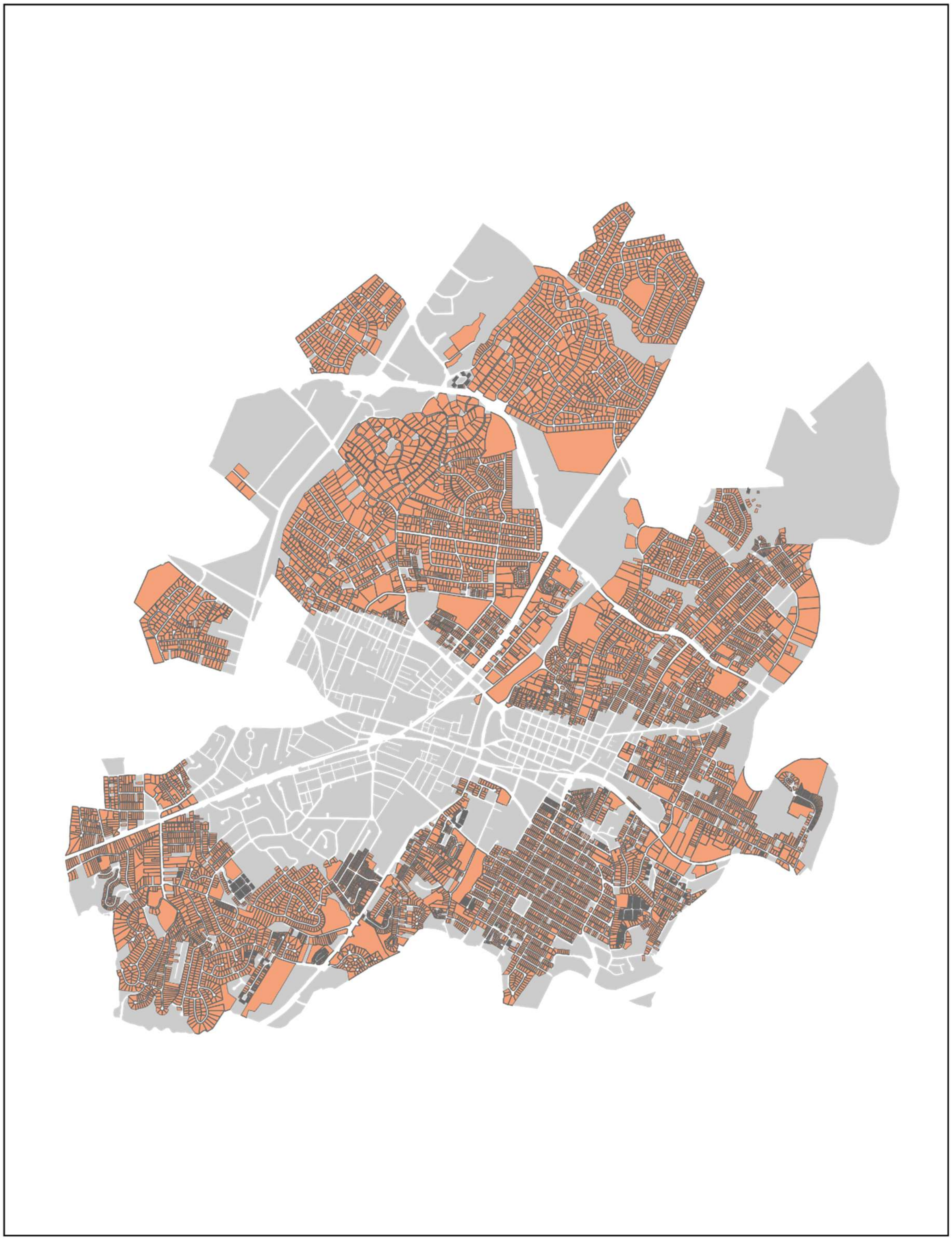


Figure A-9: City Land Use Partitions: Occupied Parcels Outside Earlier Partitions.

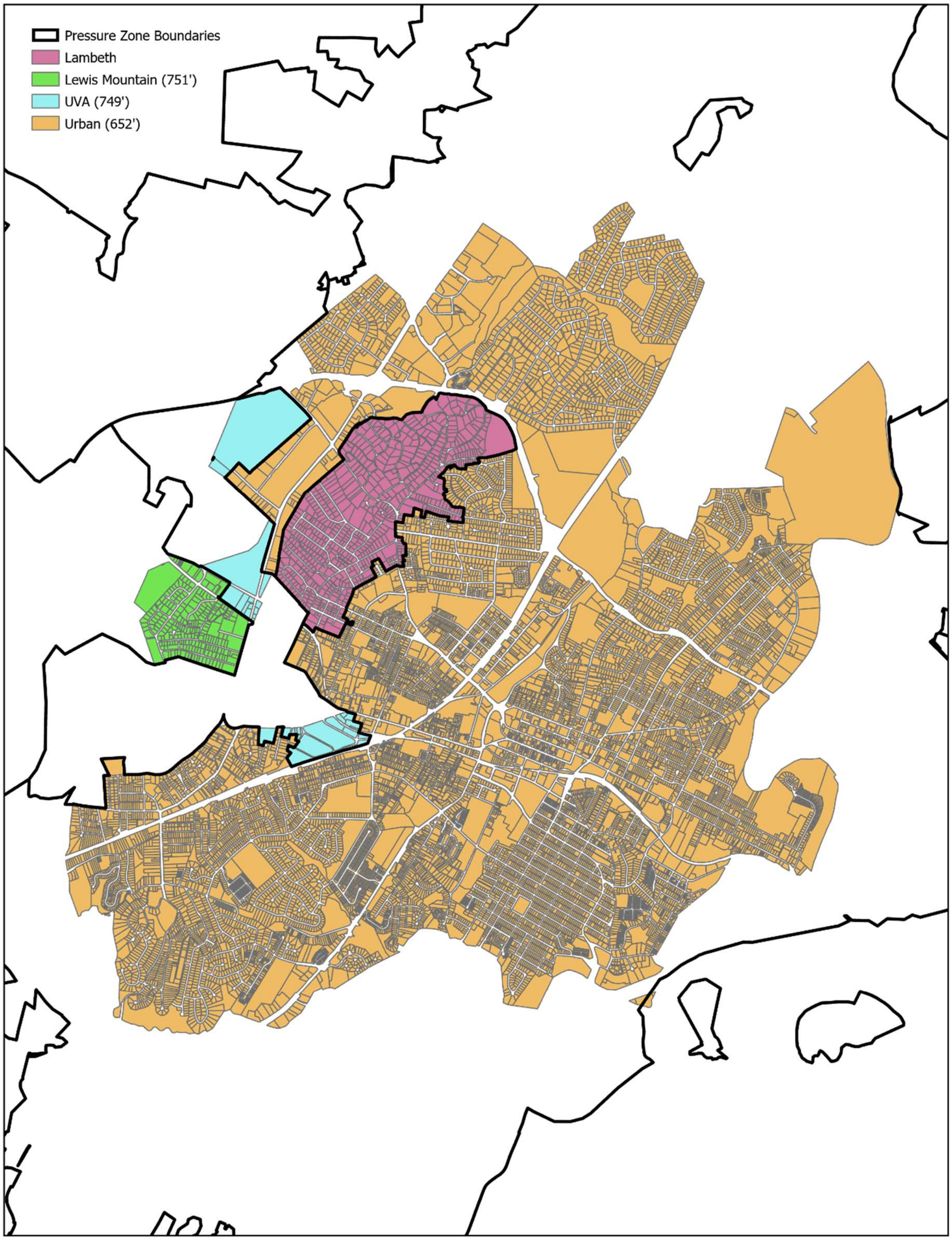


Figure A-10: City Pressure Zone Partitions

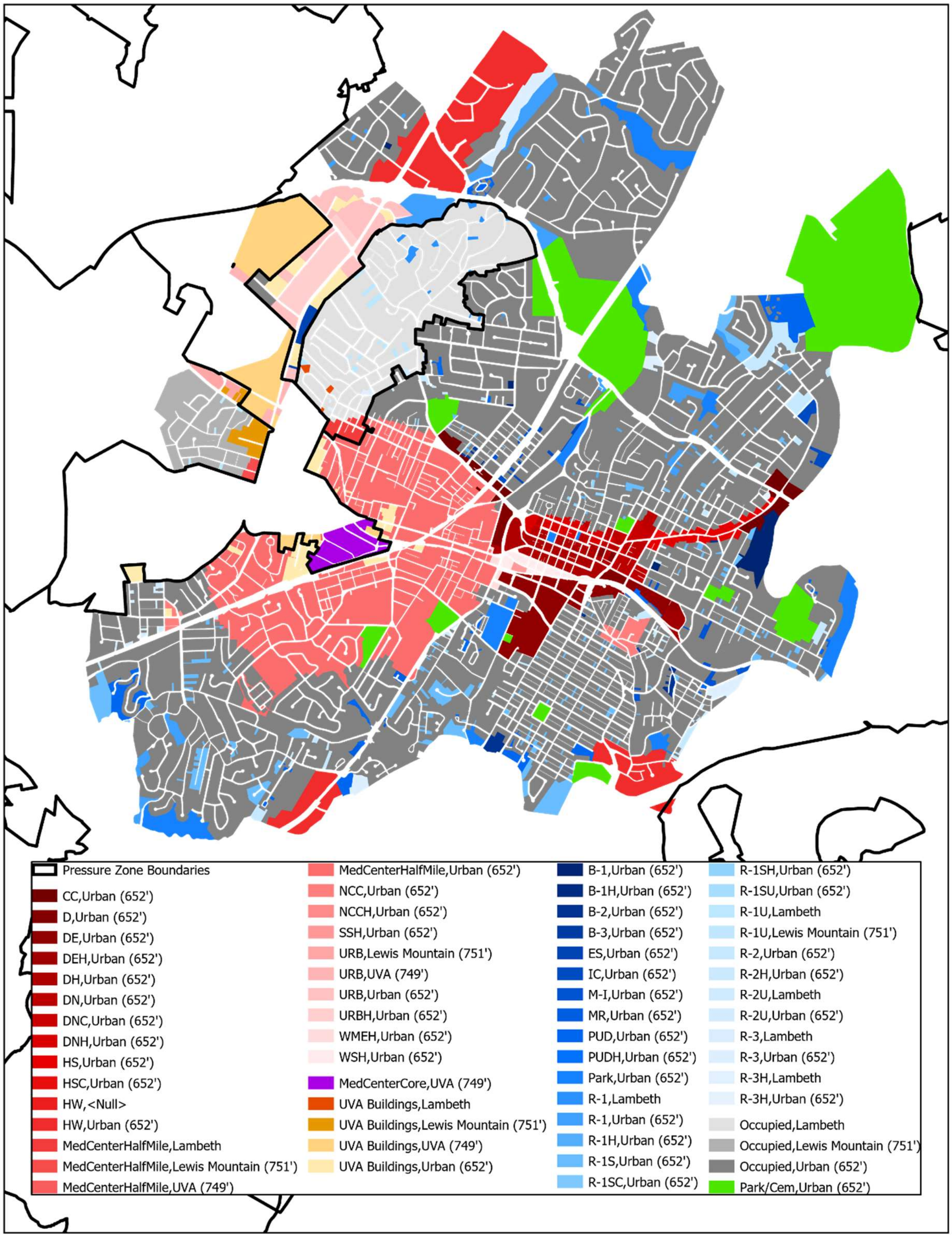


Figure A-11: Complete City Land Use Partition

Table A-3: Assumed Maximum Density Buildout Development Factors for Charlottesville *ZONE* Classifications

ZONE	SF units/acre	MF units/acre	NR ksf/acre[A]
MedCenterHalfMile	-	48	20
CC	-	48	20
CDH	-	48	20
CH	-	48	20
D	-	48	20
DE	-	48	20
DEH	-	48	20
DH	-	48	20
DN	-	48	20
DNC	-	48	20
DNH	-	48	20
HS	-	48	20
HSC	-	48	20
HW	-	48	20
NCC	-	48	20
NCCH	-	48	20
SSH	-	48	20
URB	-	48	20
URBH	-	48	20
WME	-	48	20
WMEH	-	48	20
WMNH	-	48	20
WMSH	-	48	20
WMW	-	48	20
WMWH	-	48	20
WSH	-	48	20

All neighborhood zones listed above, including the MedCenterCore, were assumed to be developed to Mixed-Use characteristics with 48 MF units/acre, 20 NR ksf/acre, and no SF units at buildout conditions.

ZONE	SF units/acre	MF units/acre	NR ksf/acre[A]
B-1[C]	-	-	10.02
B-1C[C]	-	-	10.02
B-1H[C]	-	-	10.02
B-2[C]	-	-	10.02
B-2H[C]	-	-	10.02
B-3[C]	-	-	10.02
B-3H[C]	-	-	10.02
ES[C]	-	-	10.02
IC[C]	-	-	10.89
ICH[C]	-	-	10.89
M-I[C]	-	-	10.89
MR[C]	-	21	-
PUD[D]	3	-	-
PUDH[D]	8	-	-
R-1[B]	3	-	-
R-1H[B]	3	-	-
R-1S[B]	8	-	-
R-1C[B]	8	-	-
R-1SHC[B]	8	-	-
R-1SC[B]	3	-	-
R-1SH[B]	3	-	-
R-1SU[B]	3	-	-
R-1SUH[B]	3	-	-
R-1U[B]	3	-	-
R-1UH[B]	3	-	-
R-2[B]	8	-	-
R-2C[B]	8	-	-
R-2H[B]	8	-	-
R-2U[B]	8	-	-
R-2UH[B]	8	-	-
R-3[C]	-	43	-
R-3H[C]	-	64	-
UMD[C]	-	21	-
UMDH[C]	-	21	-
UHD[C]	-	43	-
UHDH[C]	-	43	-

A – ksf = square footage in thousands
B – assumptions based on existing occupied development in these zones
C – assumptions based on definitions in zoning ordinances
D – assumptions based on existing lower- and higher-density SF development; PUD ordinances require empty space in development

Development Pacing

Having created the partitions described above, the next step was to pace development within each zone to match the City's population forecasts (Section 3.1.1 and 3.5.1). The values shown in Table A-4 describe the assumed progress, at three time horizons within the forecast period, toward the maximum build-out densities (as previously described). They described the percentage increase in development density for the respective zones between the actual development density in 2017 and the maximum build-out density. The assumed progress toward full build-out density was greater for undeveloped areas than for the areas subject to redevelopment because the existing density of undeveloped parcels is so low and it is assumed a higher fraction of the undeveloped zone will be developed in the future. The resulting development levels produced close facsimiles of the forecasted population for Charlottesville at the indicated forcast horizons. Additional population capacity was tied to new housing units and the persons per dwelling factor used for single family and multifamily housing units (2.53 for SFDUs, 2.01 for MFDUs). It is possibly noteworthy that the assumptions in the model lead to 92-94% of residential capacity growth to take place in multifamily dwelling units over the forecast horizon.

Table A-4: Development Pacing for Charlottesville

Zone / Partition	2030	2045	2070
MedCenterHalfMile	5%	10%	22%
D, DE, DEH, DH	5%	12%	22%
Other mixed use zones (left side Table A-3)	3%	6%	14%
Undeveloped/ vacant (Figure A-8)	8%	15%	35%

A.2 County Partitioning

County partitions were defined using similar concepts to the City, with partitions based on a combination of future land use plans, current occupancy, and pressure zone locations. Unlike the city, however, future land use was characterized via multiple different geographic types, including parcels and pressure zones, County master-planned Development Areas, and existing active or planned development projects, i.e. projects currently between start of permitting and end of construction. These different areas were defined with shapes that partially overlapped one another. To prevent area duplication during County partitioning, partitions were defined in order of superseding future land use definitions (Table A-5), and areas in lower-priority partitions that were overlapped by higher-priority partitions were deleted.

County UVA Partition. The highest-priority partition contained those areas of the County occupied by UVA Grounds. These areas were identified from the county parcel layer (pink section of Figure A-4) by visual cross-referencing with online UVA maps. As with the City, these areas were removed from further County forecasting consideration (a forecast of UVA demand was handled separately, see Section 3.3) and deleted from subsequent partitions.

Development Pipeline Partitions. The next-highest-priority partition contained areas currently permitted for specific developments or under construction. The County (ACOCD) provided a layer with polygons corresponding to these developments (*Development_RWSA*: Figure A-12), each tagged with future land use information indicating planned number of SF or MF units and/or NR square footage. These areas are known as the “Development Pipeline”. Each Development Pipeline polygon served as its own partition by assigning it to the pressure zone containing the polygon’s centroid and by specifying future dwelling unit and/or square footage assumptions based on that development’s permit data. There was no overlap of the County UVA Partition on Development Pipeline polygons, requiring no deletions from the latter. Development Pipeline partitions did, however, overlap some subsequent lower-priority partitions, requiring deletions as those partitions were formed. Table B-8 shows total future SF and MF dwelling units and NR square footage for Development Pipeline partitions aggregated to pressure zone.

Extra Pipeline Partitions. In addition to the Development Pipeline, three major planned developments were identified that had specific future SF/MF unit or NR square footage values that superseded county zoning and master planned development, including Sentara Martha Jefferson Hospital, Fontaine Research Park, and UVA Research Park. Each of these developments were used to define an “Extra Pipeline” partition, the third-highest priority type of partition. Polygons for these three developments were inferred from the County parcel layer (ExtraPipelinePoly: Figure A-13). As with the Development Pipeline, each Extra Pipeline polygon served as its own partition by assigning it to the pressure zone containing the polygon’s centroid and by specifying future dwelling unit and/or square footage assumptions based on that development’s permit data. There was no overlap of the County UVA or Development Pipeline partitions on the Extra Pipeline partition, so no deletions were required from the latter. Extra Pipeline Partitions did, however, overlap some subsequent lower-priority partitions, requiring deletions as those partitions were formed. Table A-5 shows total future MF dwelling units and NR square footage for Extra Pipeline partitions aggregated to pressure zone.

Table A-5: Extra Pipeline Partition Details

Project	Pressure Zone	Net Additional NR space or MF DUs		
		2030	2045	2070
Marth Jefferson Hospital Hos	Urban Ring	540 ksf	-	-
Fontaine Research Park	Urban Ring	500 ksf	366 ksf	-
UVA/North Fork Research Park	Piney Mountain	400 ksf 100 MF DUs	1000 ksf 250 MF DUs	2000 ksf 500 MF DUs

Table A-6: Zoning and Occupancy Values Used to Create County Land Use Partitions

Partition Priority Level	Partition(s)	Land use values	UseCode values	Sub-partitioning?	Future demand
1	County UVA Grounds	NA	NA	Pressure zone only	Omitted from County Forecast. UVA forecast handled separately.
2	Development Pipeline	NA	NA	separate partition for each polygon and pressure zone	Based on planned SF units, MF units, and NR sq ft for each development
3	Extra Pipeline				
4	Places29	*Land Use* column: ‘Airport District, Commercial Mixed Use,Community Mixed Use’, ‘Employment District’, ‘Employment Mixed Use’, ‘Greenspace’, ‘Heavy Industrial’, ‘Industrial’, ‘Institutional’, ‘Light Industrial’, ‘Neighborhood Density Residential’, ‘Neighborhood Density Residential Low’, ‘Neighborhood Mixed Use’, ‘Office / R & D / Flex / Light Industrial’, ‘Parks’, ‘Parks and Green Systems’, ‘Privately Owned Open Space’, ‘Public Open Space’, ‘Regional Mixed Use’, ‘River Corridor’, ‘Rural Area’, ‘Town/Village Center’, ‘Urban Density Residential’, ‘Urban Mixed Use’, ‘Urban Mixed Use (in Centers)’, ‘Urban Mixed Use (in areas around Centers)’	NA	separate partition for each Development Area, *Land Use* value, and pressure zone	Change with redevelopment towards characteristics associated with land use values
5	Pantops				
6	Southern and Western Neighborhoods				
7	Village of Rivanna				
8	Other Areas currently vacant	*Zoning* column: ‘C1 Commercial’, ‘Commercial Office’, ‘Highway Commercial’, ‘Light Industry’, ‘Neighborhood Model District’, ‘Planned Development Industrial Park’, ‘Planned Development Mixed Commercial’, ‘Planned Development Shopping Center’, ‘Planned Residential Development’, ‘Planned Unit Development’, ‘R1 Residential’, ‘R10 Residential’, ‘R15 Residential’, ‘R2 Residential’, ‘R4 Residential’, ‘R6 Residential’, ‘Rural Areas’, ‘Village Residential’	‘Vacant Commercial Land’, ‘Vacant Residential Land’	separate partition for each *Zoning* value and pressure zone	Change with new development towards residential or nonresidential characteristics specific to each ZONE type.
9	Other Areas currently occupied		Any other than those above	Pressure zone only	No change from current

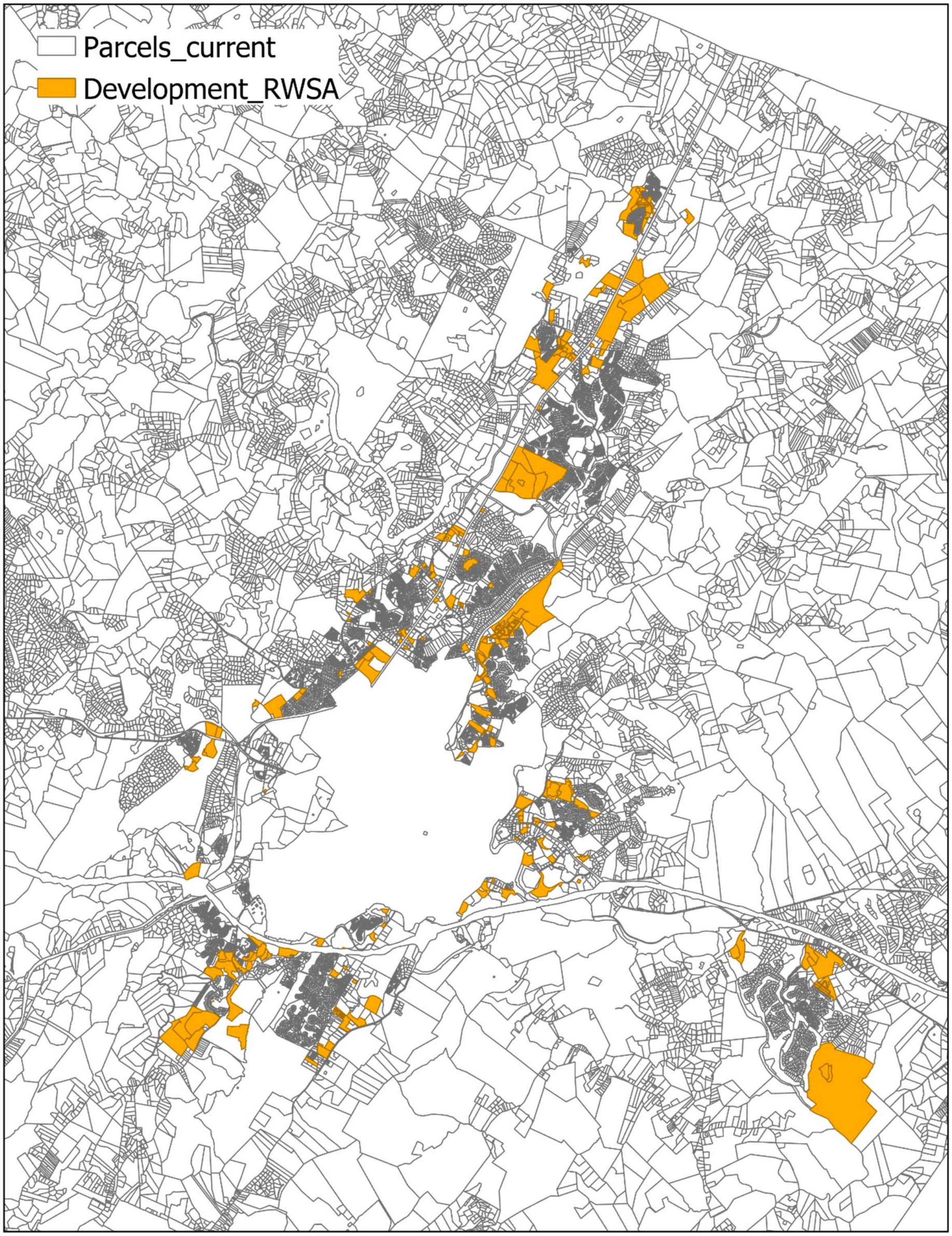


Figure A-12: County Parcel and Development Pipeline Layers.

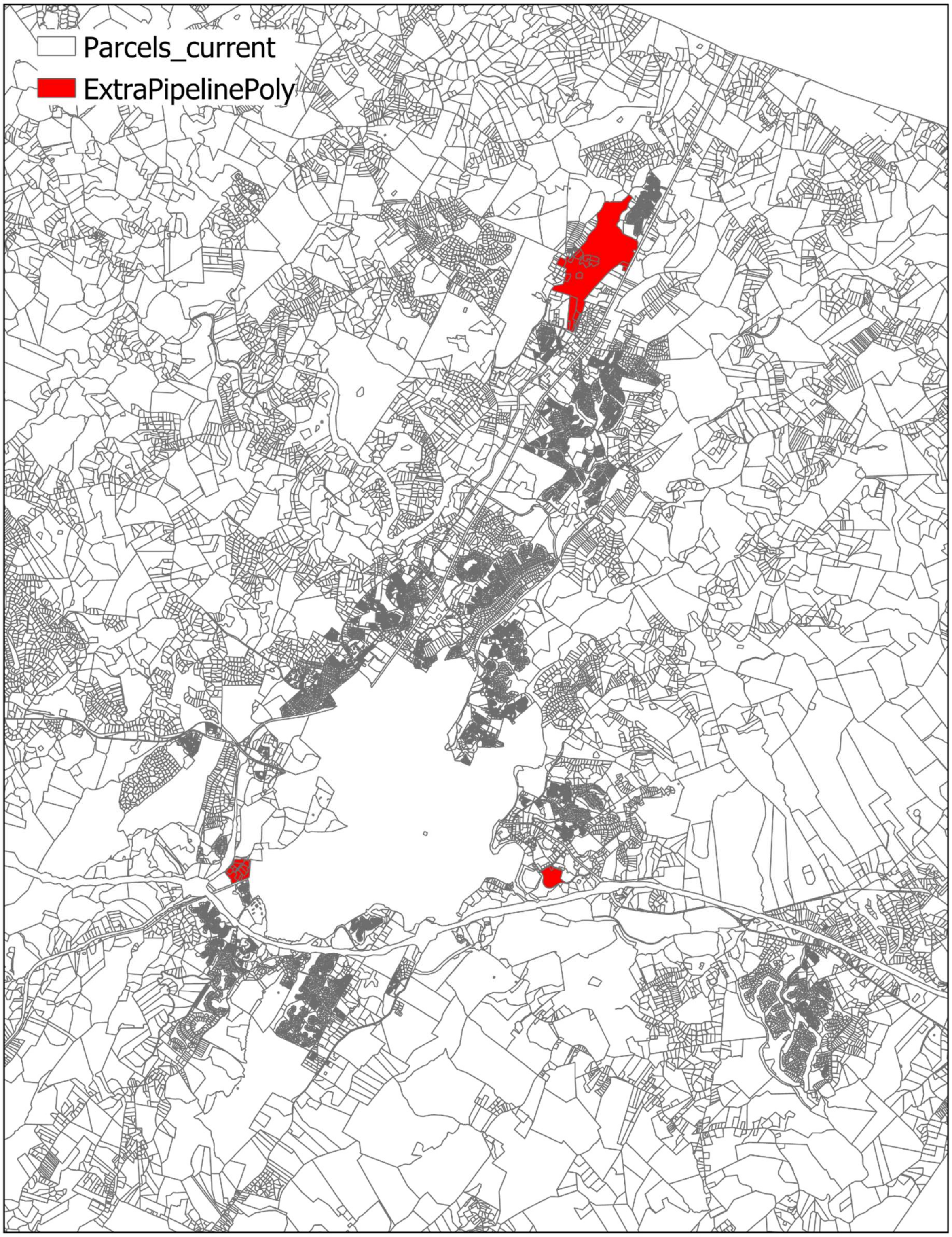


Figure A-13: County Parcel and Extra Pipeline Layers.

County Development Area Partitions. The next four highest-priority partitions were for County Development Areas, including Places29, Pantops, Village of Rivanna, and the Southern and Western Neighborhoods (Figure A-14). The County provided layers containing polygons for these areas, including Places29, Pantops, Village of Rivanna, and the Southern and Western Urban Neighborhoods. Each Development Area layer consisted of multiple polygons, each with a different future land use specification listed in the *Land Use* column of the associated layer's attribute table. Partitioning of Development Areas therefore consisted of

- deleting (trimming) polygons and portions of polygons that were overlapped by County UVA, Development Pipeline, and Extra Pipeline polygons (Figure A-15),
- assigning Development Area polygons to the pressure zones containing their centroids (Figure A-16), and
- defining partitions as groups of trimmed polygons having the same Development Area, Land Use category, and pressure zone (Figure A-17).

Finally, SF, MF, and NR development factors (units/acre and sq. ft/acre) were determined for each *Land Use* category as shown in Tables A-7 through A-10. Development factors were derived from dual assumptions for fraction of total area in each polygon developed for SF, MF, or NR sectoral use multiplied by assumptions for number of SF/MF units and NR square feet per sectoral acre. These values were inferred and estimated from data and descriptions in master plan documents.

Occupied and Vacant County Parcel Partitions. The final set of partitions consisted of occupied and vacant areas inside the County service area but outside higher-priority partitions. These partitions were based on parcel-level county zoning and occupancy data provided in the *Parcels Current* layer, zoning codes contained in the *ZONING* column of that layer's attribute table, and occupancy data contained in the *UseCode* column of *Real_Estate_Residential_Details.csv and Real_Estate_Commercial_Details.csv* files.

- First, the set of parcels contained within the County service area (omitting Crozet and Red Hill) was determined by assigning parcels to the pressure zones containing their centroids and omitting parcels whose centroids were outside any pressure zone. This formed a County parcel/pressure zone layer (*Parcels_current_Intersect_PZ_Clean*, Figure A-18).

- Then, parcels and portions of parcels overlapped by County UVA, Development Pipeline, Extra Pipeline, and Development Area partitions were deleted (trimmed) from the parcel/pressure zone intersect layer (Figure A-19).

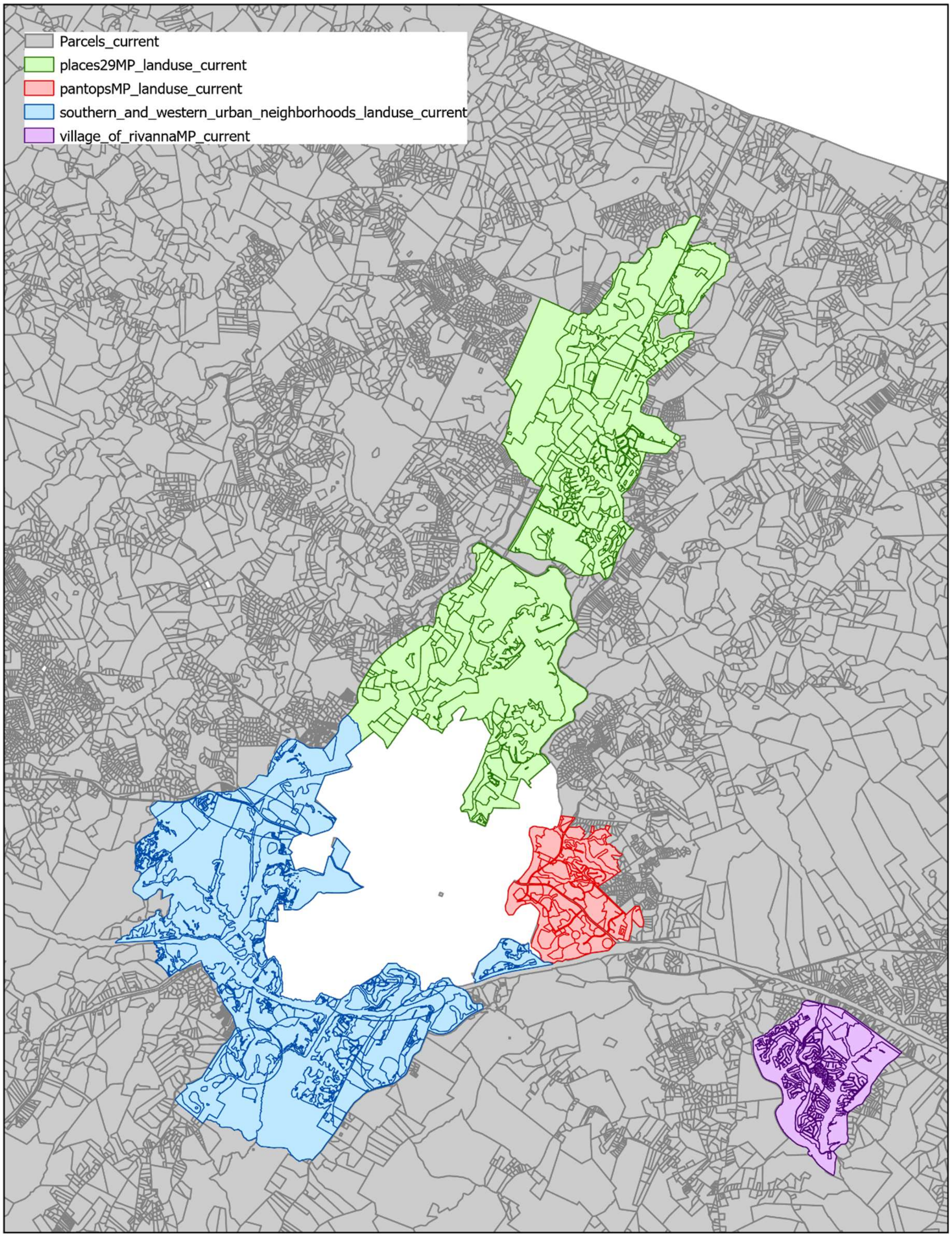


Figure A-14: County Parcel and County Master-Planned Development Area layers.

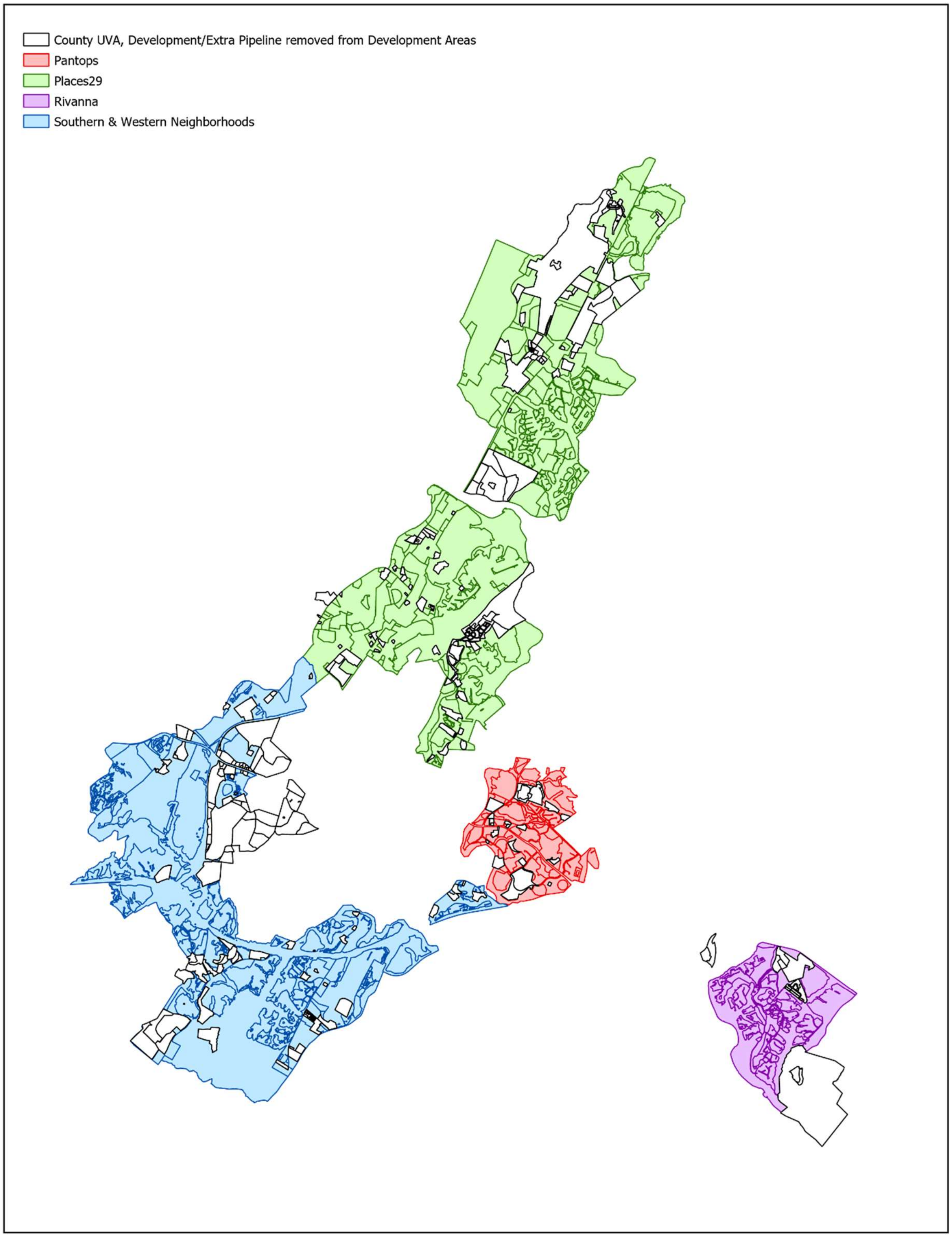


Figure A-15: Deletion of Higher-Priority Partitions from Development Area Polygons.

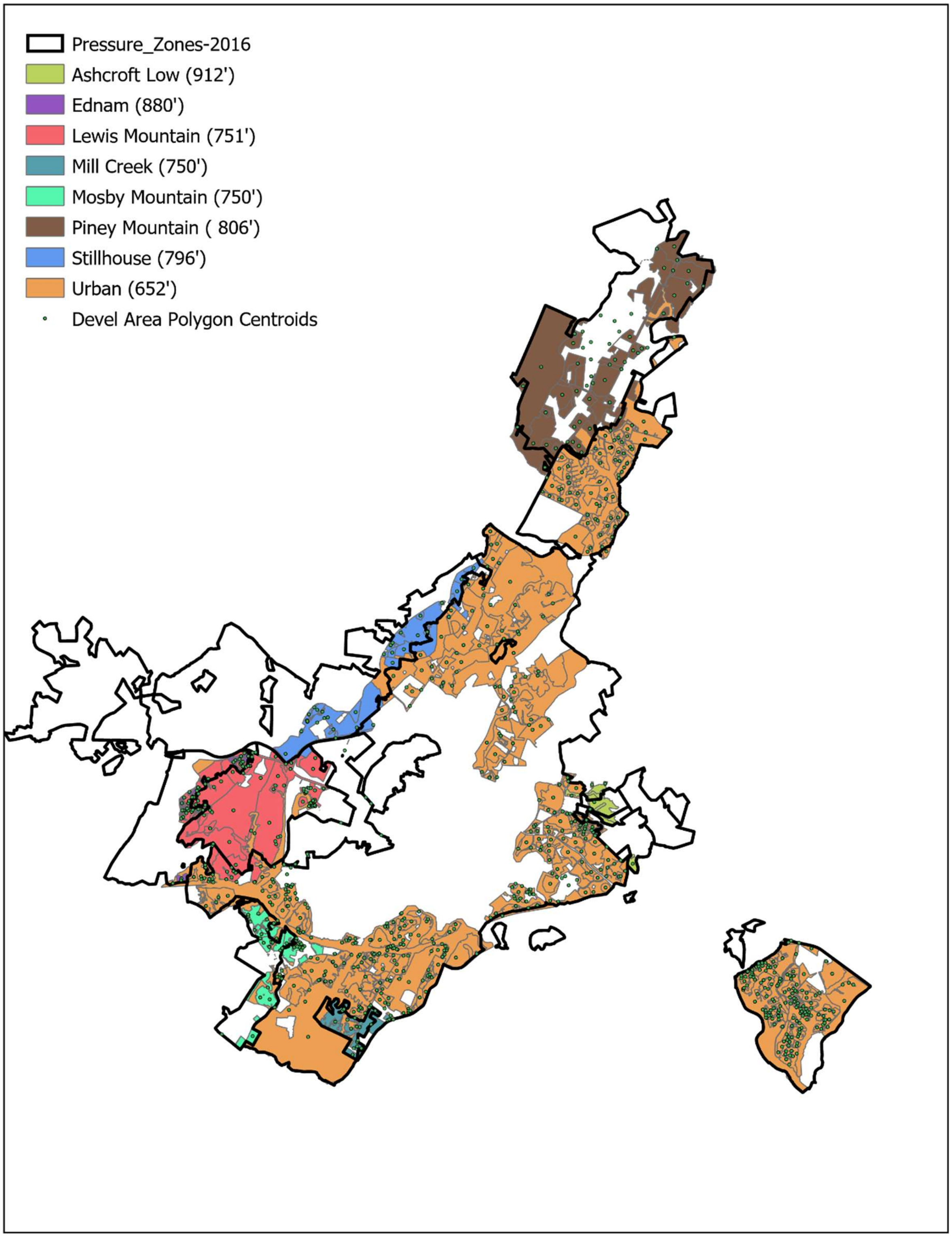


Figure A-16: Assignment of Development Area Polygons to Pressure Zones

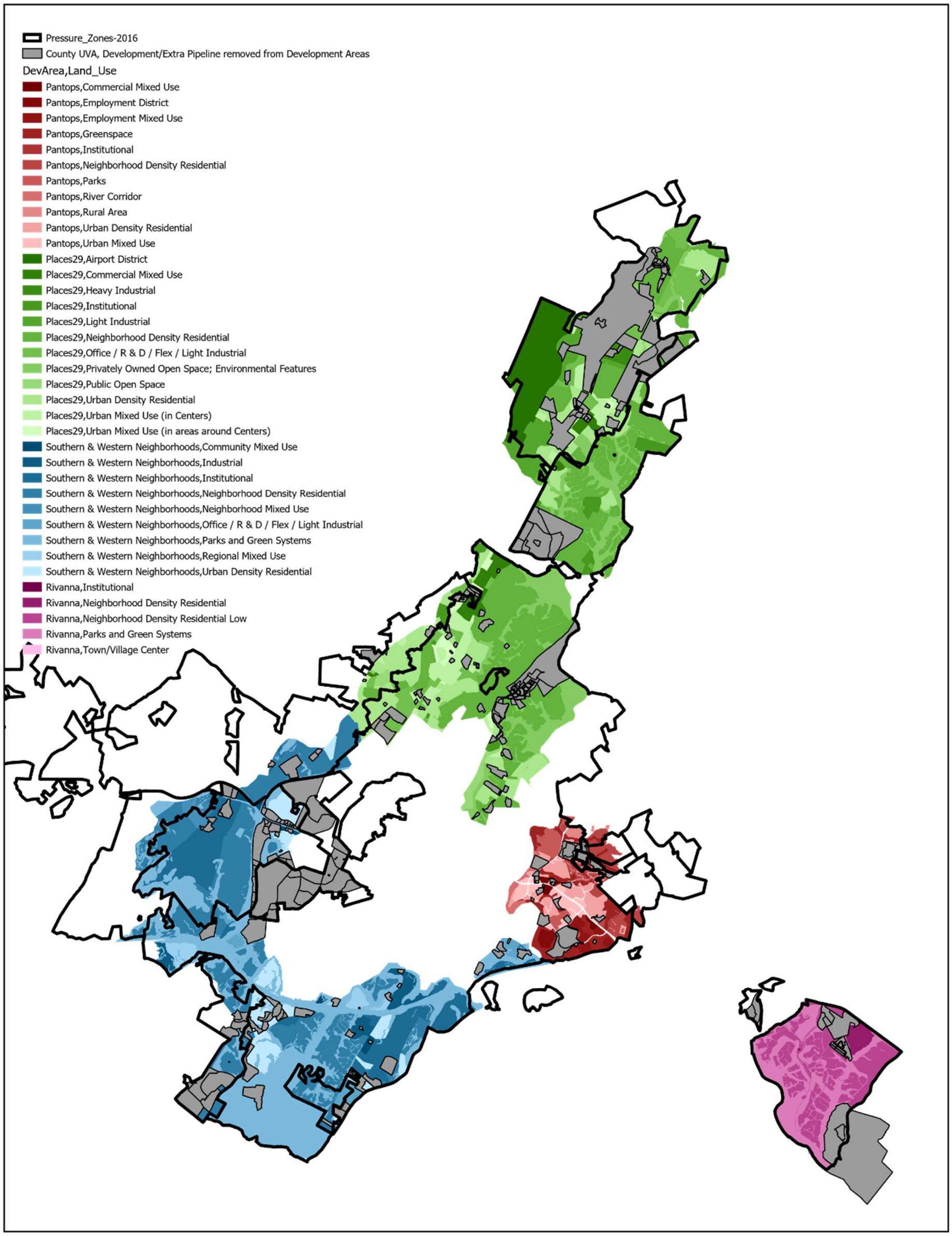


Figure A-17: Development Area Land Use Partitions.

Table A-7: Pantops Land Use Development Factor Assumptions

Land Use	Sector Area Fraction Sector Area/Total Area			Sector Area Development Density Units or ksf/Sector Area			Sector Development Factors Units or ksf/Total Area		
	SF	MF	NR	SF	MF	NR	SF	MF	NR
Commercial Mixed Use	-	0.20	0.60	-	13.00	10.02	-	2.6	6.012
Employment District	-	-	0.80	-	-	10.02	-	-	8.016
Employment Mixed Use	-	0.20	0.60	-	13.00	10.02	-	2.6	6.012
Greenspace	-	-	-	-	-	-	-	-	-
Institutional	-	-	0.60	-	-	10.02	-	-	6.012
Neighborhood Density Residential	0.80	-	-	4.50	-	-	3.6	-	-
Parks	-	-	-	-	-	-	-	-	-
Rural Area	-	-	-	-	-	-	-	-	-
Urban Density Residential	-	0.80	-	-	13.00	-	-	10.4	-
Urban Mixed Use	-	0.35	0.45	-	13.00	10.89	-	4.55	4.9005
River Corridor	-	-	-	-	-	-	-	-	-

Table A-8: Places29 Land Use Development Factor Assumptions

Land Use	Sector Area Fraction Sector Area/Total Area			Sector Area Development Density Units or ksf/Sector Area			Sector Development Factors Units or ksf/Total Area		
	SF	MF	NR	SF	MF	NR	SF	MF	NR
Neighborhood Density Residential	0.80	-	-	4.50	-	-	3.6	-	-
Urban Density Residential	-	0.80	-	-	13.00	-	-	10.4	-
Urban Mixed Use (in Centers)	-	0.35	0.45	-	18.00	10.89	-	6.3	4.9005
Urban Mixed Use (in areas around Centers)	-	0.35	0.45	-	13.00	10.89	-	4.55	4.9005
Institutional	-	-	1.00	-	-	10.02	-	-	10.02
Office / R & D / Flex / Light Industrial	-	-	0.80	-	-	10.02	-	-	8.016
Commercial Mixed Use	-	-	0.80	-	-	10.02	-	-	8.016
Light Industrial	-	-	0.80	-	-	10.89	-	-	8.712
Airport District	-	-	-	-	-	-	-	-	-
Privately Owned Open Space; Environmental Features	-	-	-	-	-	-	-	-	-
Heavy Industrial	-	-	1.00	-	-	10.02	-	-	10.02
Public Open Space	-	-	-	-	-	-	-	-	-

Table A-9: Southern & Western Land Use Development Factor Assumptions

Land Use	Sector Area Fraction Sector Area/Total Area			Sector Area Development Density Units or ksf/Sector Area			Sector Development Factors Units or ksf/Total Area		
	SF	MF	NR	SF	MF	NR	SF	MF	NR
Neighborhood Density Residential	0.80	-	-	4.50	-	-	3.6	-	-
Office / R & D / Flex / Light Industrial	-	-	1.00	-	-	10.02	-	-	10.02
Institutional	-	-	1.00	-	-	10.02	-	-	10.02
Urban Density Residential	-	0.80	-	-	13.00	-	-	10.4	-
Industrial	-	-	1.00	-	-	10.89	-	-	10.89
Parks and Green Systems	-	-	-	-	-	-	-	-	-
Community Mixed Use	-	-	0.80	-	-	10.02	-	-	8.016
Regional Mixed Use	-	-	0.80	-	-	10.02	-	-	8.016
Neighborhood Mixed Use	-	-	0.80	-	-	10.02	-	-	8.016

Table A-10: Village of Rivanna Land Use Development Factor Assumptions

Land Use	Sector Area Fraction Sector Area/Total Area			Sector Area Development Density Units or ksf/Sector Area			Sector Development Factors Units or ksf/Total Area		
	SF	MF	NR	SF	MF	NR	SF	MF	NR
Town/Village Center	300 SF units on one specific Development Area (page 36 of Village of Rivanna Master Plan)								
Neighborhood Density Residential	0.80	-	-	4.50	-	-	3.6	-	-
Institutional	-	-	1.00	-	-	10.02	-	-	10.02
Parks and Green Systems	-	-	-	-	-	-	-	-	-
Neighborhood Density Residential Low	0.80	-	-	2.00	-	-	1.6	-	-

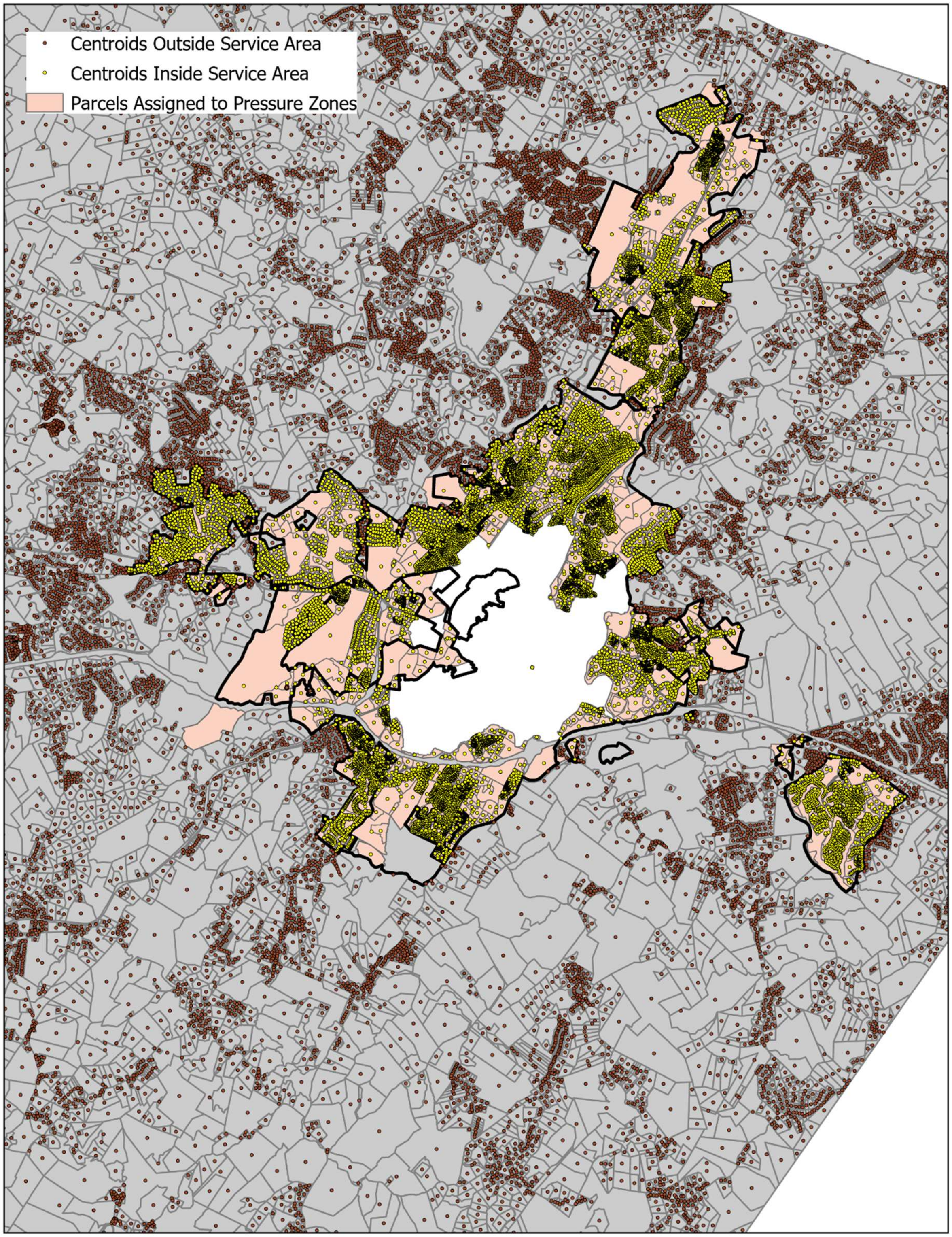


Figure A-18: County Parcels, Parcel Centroids, and Assignment of Parcels to Pressure Zones

Figure A-19: Deletion of Parcel Areas Overlapped by Higher-priority Partitions

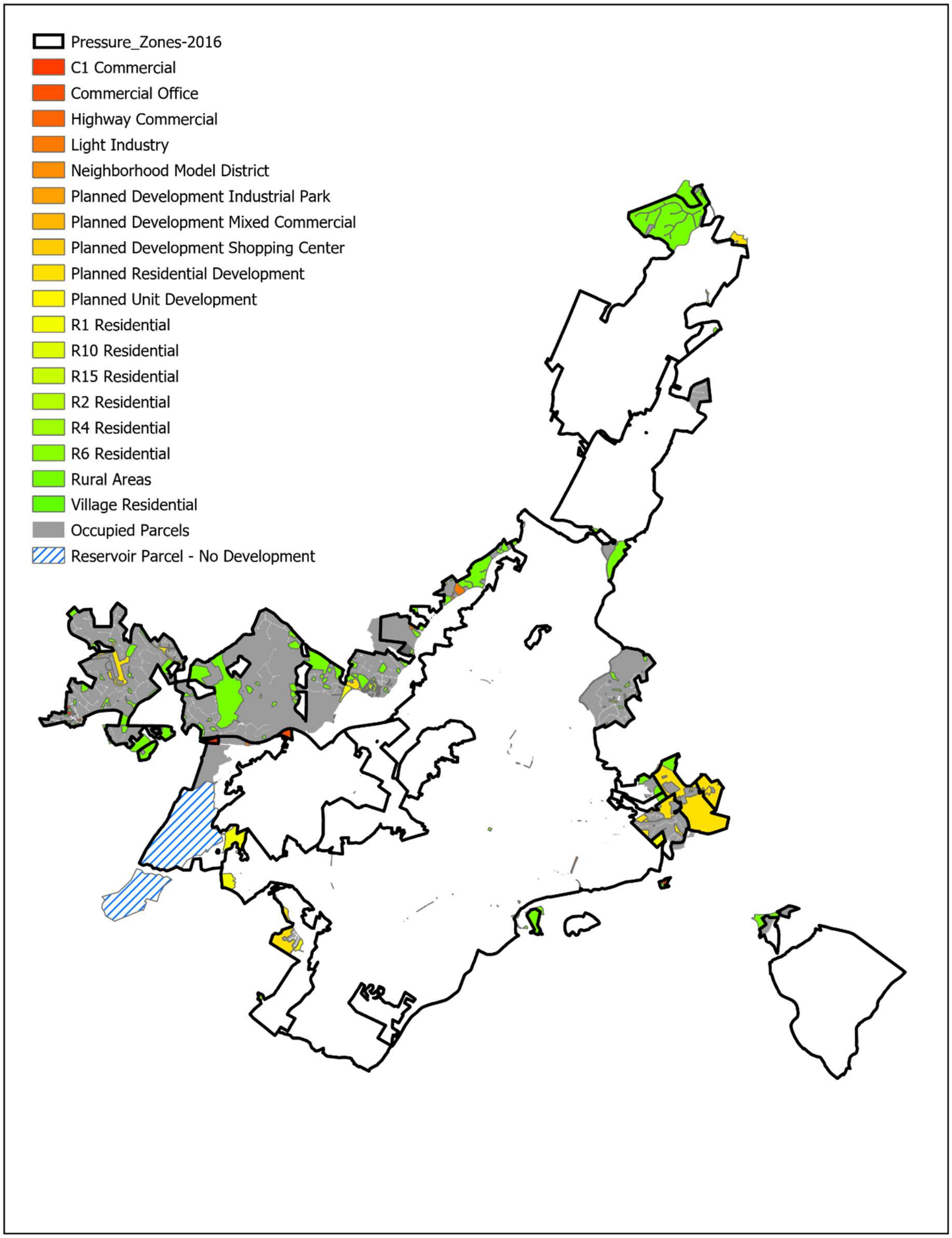


Figure A-20: Occupied and Unoccupied County Parcel Partitions

- Remaining parcels and portions of parcels were then grouped into partitions according to their pressure zone as well as whether they were vacant or occupied. Vacant parcels were those whose *UseCode* values were either 'Vacant Commercial Land' or 'Vacant Residential Land', parcels with other values were considered occupied. Vacant parcels were further partitioned by their *ZONING* values. These occupancy- and zoning-based partitions allowed the forecast to assume that vacant parcels would be developed according to zoning classifications and occupied parcels to not undergo any development (Figure A-20). One large parcel was identified in the extreme southwest of the service area that was considered vacant but that, in actuality, housed a water supply reservoir; this parcel was manually moved to the Occupied partition to prevent assumptions of future development therein.

Finally, SF, MF, and NR development factors (units/acre and sq. ft/acre) were assumed for each *ZONING* value among vacant County parcels (Table A-). These factors were inferred from specifications in zoning ordinance documents where possible.

Table A-11: Vacant County Parcel Development Factor Assumptions

ZONING	**SF unit/ac**	**MF unit/ac**	**NR ksf/ac**
Rural Areas	0.5		
R1 Residential	0.97		
R2 Residential	2		
R10 Residential	10		
R15 Residential		15	
R4 Residential	4		
R6 Residential	6		
Planned Residential Development		35	
Planned Unit Development		35	
C1 Commercial			10.02
Planned Development Industrial Park			10.89
Planned Development Mixed Commercial			10.02
Planned Development Shopping Center			10.02
Commercial Office			10.02
Highway Commercial			10.02
Light Industry			10.89
Neighborhood Model District	4.5		
Village Residential	0.7		

Combined Partitions. As with the City, land use and pressure zone partitions were used simultaneously in forecasting, such that each forecast partition corresponded to a specific combination of future land use and pressure zone. While these represent too many combinations to sensibly display on a map, Figure A-21 provides an indication of the associated partition granularity.

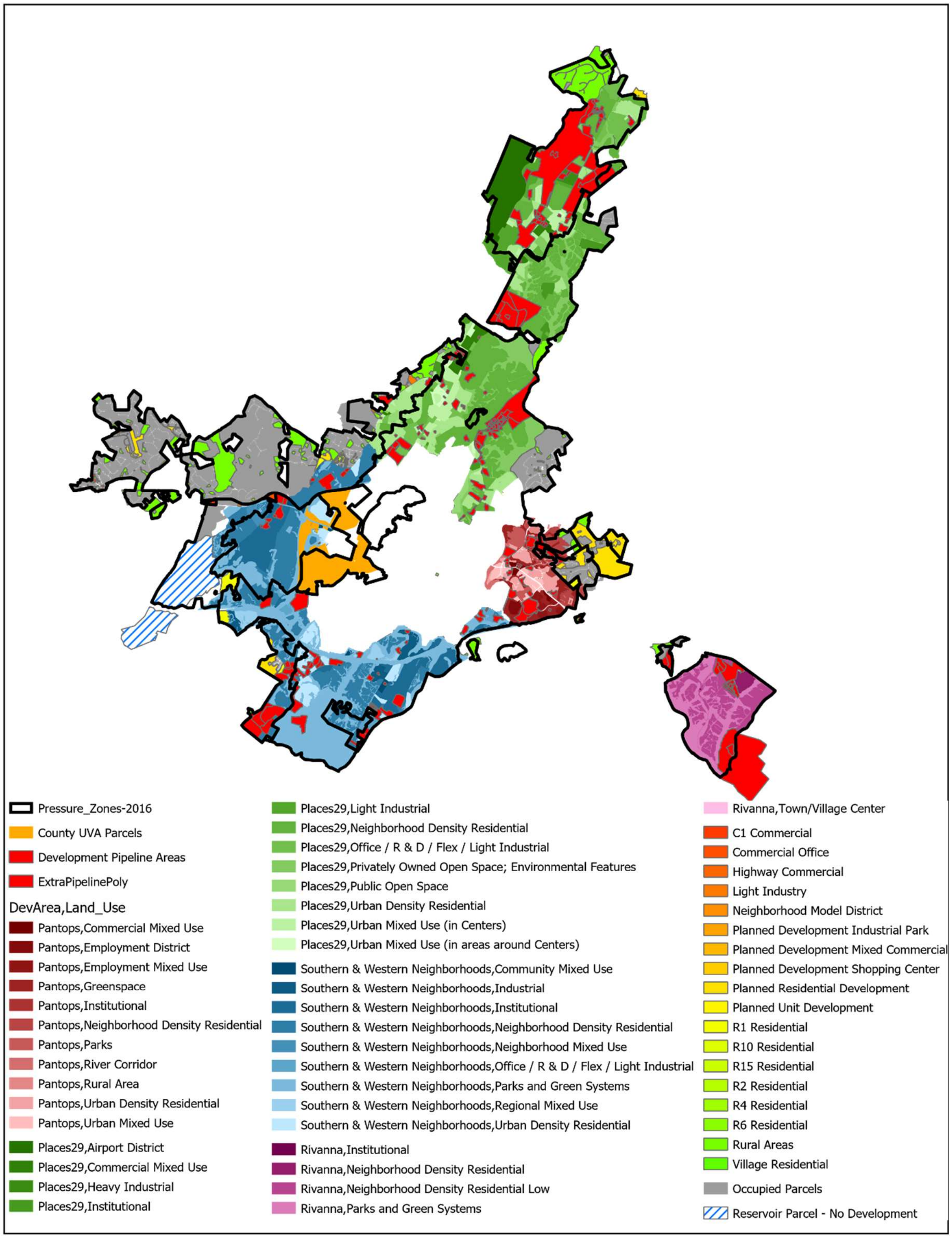


Figure A-21: Complete City Land Use Partition.

A.2.1 County Development Pacing

Having created the partitions as described above, the next step was to develop assumptions regarding the pace of development within them such that in aggregate they match the population forecasts for the County portion of the service area. Those target population values are described in Section 3.2, Table 3-2. The values shown in Table A-12 describe the progress at each time horizon between existing development density as of 2017 and maximum build-out densities (described in Section A.2 above) such that they produce reasonable facsimiles of the forecasted population for the ACSA portion of the service area at those intervals. The Development Pipeline partition was developed to the extent needed to create the number of housing units expected by the ACOCD in a spreadsheet titled "Capacity_Estimate_RWSA_20190118.xlsx". Additional population capacity was tied to new housing units and the persons per dwelling factor used with single family and multifamily housing units (2.53 for SFDUs, 2.01 for MFDUs).

Table A-12: Development Pacing for ACSA

Partition	2030	2045	2070
Development Pipeline	31%	33%	33%
Places 29	8%	24%	34%
Pantops	8%	24%	34%
S&W Neighborhoods	8%	24%	34%
Village of Rivanna	8%	24%	34%
Vacant/Undeveloped Outside masterplanned areas	8%	24%	34%

Appendix B: Water Intensity Model Details

B.1 Unit Demand Factor Analysis

To complete the buildout demand forecast, it was necessary to estimate future sectoral demand intensities, or single-family demand per dwelling unit, multifamily demand per dwelling unit, and nonresidential demand per square foot. Several published data sources exist that benchmark these values on a national average basis, but when forecasting it is generally best to produce estimates specific to the local service area, thereby accounting for socioeconomic, climatic, and development history and conditions. Individual-meter water use data paired with property appraiser data are often used for these purposes; meters are determined as serving specific SF, MF or NR properties, the number of dwelling units or square feet on each property is determined, and average intensities are determined within each sector as total consumption over a given time period divided by total units or square footage. Usually, a complete matching of all meters to property appraiser data is not available, but a sample of meters associated with property data is sufficient to produce intensity averages.

For RWSA, demand intensities in single-family, multifamily, and nonresidential water use sectors were estimated using City and County meter data for FY 2017, GIS data for meter locations and parcel polygons, and tabular information describing structures on parcels from the City from Charlottesville and the Albemarle County Office of Community Development.

B.1.1 Sectoral Classification of Meters

Both the City and County provided data indicating the type of development (SF, MF, or NR) served by each meter. For the City, use classification for each meter was recorded in a column called *Class* within the historical consumption Excel files. Meters with a *Class* value of ‘R’ and ‘M’ reflected single-family and multifamily use, respectively, while all other codes indicated nonresidential use. Visual comparison of meter locations with aerial and street-view imagery indicated that *Class* values generally aligned with the development characteristics used to define single-family and multi-family in this study. Therefore, *Class* values were used to assign City meters to water use sectors for demand intensity estimations.

For the County, use classification for each meter was indicated in a column called *UserTypeCo* within the GIS attribute table of the County’s meter layer. *UserTypeCo* values contained variants of the text “SF Residential’, ‘MF Residential’, ‘Commercial’, ‘Institutional’, or ‘Industrial’ to indicate types of use. The ACSA generally assigns the ‘SF Residential’ *UserTypeCo* to all dwellings that are individually metered, whether they are detached single-family houses, or multi-unit condominiums or apartments. The ‘MF Residential’ *UserTypeCo* is reserved for master metered apartments and multi-unit housing. Therefore, ‘SF Residential’ accounts were reviewed with aerial and street-view imagery and, if needed, reassigned to the MF designation based on the physical development characteristics[5]. For example, the apartment complex in Figure B-1 consists of multi-unit apartment buildings, the parcel for one of which is

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[5] Utilities usually apply sectoral classifications to meters to assign particular rate structures to those meters’ consumption. There may be many reasons behind assignments for individual meters that extend beyond the physical characteristics of the served properties. The adjustments to classifications made here were for purposes of demand forecasting only.

highlighted. However, this parcel and associated buildings are served by meters having *UserTypeCo* 'SF Residential' codes which were initially assumed to indicate single-family residential customers. Once this was discovered, it was determined the accounts across the ACSA system would need further review for consistent classification throughout the study because the code is inconsistent, in these cases, with true nature of the development; a set of multi-unit structures with common areas rather than individual detached houses with separate exterior areas. Because differences in water use behavior between sectors are usually influenced by physical characteristics such as these, it was necessary to classify County meters into water use sectors using a method that represented the physical characteristics of the residential structure. To this end, the following steps were taken:

- Using a GIS spatial join, each meter was identified with whichever parcel contained it or, if it was outside any parcel, whichever parcel was closest (up to a distance of 100 feet).
- Sectoral classification of each meter was then derived from land use data for its associated parcel (in parcel tables obtained from the ACOCD). The column *UseCode* in these tables described the use of each parcel in terms such as 'Apartments', 'Auditorium', 'Bank', 'Service Station', 'Single Family', etc. Each of these terms clearly related to notions of single-family, multifamily, or nonresidential land use (Table B-1), so sectoral assignments based on *UseCode* were used instead of *UserTypeCo* values when estimating sectoral demand intensity.

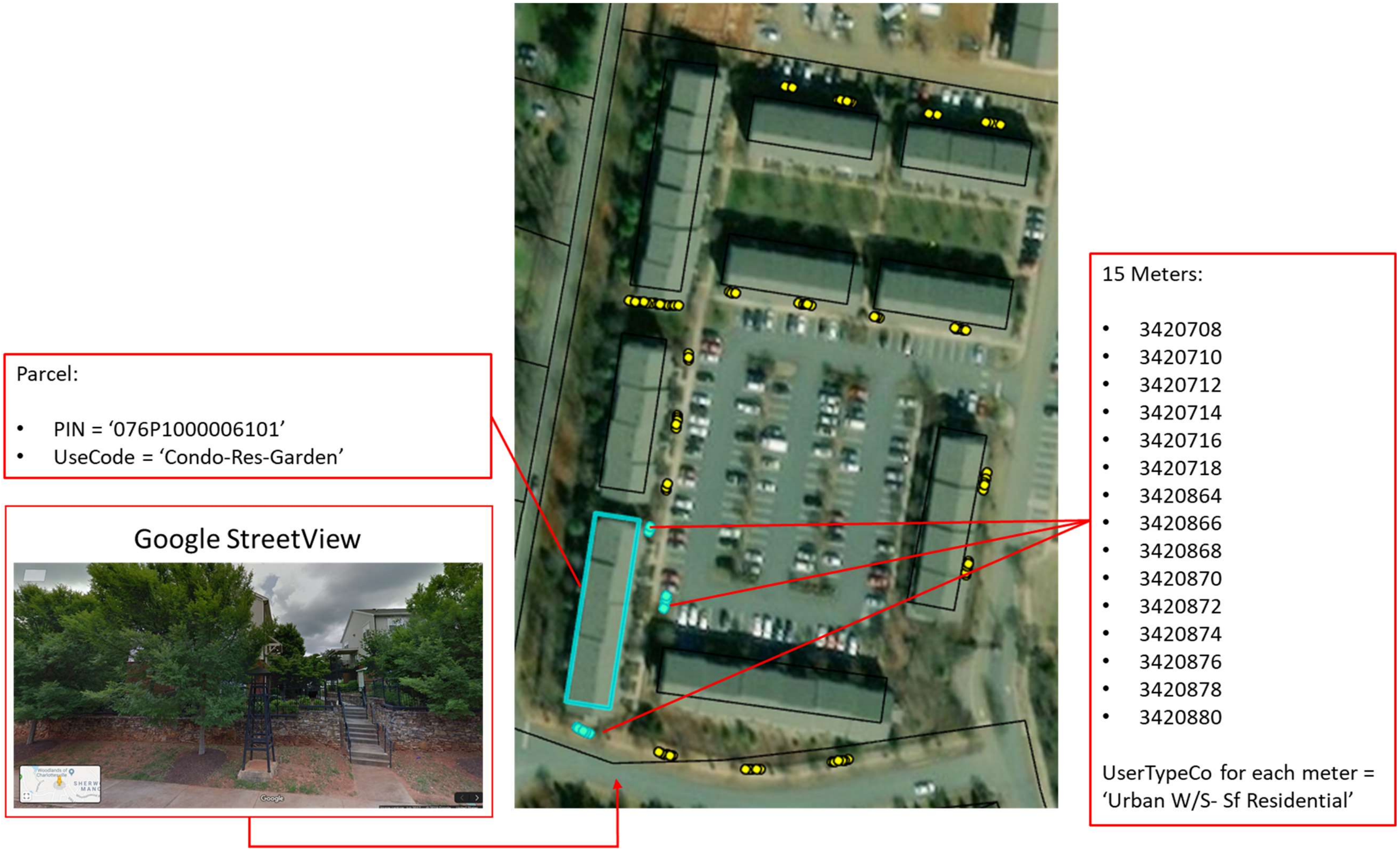


Figure B-1: Example of Different Land Use Classification by ACSA (UserTypeCo for meters) and ACOCD (UseCode for parcels)

Table B-1: Mapping of Parcel Use Codes to Water Use Sectors for County Meters

Single-family (SF): Doublewide, Loft, Mobile Home, Rectory, Single Family, Single Family-Rental, Vacant (R5-R6), Vacant Residential Land	
Multifamily (MF): 3-4 Family, Apartment, Apartments, Apartments (21+Units), Condo-Res-Garden, Condo-Res-TH, Dormitory, Duplex, Fraternity House, Mobile Home Park, Multi Resid Lo Rise Shell, Multi-Family, Multi-Family – Income, Multiple Res - Senior Citizen, Multiple Resid. (Low Rise), Small Apartment	
Nonresidential (NR): All other codes. Examples:	
Administration Bldg	Barber Shop
Armory	Barn
Auditorium	Bed & Breakfast
Auto Dealership Complete	Bowling Alley
Automobile Showroom	Business - Rural
Automotive Center	Cafeteria
Bank	etc.

In the example of Figure B-1, each of the highlighted meters was classified in the multifamily sector due to their proximity to the highlighted parcel.

Single Family Intensity. Following sectoral classification of meters, intensities were estimated for each water use sector using FY 2017 consumption data and estimates of the numbers of dwelling units or square feet in each sector. The single-family sector was most straightforward, as intensity was estimated by assuming each single-family meter served a single dwelling unit.

- City and County consumption records generally consisted of total volume metered over a 30- to 60-day period. For each single-family meter and each reading over July 2016 to June 2017, total gallons consumed and number of days between readings was obtained.
- All single-family consumption volumes thus obtained were summed, producing total gallons consumed through SF meters in FY 2017. Likewise, the numbers of days between readings were summed across all records, producing total meter-consumption-days through SF meters in FY 2017.
- Assuming each meter was associated with one SF unit, average SF demand intensity in gallons per unit per day was determined for FY 2017 by dividing total SF gallons by total SF meter-consumption-days. This estimate was a single average over all readings in FY 2017, reflecting no seasonality due to summer/winter weather or student occupancy.

Average single-family intensity for FY 2017 was estimated to be 109.4 gal/dwelling unit/day.

Table B-2: Estimated FY 2017 Demand Intensities by Sector

Sector	Estimated Intensity
Single-family	109.4 gal/unit/day
Multifamily	79.5 gal/unit/day
Non-Residential	75.0 gal/ksf/day

Nonresidential Intensity. Nonresidential intensities were estimated from total gallons and meter-consumption-days for NR meters over FY 2017, then dividing total gallons divided by total days to produce average gallons per NR meter per day, then dividing that number by the total number of nonresidential building square feet served by those meters.

- Total building square footage on each parcel was provided by both the City and the ACOCD.
- Land use data for County parcels were taken from the same parcel data file and *UseCode* column used to classify County meters. Land use data for City parcels were contained in a similar *UseCode* column in a similar parcel file to that of the County. The City *UseCode* values were used to identify NR parcels in a manner similar to the County parcels.
- Assuming that each NR parcel within the City and County service areas was served by one of the two utilities, total NR square footage was taken as the sum of square footage across City and County parcels contained within the service area (i.e., mapped to some pressure zone). This total square footage was used as the divisor to determine NR intensity in gallons per thousand square feet per day.
- Average nonresidential intensity for FY 2017 was estimated to be 75.0 gal/ksf/day.

Multifamily Intensity. To estimate multifamily intensity, it was necessary to know the number of dwelling units served by each multi-family meter used in the estimate. This requirement generally arises since meters that serve multifamily structures often serve more than one dwelling unit, or even all units, in those structures. Usually, property appraisers can provide information on the number of dwelling units for multifamily parcels; then, through a matching of meters to parcels, consumption per multifamily dwelling unit can be estimated. Unfortunately, neither the City nor the ACOCD had this information generally available for all multifamily parcels. ACOCD, however, was able to provide parcel-level unit information for those multifamily developments constructed after 2000 (including "single-family townhomes", which were regarded as multifamily structures in this estimate) through Certificate of Occupancy records. Thus, it was possible to identify 3024 dwelling units across 1139 parcels for 36 multifamily properties (Table B-3), and those units were served by a total of 1089 meters matched to their parcels through the sectoral identification process. Even though this represented a subset of newer multifamily dwellings in the County service area only, it was sufficient to produce a reasonable multifamily intensity estimate that could be applied across the region. Average nonresidential intensity for FY 2017 was estimated to be 79.5 gal/ksf/day. Note that this estimate might benefit from greater availability of dwelling unit information, particularly for properties that are older and in denser areas such as the City.

Table B-3: Properties Contained in the Multifamily Intensity Estimation Sample

Development or Location	Type	Number of Meters	Number of Parcels	Number of Dwelling Units
Arden Place	Multifamily	7	7	212
Bailey House Avermore	Multifamily	1	1	92
Carriage Gate	Multifamily	2	2	28
Cavalier Crossing	Multifamily	7	11	132
Commonwealth Senior Living	Multifamily	1	1	86
Eagles Landing Apts	Multifamily	10	18	504
Haven At Stonefield	Multifamily	8	9	276
Jefferson Ridge	Multifamily	5	6	150
Park View at South Pantops	Multifamily	1	1	90
Riverbed Condos Missing 30 Units	Multifamily	2	6	197
Treesdale Park	Multifamily	8	4	88
White Gables Condos Missing 1 Bldg	Multifamily	2	2	20
Woodlands Of Charlottesville	Multifamily	10	10	111
Avinity Loop	Townhome	107	102	102
Belvedere Blvd	Townhome	19	19	19
BlueJay Way	Townhome	37	35	35
Carrington PL	Townhome	9	9	9
Chatham Rdg	Townhome	15	13	13
Elm Tree	Townhome	65	63	63
Glenwood Station	Townhome	29	28	28
Lochlyn Hill Dr	Townhome	5	5	5
Lockwood	Townhome	17	17	17
More Belvedere	Townhome	20	19	19
Pantops Cottage	Townhome	17	17	17
Pebble Beach Ct	Townhome	39	39	39
Rolkin Rd	Townhome	349	343	343
Silk Wood Ct	Townhome	26	25	25
Somer Chase	Townhome	64	64	64
Stonehenge Way	Townhome	14	14	14
Templehof	Townhome	21	22	22
Timberwood	Townhome	72	71	71
TownBrook Crossing	Townhome	18	17	17
Tudor Ct	Townhome	44	44	44
Turnberry	Townhome	32	32	32
Webland	Townhome	6	40	40
	TOTALS	1089	1116	3024

B.2 City and County Buildout Forecasts

Buildout forecasts were developed by multiplying future SF and MF dwelling unit and NR square footage projections for each partition by the demand intensities found in Table B-2.

- **City of Charlottesville.** Tables B-4 through B-6 show total and sectoral current demands and buildout forecasts by land use/pressure zone partition for the City. Table B-7 shows total City demands from these tables summed to pressure zone. Total buildout demand for the City is estimated at 8.01 MGD, while current demand is 3.01 MGD.

- **ACSA.** Tables B-8 through B-15 show total and sectoral current demands and buildout forecasts by land use/pressure zone partition for ACSA. Table B-16 shows total ACSA demands from these tables summed to pressure zone. Total ACSA buildout demand is estimated at 9.82 MGD, while current demand is 4.03 MGD.

The magnitudes of buildout demand in comparison to current demand may seem shocking at first. However, it should be noted that buildout demand assumes that every possible portion of area is developed to full capacity according to development factor assumptions, with multiple caveats:

- No assumption is made of when actual buildout conditions are achieved, *if ever*. Buildout demand merely serves as a maximum limit for future demand and as an endpoint for gradual pacing of actual demand projections over time, an exercise that is described in Appendix A.

- The nature of buildout is subject to planning changes. Actual development intensity in the future may differ from current assumptions of development factors, especially if public support of or opposition to development changes. Also, when expressed in ordinances and master plans, these factors may have been determined based on multiple development goals and criteria, of which future water demand is only one. Development intensity changes directly impact the number of sectoral water users, and thus demand, at buildout.

- Buildout demand as calculated in this work does not include any consideration of increasing water use efficiency in the future. Starting in the early 1980's, water using appliances (toilets, washing machines, etc.) available in the marketplace have become substantially more efficient as each year has passed. This trend is expected to continue over the long term. As old appliances reach end-of-life and are replaced, the modern replacement appliances will therefore necessarily use less water than their predecessors. Estimation of this effect is beyond the scope of this work but would undoubtedly have an effect of reducing buildout demand.

Table B-4: City of Charlottesville Current Demand and Buildout Forecast: Mixed-Use Redevelopment Areas

ZONE	Pressure Zone	Total Acres	Future Land Use[A]		Sectoral Demands[B]		Total gal/day Demands	
			MF units	NR ksf	MF gpd	NR gpd	Buildout	Current
CC	Urban (652')	26.6	1277	532	101523	39907	141429	17506
D	Urban (652')	11.5	553	230	43927	17267	61194	9551
DE	Urban (652')	66.8	3208	1337	255071	100264	355335	46051
DEH	Urban (652')	7.7	371	154	29476	11587	41063	18778
DH	Urban (652')	37.3	1788	745	142159	55880	198038	119555
DN	Urban (652')	24.0	1151	480	91518	35974	127492	13117
DNC	Urban (652')	5.2	250	104	19900	7822	27723	5423
DNH	Urban (652')	12.8	615	256	48862	19207	68069	8299
HS	Urban (652')	17.2	825	344	65580	25778	91359	12972
HSC	Urban (652')	1.5	72	30	5752	2261	8013	465
HW	Urban (652')	219.2	10520	4383	836372	328762	1165134	222731
MedCenterHalfMile	Lambeth	10.8	519	216	41277	16225	57503	14068
MedCenterHalfMile	Lewis Mountain (751')	3.8	183	76	14537	5714	20251	365
MedCenterHalfMile	Urban (652')	556.5	26713	11131	2123723	834797	2958520	591087
MedCenterHalfMile	UVA (749')	0.2	9	4	717	282	999	0
NCC	Urban (652')	16.8	808	337	64273	25265	89537	13771
NCCH	Urban (652')	0.3	13	5	1033	406	1439	1539
SSH	Urban (652')	1.6	77	32	6109	2401	8510	2513
URB	Lewis Mountain (751')	8.6	412	172	32778	12884	45662	17108
URB	Urban (652')	57.7	2769	1154	220171	86545	306717	57020
URB	UVA (749')	7.8	374	156	29748	11693	41441	3640
URBH	Urban (652')	39.7	1905	794	151456	59534	210990	36588
WMEH	Urban (652')	2.6	125	52	9910	3895	13805	2699
WSH	Urban (652')	10.2	488	203	38779	15243	54022	19849
						Total (MGD)	**6.13**	**1.23**

A – Acres times development factors in Table A-3.

B – Future land use times demand intensities in Table B-2.

Table B-5: City of Charlottesville Current Demand and Buildout Forecast: Vacant Areas Outside Mixed-Use Redevelopment Areas

ZONE	Pressure Zone	Total Acres	Future Land Use[A]			Sectoral Demands[B]			Total gal/day Demands	
			SF units	MF units	NR ksf	SF gpd	MF gpd	NR gpd	Buildout	Current
B-1	Urban (652')	24.4	0	0	245	0	0	18363	18363	1901
B-1H	Urban (652')	0.0	0	0	0	0	0	17	17	0
B-2	Urban (652')	7.5	0	0	75	0	0	5647	5647	7116
B-3	Urban (652')	1.0	0	0	10	0	0	755	755	803
ES	Urban (652')	6.1	0	0	61	0	0	4607	4607	0
IC	Urban (652')	11.1	0	0	121	0	0	9045	9045	506
M-I	Urban (652')	6.9	0	0	76	0	0	5675	5675	398
MR	Urban (652')	2.7	0	56	0	0	4436	0	4436	295
Park	Urban (652')	120.1	0	0	0	0	0	0	4987	4987
PUD	Urban (652')	58.0	174	0	0	19021	0	0	19021	4557
PUDH	Urban (652')	0.1	1	0	0	123	0	0	123	0
R-1	Lambeth	6.3	19	0	0	2053	0	0	2053	607
R-1	Urban (652')	75.1	225	0	0	24632	0	0	24632	1234
R-1H	Urban (652')	0.4	1	0	0	138	0	0	138	88
R-1S	Urban (652')	103.7	829	0	0	90742	0	0	90742	10183
R-1SC	Urban (652')	0.6	2	0	0	187	0	0	187	0
R-1SH	Urban (652')	1.2	4	0	0	410	0	0	410	287
R-1SU	Urban (652')	0.3	1	0	0	106	0	0	106	131
R-1U	Lambeth	7.4	22	0	0	2439	0	0	2439	1137
R-1U	Lewis Mountain (751')	1.7	5	0	0	565	0	0	565	132
R-2	Urban (652')	41.7	334	0	0	36492	0	0	36492	11926
R-2H	Urban (652')	0.9	8	0	0	823	0	0	823	254
R-2U	Lambeth	0.9	7	0	0	760	0	0	760	0
R-2U	Urban (652')	3.9	31	0	0	3375	0	0	3375	396
R-3	Lambeth	0.3	0	12	0	0	934	0	934	0
R-3	Urban (652')	37.7	0	1622	0	0	128966	0	128966	15038
R-3H	Lambeth	1.0	0	66	0	0	5269	0	5269	107
R-3H	Urban (652')	1.0	0	65	0	0	5134	0	5134	401
								Total (MGD)	**0.37**	**0.06**

A – Acres times development factors in Table A-3. B – Future land use times demand intensities in Table B-2.

Table B-6: City of Charlottesville Current Demand: Occupied Areas Outside Mixed-Use Redevelopment Areas (Assumed to Not Change in Future)

Pressure Zone	Current Demand, MGD
Lewis Mountain (751')	0.05
Urban (652')	1.48
Lambeth	0.17
Stillhouse (796')	<0.01
UVA (749')	0.02
Total	**1.72**

Table B-7: City of Charlottesville Current Demand and Buildout Forecast by Pressure Zone

Pressure Zone	Total Demand, MGD	
	Current	Buildout
Lewis Mountain (751')	0.06	0.11
Urban (652')	2.74	7.58
Lambeth	0.18	0.23
Stillhouse (796')	<0.01	<0.01
UVA (749')	0.02	0.10
Total	**3.01**	**8.01**

Table B-8: ACSA Current Demand and Buildout Forecast: Development Pipeline

Pressure Zone	Future Land Use[A]			Sectoral Demands[B]			Total gal/day Demands	
	SF units	MF units	NR ksf	SF gpd	MF gpd	NR gpd	Buildout	Current
Urban (652’)	2714	5126	3111	296912	407517	233305	937734	269624
Piney Mountain (806’)	1730	1924	365	189262	152958	27373	369593	77724
Ashcroft Low (912')	180	0	0	19692	0	0	19692	1257
Mosby Mountain (750')	277	0	0	30304	0	0	30304	9103
Lewis Mountain (751')	76	65	16	8314	5168	1163	14645	14952
Stillhouse (796')	67	40	124	7330	3180	9328	19838	3270
Mill Creek (750')	30	0	0	3282	0	0	3282	0
						Total (MGD):	**1.40**	**0.37**

A – Specified in Development Permits. B – Future land use times demand intensities in Table B-2.

Table B-9: ACSA Current Demand and Buildout Forecast: Extra Pipeline

Development Name and Pressure Zone	Future Land Use[A]		Sectoral Demands[B]		Total gal/day Demands	
	MF units	NR ksf	MF gpd	NR gpd	Buildout	Current
Martha Jefferson Hospital: Urban (652’)	0	540	0	48600	0.049	0
Fontaine Research Park: Urban (652’)	0	866	0	64950	0.065	0
UVA Research Park: Piney Mountain (806’)	500	2000	39750	150000	0.190	0

A – Specified in Development Permits. B – Future land use times demand intensities in Table B-2, except for Martha Jefferson Hospital whose demand intensity was assumed to be 90 gal/ksf/day.

Table B-10: ACSA Current Demand and Buildout Forecast: Pantops Development Area

Land Use	Pressure Zone	Total Acres	Future Land Use[A]			Sectoral Demands[B]			Total gal/day Demands	
			SF units	MF units	NR ksf	SF gpd	MF gpd	NR gpd	Buildout	Current
Greenspace	Ashcroft Low (912')	47.9	0	0	0	0	0	0	0	1154
Neighborhood Density Residential	Ashcroft Low (912')	101.7	366	0	0	40065	0	0	40065	26766
Rural Area	Ashcroft Low (912')	2.0	0	0	0	0	0	0	0	0
Commercial Mixed Use	Urban (652')	30.3	0	79	182	0	6266	13670	19936	17970
Employment District	Urban (652')	32.3	0	0	259	0	0	19408	19408	14857
Employment Mixed Use	Urban (652')	66.3	0	172	398	0	13698	29881	43579	22962
Greenspace	Urban (652')	320.5	0	0	0	0	0	0	0	2643
Institutional	Urban (652')	1.2	0	0	7	0	0	532	532	300
Neighborhood Density Residential	Urban (652')	133.9	482	0	0	52747	0	0	52747	19764
Parks	Urban (652')	107.7	0	0	0	0	0	0	27	27
River Corridor	Urban (652')	69.1	0	0	0	0	0	0	0	0
Rural Area	Urban (652')	30.9	0	0	0	0	0	0	0	0
Urban Density Residential	Urban (652')	211.4	0	2199	0	0	174822	0	174822	182387
Urban Mixed Use	Urban (652')	119.6	0	544	586	0	43266	43961	87227	60446
								Total (MGD)	**0.44**	**0.35**

A – Acres times development factors in Table A-7. B – Future land use times demand intensities in Table B-2.

Table B-11: ACSA Current Demand and Buildout Forecast: Village of Rivanna Development Area

Land Use	Pressure Zone	Total Acres	Future Land Use[A]			Sectoral Demands[B]			Total gal/day Demands	
			SF units	MF units	NR ksf	SF gpd	MF gpd	NR gpd	Buildout	Current
Institutional	Urban (652')	0.5	0	0	5	0	0	351	351	662
Neighborhood Density Residential	Urban (652')	70.6	254	0	0	27821	0	0	27821	0
Neighb. Density Residential Low	Urban (652')	680.6	1089	0	0	119133	0	0	119133	126106
Parks and Green Systems	Urban (652')	714.3	0	0	0	0	0	0	13264	13264
Town/Village Center	Urban (652')	1.3	300[C]	0	0	32820	0	0	32820	0
								Total (MGD)	**0.19**	**0.14**

A – Acres times development factors in Table A-10. B – Future land use times demand intensities in Table B-2. C – Units explicitly specified in Master Plan

Table B-12: ACSA Current Demand and Buildout Forecast: Places29 Development Area

Land Use	Pressure Zone	Total Acres	Future Land Use[A]			Sectoral Demands[B]			Total gal/day Demands	
			SF units	MF units	NR ksf	SF gpd	MF gpd	NR gpd	Buildout	Current
Airport District	Piney Mountain (806')	607.9	0	0	0	0	0	0	0	4887
Commercial Mixed Use	Piney Mountain (806')	39.5	0	0	317	0	0	23763	23763	20930
Heavy Industrial	Piney Mountain (806')	40.4	0	0	405	0	0	30353	30353	6475
Institutional	Piney Mountain (806')	<0.1	0	0	0	0	0	1	1	0
Light Industrial	Piney Mountain (806')	309.0	0	0	2692	0	0	201870	201870	18911
Neighborhood Density Residential	Piney Mountain (806')	458.9	1652	0	0	180733	0	0	180733	65214
Office / R & D / Flex / Light Industrial	Piney Mountain (806')	287.8	0	0	2307	0	0	173023	173023	44288
Privately Owned Open Space; Env. Features	Piney Mountain (806')	32.9	0	0	0	0	0	0	1538	1538
Urban Density Residential	Piney Mountain (806')	297.2	0	3090	0	0	245688	0	245688	33482
Urban Mixed Use (in areas around Centers)	Piney Mountain (806')	5.2	0	24	25	0	1882	1912	3794	1538
Urban Mixed Use (in Centers)	Piney Mountain (806')	126.3	0	796	619	0	63261	46423	109684	28098
Commercial Mixed Use	Stillhouse (796')	4.9	0	0	39	0	0	2961	2961	1782
Institutional	Stillhouse (796')	26.6	0	0	266	0	0	19972	19972	5060
Neighborhood Density Residential	Stillhouse (796')	23.9	86	0	0	9397	0	0	9397	7750
Office / R & D / Flex / Light Industrial	Stillhouse (796')	30.3	0	0	243	0	0	18225	18225	4443
Privately Owned Open Space; Env. Features	Stillhouse (796')	2.4	0	0	0	0	0	0	0	0
Public Open Space	Stillhouse (796')	36.2	0	0	0	0	0	0	11321	11321
Urban Density Residential	Stillhouse (796')	250.9	0	2610	0	0	207456	0	207456	226161
Urban Mixed Use (in Centers)	Stillhouse (796')	22.2	0	140	109	0	11132	8169	19301	8419
Commercial Mixed Use	Urban (652')	140.0	0	0	1122	0	0	84158	84158	56242
Institutional	Urban (652')	154.6	0	0	1549	0	0	116203	116203	7486
Neighborhood Density Residential	Urban (652')	2249.1	8097	0	0	885768	0	0	885768	503796
Office / R & D / Flex / Light Industrial	Urban (652')	164.2	0	0	1316	0	0	98706	98706	84895
Privately Owned Open Space; Env. Features	Urban (652')	1049.3	0	0	0	0	0	0	20834	20834
Public Open Space	Urban (652')	64.8	0	0	0	0	0	0	1116	1116
Urban Density Residential	Urban (652')	636.0	0	6614	0	0	525825	0	525825	501589
Urban Mixed Use (in areas around Centers)	Urban (652')	84.8	0	386	416	0	30680	31173	61852	10482
Urban Mixed Use (in Centers)	Urban (652')	231.4	0	1458	1134	0	115875	85032	200908	93528
								Total (MGD)	**3.26**	**1.77**

A – Acres times development factors in Table A-8. B – Future land use times demand intensities in Table B-2.

Table B-13: ACSA Current Demand and Buildout Forecast: Vacant Land outside County Development Areas (Ashcroft High through Piney Mountain Pressure Zones)

ZONING	Pressure Zone	Total Acres	Future Land Use[A]			Sectoral Demands[B]			Total gal/day Demands	
			SF units	MF units	NR ksf	SF gpd	MF gpd	NR gpd	Buildout	Current
Planned Residential Development	Ashcroft High (1341')	7.2	0	253	0	0	20147	0	20147	0
Planned Residential Development	Ashcroft Low (912')	69.9	0	2448	0	0	194583	0	194583	0
R1 Residential	Ashcroft Low (912')	0.3	0	0	0	31	0	0	31	0
Rural Areas	Ashcroft Low (912')	31.7	16	0	0	1732	0	0	1732	0
Planned Residential Development	Ashcroft Middle	350.0	0	12249	0	0	973783	0	973783	0
Rural Areas	Ashcroft Middle	25.9	13	0	0	1415	0	0	1415	0
Highway Commercial	Ednam (880')	1.1	0	0	11	0	0	857	857	0
Light Industry	Ednam (880')	2.7	0	0	29	0	0	2193	2193	61
R1 Residential	Ednam (880')	58.0	56	0	0	6158	0	0	6158	0
Rural Areas	Ednam (880')	1032.0	0[C]	0	0	0	0	0	1843	1843
Commercial Office	Lewis Mountain (751')	0.0	0	0	0	0	0	0	0	0
Highway Commercial	Lewis Mountain (751')	0.0	0	0	0	0	0	0	0	0
R1 Residential	Lewis Mountain (751')	1.9	2	0	0	202	0	0	202	0
R15 Residential	Lewis Mountain (751')	0.0	0	1	0	0	42	0	42	0
Planned Residential Development	Mosby Mountain (750')	70.6	0	2470	0	0	196372	0	196372	0
R1 Residential	Mosby Mountain (750')	8.3	8	0	0	876	0	0	876	0
Rural Areas	Mosby Mountain (750')	4.9	2	0	0	269	0	0	269	0
Light Industry	Piney Mountain (806')	0.4	0	0	4	0	0	299	299	0
Planned Development Ind. Park	Piney Mountain (806')	1.7	0	0	19	0	0	1415	1415	0
Planned Residential Development	Piney Mountain (806')	32.1	0	1124	0	0	89347	0	89347	0
Rural Areas	Piney Mountain (806')	456.1	228	0	0	24948	0	0	24948	15863
								Total (MGD)	**1.51**	**0.02**

A – Acres times development factors in Table A-11. B – Future land use times demand intensities in Table B-2.
C – Partition corresponds to Ragged Mountain Protected Area. Assumed no development.

Table B-14: ACSA Current Demand and Buildout Forecast: Vacant Land outside County Development Areas (Stillhouse and Urban Pressure Zones)

ZONING	Pressure Zone	Total Acres	Future Land Use[A]			Sectoral Demands[B]			Total gal/day Demands	
			SF units	MF units	NR ksf	SF gpd	MF gpd	NR gpd	Buildout	Current
C1 Commercial	Stillhouse (796')	13.4	0	0	134	0	0	10084	10084	0
Commercial Office	Stillhouse (796')	12.9	0	0	129	0	0	9699	9699	0
Light Industry	Stillhouse (796')	18.2	0	0	198	0	0	14851	14851	449
Neighborhood Model District	Stillhouse (796')	1.1	5	0	0	530	0	0	530	0
Planned Residential Development	Stillhouse (796')	89.4	0	3131	0	0	248891	0	248891	0
R1 Residential	Stillhouse (796')	13.1	13	0	0	1395	0	0	1395	0
R10 Residential	Stillhouse (796')	0.0	0	0	0	4	0	0	4	0
R15 Residential	Stillhouse (796')	17.1	0	257	0	0	20409	0	20409	55504
R4 Residential	Stillhouse (796')	0.0	0	0	0	0	0	0	0	0
R6 Residential	Stillhouse (796')	11.3	68	0	0	7396	0	0	7396	4223
Rural Areas	Stillhouse (796')	770.7	385	0	0	42156	0	0	42156	9551
Village Residential	Stillhouse (796')	12.1	8	0	0	926	0	0	926	0
C1 Commercial	Urban (652')	0.0	0	0	0	0	0	23	23	0
Commercial Office	Urban (652')	3.5	0	0	35	0	0	2639	2639	0
Highway Commercial	Urban (652')	4.5	0	0	45	0	0	3403	3403	6038
Light Industry	Urban (652')	0.8	0	0	9	0	0	678	678	0
Neighborhood Model District	Urban (652')	0.0	0	0	0	5	0	0	5	0
Planned Development Mixed Comm.	Urban (652')	1.6	0	0	16	0	0	1221	1221	0
Planned Development Shopping Ctr.	Urban (652')	0.1	0	0	1	0	0	58	58	0
Planned Residential Development	Urban (652')	10.2	0	356	0	0	28323	0	28323	0
Planned Unit Development	Urban (652')	0.2	0	6	0	0	514	0	514	0
R1 Residential	Urban (652')	53.0	51	0	0	5627	0	0	5627	0
R15 Residential	Urban (652')	1.7	0	25	0	0	2010	0	2010	0
R2 Residential	Urban (652')	0.0	0	0	0	3	0	0	3	0
R4 Residential	Urban (652')	9.5	38	0	0	4173	0	0	4173	0
R6 Residential	Urban (652')	1.3	8	0	0	885	0	0	885	0
Rural Areas	Urban (652')	173.1	87	0	0	9469	0	0	9469	1137
								Total (MGD)	**0.42**	**0.08**

A – Acres times development factors in Table A-11. B – Future land use times demand intensities in Table B-2.

Table B-15: ACSA Current Demand: Occupied Areas Outside County Development Areas (Assumed to Not Change in Future)

Pressure Zone	Current Demand, MGD
Ashcroft High (1341')	<0.01
Ashcroft Low (912')	0.02
Ashcroft Middle	<0.01
Ednam (880')	0.01
Lewis Mountain (751')	0.02
Mosby Mountain (750')	0.01
Piney Mountain (806')	<0.01
Stillhouse (796')	0.23
Urban (652')	0.04
Total	**0.32**

Table B-16: ACSA Current Demand and Buildout Forecast by Pressure Zone

Pressure Zone	Total Demand, MGD	
	Current	Buildout
Ashcroft High (1341')	0.00	0.02
Ashcroft Low (912')	0.05	0.27
Ashcroft Middle	0.00	0.98
Ednam (880')	0.04	0.04
Lewis Mountain (751')	0.24	0.75
Mosby Mountain (750')	0.08	0.39
Piney Mountain (806')	0.32	1.65
Stillhouse (796')	0.67	1.04
Urban (652')	2.63	4.69
Total	**4.03**	**9.82**

Appendix C: Annual Weather and Demand Variability Analysis

On time scales as short as a day or as long as a year, weather variations can significantly influence a utility's total demand. Anticipating variability in the demand forecasts due to weather, an analysis was performed to account for the extent of the correlation of weather measures with water demand for this area on an annual basis. An annual basis was chosen since variability at that level would potentially begin to influence the safe yield of RWSA's reservoir system. Fluctuation due to weather, flushing, or fire emergencies at the daily or weekly scale will impact the capacity needs for other types of infrastructure investments such as water treatment and pumping facility size, but it is variability at the annual scale that needs to be accounted for when conducting reservoir yield analyses and determining when it is necessary to bring new reservoir capacity into service.

Weather data (including temperature, precipitation, wind speed, and relative humidity) from 1980 to 2018 was gathered from NOAA's ACIS system including two National Weather Service Cooperative (COOP) stations and the Albemarle airport. Approximately thirty years' worth of data is required to calculate a climate average that is representative of current extremes (IPCC, 2013).

When attempting to use weather variables to explain water demand, it has consistently been found that excluding temperature and precipitation over certain months proved superior to using the entire calendar year of weather data. Specifically, temperature and precipitation data from April to November has had the best fit (highest R^2 value) for previous models. The fact that April through November would prove better matched to water demand appears to be explained by the fact that those months are most likely to include outdoor watering and the greatest building cooling demands in Virginia and North Carolina (where previous models have been developed).

These values were then compared to the mean in units of standard deviation, as depicted for temperature and precipitation in Figure C-1. Using the difference from the mean, rather than directly using the weather measures in the regression model, the model's intercept, in particular, will be meaningful and describe the unit demand in an average weather year.

Figure C-1: April through November Temperature and Precipitation Data

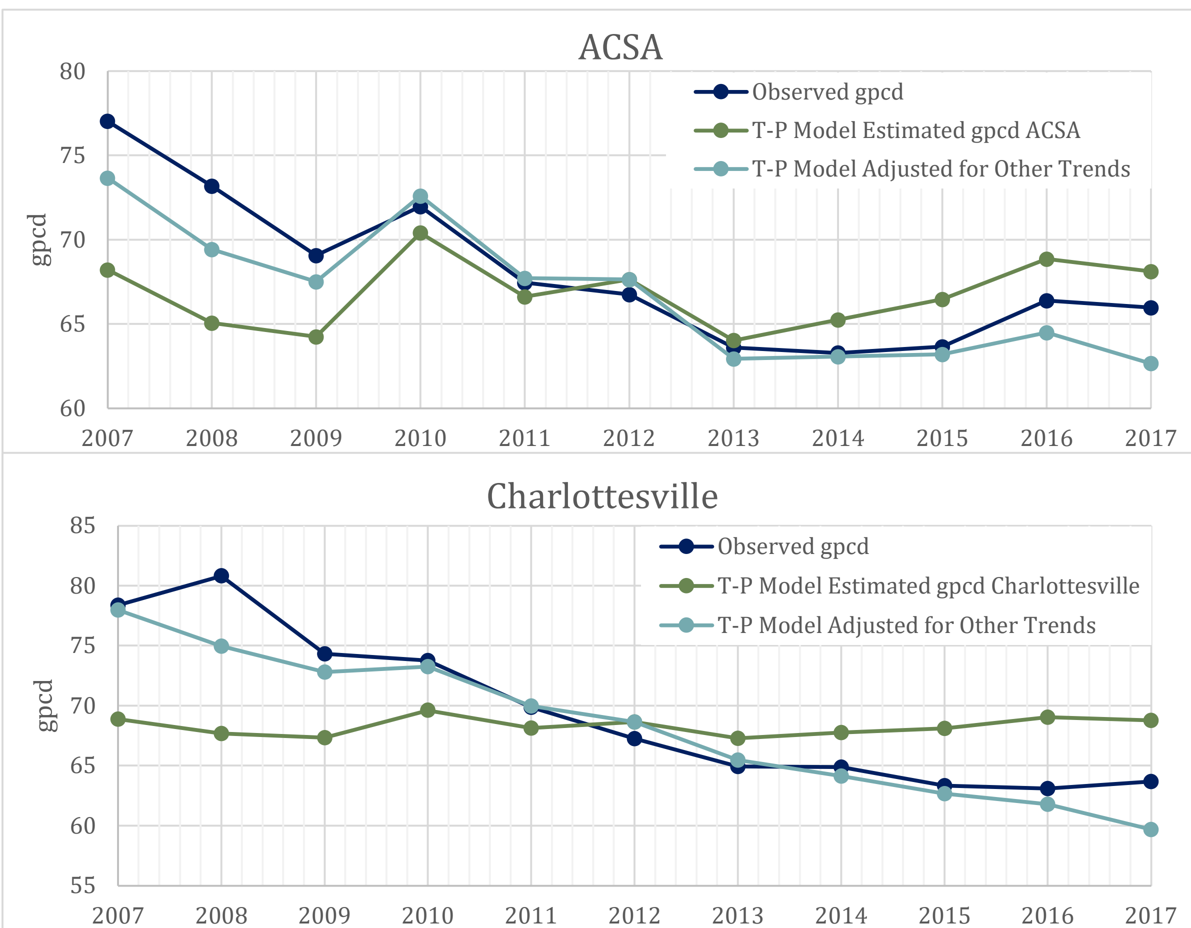
A standard least squares multi-linear regression was performed using temperature and precipitation as the explanatory (independent) variables for aggregate per capita water demand for the City of Charlottesville and ACSA annual per capita demand from 2007 to 2018. Ideally the timeframe chosen to fit the data would not contain major shifts in other variables that influence water use such as the economy, water price, high precipitation events such as from tropical storms or hurricanes, or utility imposed mandatory conservation. For each of the City of Charlottesville and Albemarle County, analyses were performed from 2007, 2008, 2009, and 2010 to 2017 to explore a range of fits with the weather measures. Additionally, the 2010 to 2014 demands for the County were analyzed since this represented a period of constant pricing and 2009 to 2013 for the City of Charlottesville which also represented a period of near constant pricing. The demand in these periods were normalized around their mean value to account for external conservation trends in developing the weather coefficients. In an additional attempt to account for variations outside of weather fluctuations, an average was taken of the five sets of coefficients for each location.

The sets of analyses proved that only temperature and precipitation had consistently reasonable fits with both the City of Charlottesville or ACSA demand data. This was assessed using the adjusted R-squared for each model fit, to account for the number of variables analyzed causing overfitting. The adjusted R^2 for the averaged model is 0.71 for ACSA and 0.82 for the City of Charlottesville. The adjusted R^2 for the UVA model, analyzed using 2010-2018 data, was 0.73. Table C-1 contains the model coefficients and intercepts for each service area. Because the model was set up using variance from the mean, the intercept is meaningful and represents the estimated per capita demand during a year with average weather during the growing season.

Table C-1: Weather Variability Parameters and Climate Normal Unit Demand

Service Area	Temperature Variation (%)	Precipitation Variation (%)	Climate Normal Demand
ACSA	+2.45	-2.17	66.41 gpcd
Charlottesville	+0.83	-0.88	68.14 gpcd
UVA	+3.30	-2.29	87.7 gpd/ksf

Figure C-2: Predicted Unit Demand (gpcd) from Growing Season Temperature and Precipitation



Once the demand response relationships were developed, 5000 trials were generated using Monte Carlo Simulation (MCS) techniques with each trial representing the temperature and precipitation outcome of a single growing season. The Oracle Crystal Ball package was used as the MCS software. The relationship between growing season temperature and precipitation were found to have a weakly-correlated inverse relationship (correlation coefficient = -0.27) based on a statistical fit of the 1980-2018 weather data. The MCS software takes this correlation into account. Table C-2 summarizes the combined influence of temperature and precipitation on water demand by service area. The adjustment to the demand is indicated at each reported percentile, with 'Min' being lowest demand (extreme cool and wet) for the 5000 trials and 'Max' representing the highest demand (extreme heat and dry) observed in the 5000 trials. The modeled demand response to the simulated weather conditions comes from Table C-1.

Table C-2: Modeled Demand Adjustments by Percentile

Percentiles	ACSA Demand Adjustment	Charlottesville Demand Adjustment	UVA Demand Adjustment
Min	-14.04%	-5.06%	-17.68%
1%	-8.50%	-3.15%	-10.41%
5%	-5.85%	-2.16%	-7.26%
10%	-4.45%	-1.64%	-5.35%
25%	-2.43%	-0.88%	-3.00%
50%	-0.23%	-0.07%	-0.30%
75%	1.89%	0.69%	2.30%
90%	3.81%	1.40%	4.69%
95%	4.93%	1.79%	6.15%
99%	7.46%	2.62%	9.50%
Max	13.74%	4.87%	17.58%

References

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Appendix D: Peak Day Factor Calculation Using System Mass Balance Approach

The Mass Balance Method was developed to provide a second, more in depth, analysis of the peak day demand for the Urban Service Area. The purpose was to filter out peak that might be driven by refilling clearwells at WTPs or other events that might not be truly representative of system demand. This method excludes any in-plant water usage from its peak day calculations. The analysis began by gathering historical pumping and tank level data for the service area and calculating daily system demands in accordance with the system schematic shown in Figure D-1. The system schematic includes pressure zones, tanks, PRVs, treatment plants, and pump stations, which were each used in the analysis. The goal was to provide a second set of statistical results to use in comparison with the peaking factor results determined in the WTP Production Method described in Section 4.

The Mass Balance Method relied heavily on the available historical data for pumping and tank level operations in the Urban Service Area. The Urban Service Area is served by a combination of 13 pump stations and 12 storage tanks. Due to the number of data sources needed to complete this analysis for the Urban System and the inconsistency of recorded data, it was impossible to find any periods when all 25 sources reported reliable values. Figure D-2 shows the available pump station and tank level data provided to Hazen and Sawyer to perform the analysis. The figure shows the fraction of reliable hourly data available in each 24-hr period from July 2010 to December 2018 for each pump station and tank in the system. A full-height purple bar indicates all the data is available from the specified source. A flat line indicates no data and heights in between indicate partial records for the period. The most reliable range of record keeping came over the course of 2017 and 2018, but even then a minimum of 2 of the 25 datasets were incomplete. In the interest of completing the analysis, trends were developed to match historical values and fill in missing data ranges. The trend mimicked historical average monthly data and sloped in the direction of historical values. An example of the trend developed for the Lambeth Pump Station is shown in Figure D-3. Using new input provided by trending data, the years 2013 to 2018 were evaluated for the Mass Balance Method. Figure D-4 illustrates the consistent trend in peaking factors over the past six years. The consistency observed over the time frame may be a result of filling in missing data with average monthly values, thus eliminating the likelihood of peak days in the system. Peaking factors averaged 1.24 throughout the dataset. The maximum and minimum peaking factor was 1.29 in 2016 and 1.17 in 2018, respectively. Figure D-5 illustrates a box and whisker plot of peaking factors for both the WTP Production Method and Mass Balance Method. The Mass Balance method did not accurately represent peaks in the system due to the missing data. Therefore, The WTP Production Method was used to recommend a peaking factor to RWSA and is further addressed in Section 4.

Figure D-1: Mass Balance Method – RWSA System Schematic

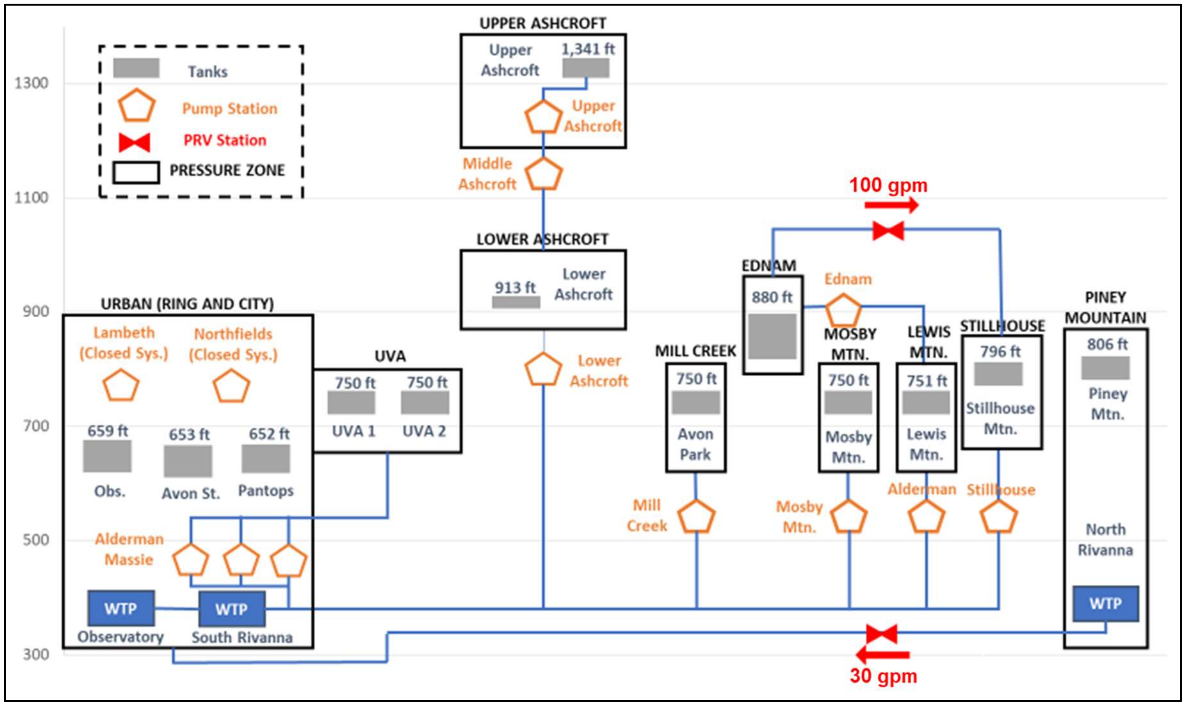


Figure D-2: Mass Balance Method – Hourly Data Availability for Pump Station Flow and Tank Level by Day

Figure D-3: Mass Balance Method – Lambeth PS Example of Trends Developed

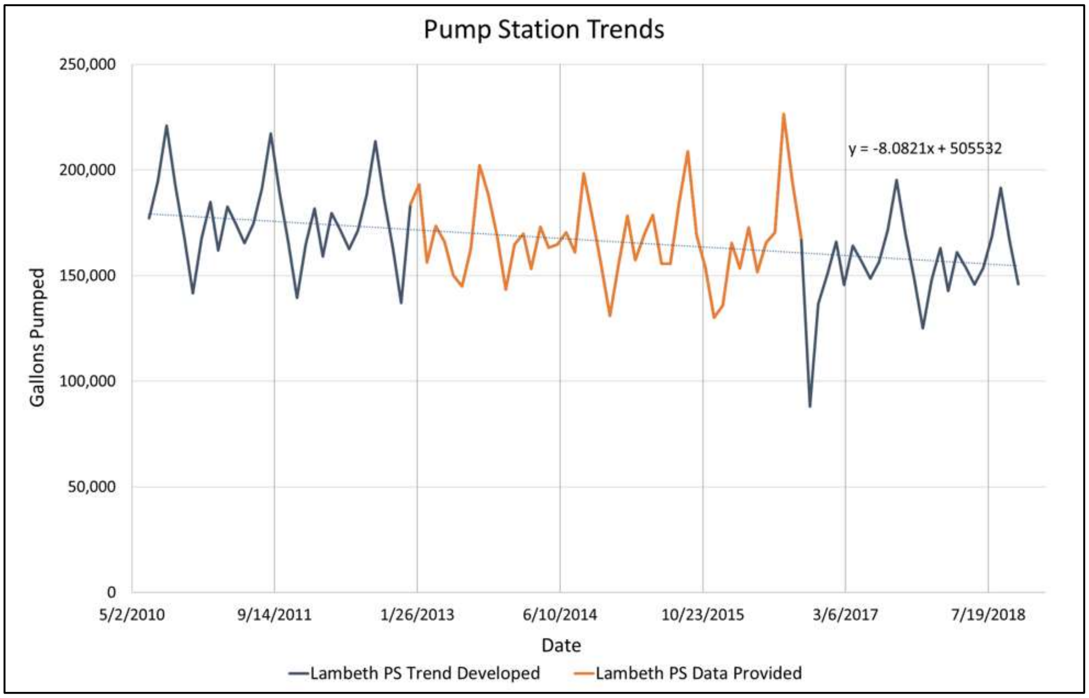


Figure D-4: Mass Balance Method – Historical Maximum Day Peaking Factors

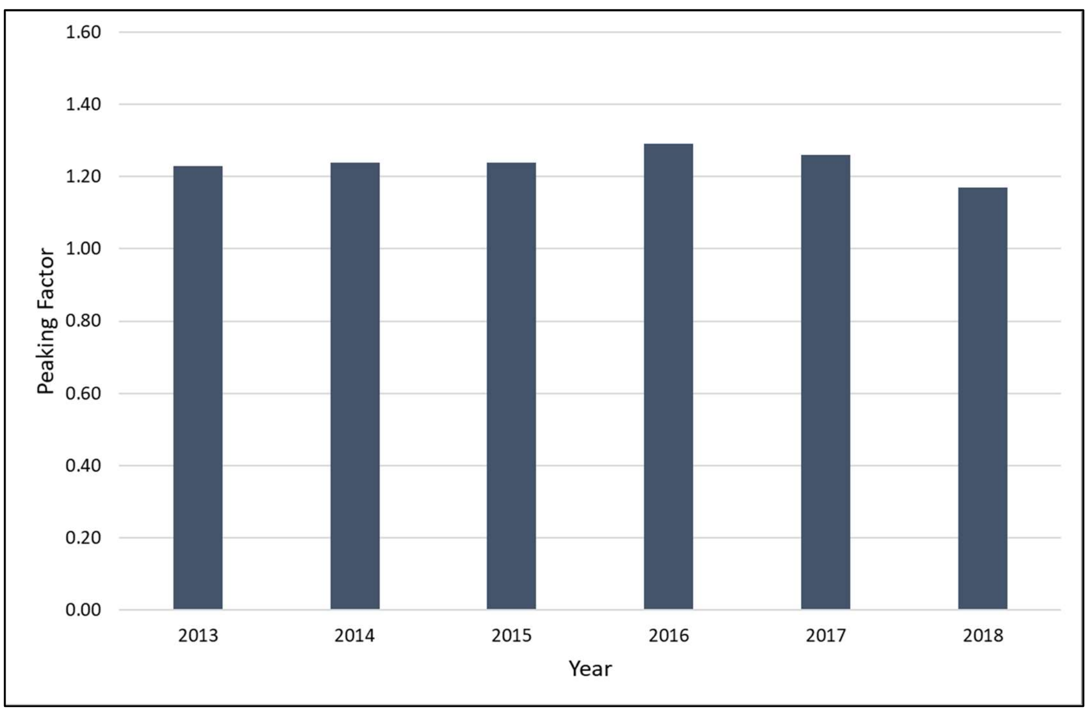


Figure D-5: Peaking Factors – WTP Production Method (left) and Mass Balance Method (right)