Cumulative Water Use and Availability Study for the Susquehanna River Basin

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SUSQUEHANNA RIVER BASIN COMMISSION
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The Susquehanna River Basin Commission (Commission) was created as an independent agency by a federal-interstate compact* among the states of Maryland and New York, the Commonwealth of Pennsylvania, and the federal government. In creating the Commission, the Congress and state legislatures formally recognized the water resources of the Susquehanna River Basin as a regional asset vested with local, state, and national interests for which all the parties share responsibility. As the single federal-interstate water resources agency with basin-wide authority, the Commission's goal is to coordinate the planning, conservation, management, utilization, development, and control of basin water resources among the public and private sectors.

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GLOSSARY

Average Daily Flow (ADF) – The average of mean daily streamflows for a period of record.

Baseflow – The portion of streamflow typically attributed to groundwater discharge, which can sustain streamflow over long-term periods of dry conditions. A range of baseflow recurrence intervals were estimated for the study, including average, 2-, 5-, 10-, 25-, and 50-year baseflow.

Consumptive Use (CU) – The loss of water due to a variety of processes by which the water is not returned to the Basin undiminished in quantity.

Consumptive Use (CU) Coefficient – A factor represented as a percentage or decimal derived by dividing the amount of CU by the total amount of water withdrawn for a given water use category. This study used published CU coefficients by industry code to convert water withdrawals to CU where CU data were not available.

Grandfathered Project – Withdrawals and/or consumptive water uses that predate the dates in Section 806.4(a) and therefore do not require Commission review and approval to continue operations, provided the project did not modify the way they do business such as changing the nature of the water use, increasing the quantity of usage, adding a new water source, or changing ownership.

Hydrologic Unit Code (HUC) – Standard hierarchical system used to delineate watersheds based on surface hydrologic features and classify them based on a unique code consisting of two to 12 digits representing six levels of classification ranging from region (HUC-2) to subwatershed (HUC-12). HUC-10 was defined as the target spatial scale for this study based on consideration of existing/future regulatory and planning objectives and data availability.

Percent Exceedance Flow – The flow that is exceeded a certain percent of the time. For example, a June 95 percent exceedance (P95) flow represents a low flow that has been exceeded 95 percent of all days in June over the period of record.

Pour Point – A point located at the outlet of a watershed, which for this study refers to HUC-10 watershed outlet points.

Protection, Mitigation, and Enhancement (PM&E) Measures – Measures implemented to avoid, minimize, or mitigate potential CU impacts to competing users, water quality, and aquatic resources. Examples include water use reductions, passby flows, conservation releases, CU mitigation releases, and/or water use caps.

Seven-Day, Ten-Year (7Q10) Flow – Annual 7-day minimum flow with a 10-year recurrence interval.

Water Availability – The hydrologic capacity of a water source or watershed to sustain additional water demands after considering other current water uses and water conditions.

Water Capacity – The natural ability of a watershed to sustainably support streamflow over time, during varied climatic conditions.

Water Use – Water use broadly refers to water withdrawals and/or CU by public water suppliers, various industries including agriculture, and the general public.

EXECUTIVE SUMMARY

The Susquehanna River Basin Commission's (Commission's) mission is to enhance public welfare through comprehensive planning, water supply allocation, and management of the water resources of the Basin (Susquehanna River Basin Compact). The Commission's Comprehensive Plan includes a goal to, through planning and regulatory actions, manage water resources beginning at the watershed level to assure short-term resource availability and long-term balance between healthy ecosystems and economic viability (SRBC, 2013). The Cumulative Water Use and Availability Study (CWUAS) represents the most comprehensive evaluation of water use and availability throughout the Basin conducted to date. The scope of the study entailed (1) quantification of consumptive use (CU); (2) determination of water capacity and availability; (3) development of a GIS-based tool; and (4) consideration of protection, mitigation and enhancement (PM&E) measures. The 10-digit Hydrologic Unit Code (HUC-10) was the target spatial scale for the study and included 170 watersheds in the Basin.

The Commission defines CU as the loss of water due to a variety of processes by which the water is not returned to the Basin. A water use database was developed by integrating Commission, New York, Pennsylvania, and Maryland records. Estimates of unregulated CU by the self-supplied residential and agricultural sectors were generated. Projections of CU in 2030 were developed based on trend analysis and published forecast information. Total 2014 approved and reported CU were 1,034.8 and 367.0 million gallons per day (mgd), respectively. Projected 2030 approved and reported CU were 1,203.3 and 405.4 mgd, respectively. The majority of approved/reported CU was associated with the public water supply (47/31 percent) and electric power generation sectors (21/30 percent). Approved and reported CU by the natural gas industry were estimated to be 12 and 9 percent, respectively. Approved CU was greater than 50 mgd for 7 percent of the watersheds in the Basin. The majority of watersheds, 74 percent, were assessed as having approved CU less than 10 mgd. Of these, 65 percent had approved CU less than 5 mgd and 32 percent had less than 1 mgd.

Water capacity is the natural ability of a watershed to sustainably provide streamflow over time, during varied climatic conditions (NJ Highlands Council, 2008). Hydrologic analyses were conducted to estimate various streamflow statistics for gaged and ungaged watersheds. A literature review identified several approaches to quantifying water capacity, including baseflow recurrence interval, low flow margin, ecological limits of hydrologic alteration (ELOHA), and others. The Commission chose 50 percent of 10-year baseflow minus September P75/P95 flow as the selected water capacity threshold. Water capacity for the Basin was estimated at 4,371.2 mgd. Capacity was greater than 10 mgd for 88 percent, and greater than 25 mgd for 56 percent, of watersheds. Water capacity was less than 5 mgd for 3 percent of watersheds. The lowest water capacities were estimated for headwater drainages generally less than 100 square miles.

Water availability is defined as the hydrologic capacity of a watershed to sustain additional water demands, considering current water uses and conditions (Global Environmental Management Initiative, 2012). Water availability was calculated by subtracting cumulative CU from water capacity. Water capacity for most watersheds was deemed adequate to satisfy existing CU and avoid demand conflicts. Water availability for the Basin was calculated at

3,336.4 mgd based on total 2014 approved CU. Watersheds drained by mainstem rivers exhibited the greatest availability as a function of cumulative drainage size and water use. Water availability was greater than 10 mgd for 82 percent, and more than 25 mgd for 54 percent, of watersheds. Availability was less than 5 mgd for 9 percent, and less than 1 mgd for 4 percent, of watersheds. Most watersheds with the lowest water availability were located in the Lower Susquehanna subbasin. Focus watershed analyses provided insight into the influence of spatial scale in assessing water availability.

A suite of PM&E measures was evaluated for their effect on cumulative water use and availability. The combined influence of use reductions, passby flows, and CU mitigation during a simulated drought resulted in over 100 mgd of CU offsets in mainstem Susquehanna River watersheds. Significant offsets were noted in tributary watersheds downstream of United States Army Corps of Engineers (USACE) reservoirs, providing insight into the effectiveness of the Commission's CU mitigation strategy. Several watersheds in northern Pennsylvania also reflected substantial CU offsets from passby flows, driven by numerous natural gas withdrawals conditioned with passby flow requirements. Existing PM&E measures have not always been implemented in watersheds with limited water availability, which affords future opportunities.

A data-driven GIS-based tool was developed for automating the quantification of water use, capacity, and availability at user input pour point locations. The tool allows users to delineate a watershed, generate watershed characteristics and flow statistics, compute current and projected CU, and calculate water capacity and availability. An interactive, public-facing web map was also developed for use by project sponsors, non-governmental organizations, and the public. It displays information including approved and reported CU, water capacity, and water availability summarized by watershed. Both tools are expected to inform water resources planning and management by the Commission and stakeholders.

A set of recommendations was developed to (1) improve future evaluations of cumulative water use and availability; and (2) enhance strategies for addressing water use versus availability conflicts. A subset of those recommendations include:

- Verify water use and discharge information associated with significant projects located in watersheds with relatively high cumulative CU, and take steps to fill existing information gaps regarding accurate valuations of unregulated water uses.

- Confirm low flow conditions through continuous streamflow monitoring or field investigations during drought events for identified watersheds with limited water capacity available to support water resources development.

- Conduct finer scale water availability analyses or detailed water budgets, in partnership with local stakeholders, for identified watersheds with relatively low water availability.

- Continue to implement limitations on water uses recognizing reasonable foreseeable needs, standards for passby flows, conservation releases, and CU mitigation requirements, particularly in watersheds identified as having limited water capacity or availability.

1.0 INTRODUCTION

1.1 Regulatory Authority

The Susquehanna River Basin Commission's (Commission's) mission, as defined in the Susquehanna River Basin Compact, is to enhance public welfare through comprehensive planning, water supply allocation, and management of the water resources of the Susquehanna River Basin (Susquehanna River Basin Compact, Preamble and § 1.3). The Commission's leadership role in Basin water resources planning and management is exercised through its regulatory function, which fills regulatory gaps that exist in member states' (New York, Pennsylvania, and Maryland) water management programs. There is an ongoing interface between the Commission and state regulatory programs to ensure each meets its objectives without duplication of work or inconsistencies.

In general, the Commission regulates groundwater and surface water withdrawals of 100,000 gallons per day (gpd) or more (peak 30-day average), consumptive use (CU) and out-of-Basin diversions of 20,000 gpd or more (peak 30-day average), and all in-Basin diversions (18 C.F.R. § 806.4). The main purposes of the regulations are designed to avoid conflict among water users, protect public health, safety and welfare, manage and protect water quality, consider economic development factors, protect fisheries and aquatic habitat, and safeguard the Chesapeake Bay (18 C.F.R. § 806.2). Projects and proposals for development, use and management of the water resources of the Basin are evaluated in terms of their compatibility with the objectives, goals, standards, and criteria set forth in the Commission's Comprehensive Plan, and on the basis of public input regarding project impacts (18 C.F.R. § 806.21). Every project, independent of the industry or entity from which the application originates, is evaluated solely upon its technical merits and the scientific and engineering information upon which the application is based.

1.2 Planning Context

In the Comprehensive Plan, the Commission grouped management responsibilities into six Priority Management Areas (PMA), one that is Sustainable Water Development. The desired result of this PMA is to regulate and plan for water resources development in a manner that maintains economic viability, protects instream users, and ensures ecological diversity; and meets immediate and future needs of the people of the Basin for domestic, municipal, commercial, agricultural, and industrial water supply and recreational activities. Accordingly, an important goal under the Sustainable Water Development PMA is to support and encourage the sustainable use of water for domestic, industrial, municipal, commercial, agricultural, and recreational activities in the Basin. The goal states that, through planning and regulatory actions, the Commission should strive to manage water resources beginning at the watershed level, based on a 15-year planning horizon, to assure short-term resource availability and long-term balance between healthy ecosystems and economic viability. A key action needed to achieve this goal includes completion of a Cumulative Water Use and Availability Study (CWUAS) to comprehensively evaluate cumulative CU, determine water availability at varying spatial scales, consider locally sustainable limits for water use, and assess alternatives for avoiding, minimizing, or mitigating potential impacts to the water resources of the Basin (SRBC, 2013).

1.3 Related Studies

Initiatives aimed at addressing water use and availability at various watershed scales are becoming more common in contemporary water resources management. Related efforts within and adjacent to the Commission's member states have produced insightful technical reports and analytical tools. A concerted effort was made to evaluate those products, summarize their scope and applicability, and identify their limitations with respect to the Commission's objectives in launching the CWUAS and internal GIS-based tool development. The studies included the New Jersey Highlands Council Water Use and Availability Technical Report (NJ Highlands Council, 2008), Pennsylvania State Water Plan and Water Analysis Screening Tool (Stuckey, 2008), Pennsylvania Yield Analysis Tool (Buchart Horn, Inc., 2008), Maryland StreamStats Water Use Summaries (Ries III et al., 2010), and United States Geological Survey (USGS) National Water Census (Alley et al., 2013).

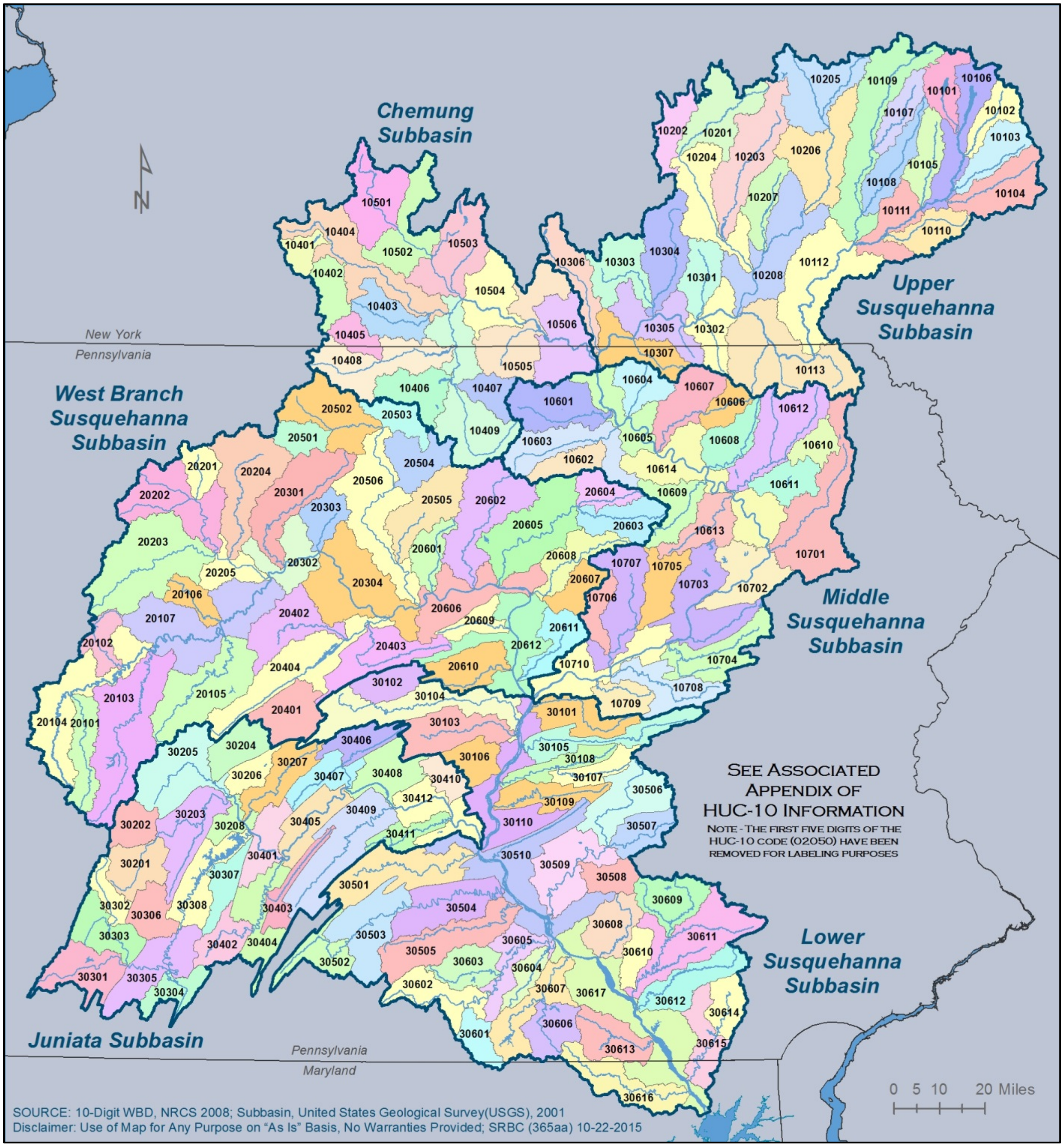
A review of existing and proposed water use and availability studies and tools has identified a variety of attributes and limitations when considered in the context of applicability to water resources planning and regulation in the Susquehanna River Basin. The most common limitations are a lack of: (1) mandatory, standardized water use data across a defined watershed unit; (2) flexibility for accommodating regularly updated water withdrawal and CU data; (3) defined water capacity metrics for planning and regulatory applications; and (4) iterative evaluation of water resources management measures. The Commission is uniquely positioned to complete a study and develop a tool tailored to addressing cumulative water use and availability at the Basin scale due to regulatory authority over water withdrawals and CU, maintenance of a robust water use database containing updated water use records, and intact regulations, policies, and plans that facilitate the identification of potentially stressed areas and establishment of protective conditions and mitigation requirements.

1.4 Purpose and Scope

The purpose of the study was to develop an approach to comprehensively evaluate the potential cumulative impact of CU within the Susquehanna River Basin. As increased water requirements for human uses have the potential to impact competing demands, including aquatic ecosystems, within the Basin, it is critically important to quantify CU and ascertain how much water capacity is sustainably available for development. The increased demand for water within the Basin in recent years by public water supplies, electric power generation, and, more recently, the natural gas industry, has created an elevated need to compute existing and projected CU, determine water capacity and availability at varying spatial scales, and to evaluate alternatives for avoiding, minimizing, or mitigating the potential effects of cumulative CU throughout the Basin. Accordingly, the scope of the study included the following major components.

Quantification of consumptive use

Commission staff compiled a comprehensive Basinwide water use database by integrating available water use datasets, including Commission and member state records, and developing water use estimates to fill data gaps. Specifications for periodic updates to water use data records were developed. A standardized methodology, with documented assumptions, was established for calculating existing and projected cumulative CU at the project (regulatory) and watershed (planning) scales. Variability in CU, including discrepancies between approved and reported quantities, was incorporated. For planning applications, the Watershed Boundary Dataset (WBD) 10-digit Hydrologic Unit Code (HUC-10) was defined as the target spatial scale based on consideration of existing/future regulatory and planning objectives and data availability. Figure 1 shows the HUC-10 watersheds in the Basin. CU at the HUC-10 scale, and cumulative CU at larger spatial scales, was evaluated and quantified using the standard methodology. Projections were also developed to estimate future CU based on available population, energy demand, agricultural trends, and other published forecast information.



SEE ASSOCIATED APPENDIX OF HUC-10 INFORMATION

NOTE - THE FIRST FIVE DIGITS OF THE HUC-10 CODE (02050) HAVE BEEN REMOVED FOR LABELING PURPOSES

SOURCE: 10-Digit WBD, NRCS 2008; Subbasin, United States Geological Survey(USGS), 2001
Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (365aa) 10-22-2015

Figure 1. HUC-10 Watersheds in the Susquehanna River Basin

Determination of water capacity and availability

Commission staff reviewed pertinent literature, including environmental flow studies and state water plans, relevant to water availability studies. The numerous methods utilized to determine water availability in various regions of the country were identified and evaluated. The goal was to select a suitable methodology that could be applied uniformly across the Basin. A list of reference gages was formulated for use in characterizing hydrologic regimes for both gaged and ungaged watersheds throughout the Basin. A suite of methodologies was initially applied as a pilot effort, to evaluate resultant water capacities and availabilities for reference gage watersheds. A Geographic Information System (GIS) map library was created to view results graphically. Based on the results from the pilot watersheds, a shortlist of preferred methodologies was refined and applied to HUC-10 watersheds throughout the Basin. The water capacity and availability results were compared to those of other related studies, assessed against existing Commission plans and policies, and vetted with partner agencies and stakeholders. Commission staff leveraged this information to formulate a selected water capacity threshold that could be used to calculate water availability for HUC-10 watersheds within the Basin.

Development of GIS-based tool

Commission staff developed a cumulative water use and availability tool based on the comprehensive water use database and water capacity methodologies described previously. The tool automated the (1) quantification and graphic presentation of existing and projected CU; (2) quantification and graphic presentation of water capacity; and (3) assessment of cumulative water availability at the project and watershed scales. The tool will enable spatial analyses to identify watersheds with existing or projected water availability concerns. It will also allow for various Protection, Mitigation, and Enhancement (PM&E) measures to be simulated, such as water use reductions, passby flow restrictions, CU mitigation, and conservation releases. These components will assist Commission staff in making water resource management decisions. A publically available web map was also developed to provide Basinwide and HUC-10 watershed based results for approved and reported CU, water capacity, and water availability. This interactive web map can be used by project sponsors, consultants, organizations, academia, and the general public to see general Basin trends, cumulative watershed results, and to quickly screen areas for water resources development.

Consideration of Protection, Mitigation, and Enhancement measures

A series of PM&E measures was made available for evaluating existing or proposed management alternatives for addressing potential water supply and demand conflicts. The PM&E measures may be implemented to avoid, minimize, or mitigate potential CU impacts to instream flow needs, water quality, and competing users. Example measures include, but are not limited to, passby flows, conservation releases, CU mitigation releases, water use reductions, and/or watershed caps. PM&E measures currently in place to address low flow conditions were simulated against water availability results. These measures were evaluated individually and as part of a scenario with all occurring simultaneously. The GIS-based tool will enable Commission staff to assess the impact of various PM&E measures in offsetting cumulative CU and the resultant effect on water availability for Basin watersheds during technical reviews of proposed water withdrawal and CU applications. Other proposed uses of the tool include informing various water resources planning efforts such as the identification of potentially stressed and water challenged areas within the Basin.

2.0 WATER USE

For the purposes of the study, water use broadly refers to water withdrawals and/or CU by public water suppliers, various industries, including agriculture, and the general public. The Commission defines CU as the loss of water due to a variety of processes by which the water is not returned to the Basin undiminished in quantity. As such, the study focused on quantifying cumulative CU for assessing water availability in Basin watersheds and was categorized as follows:

- Regulated CU refers to Commission and member state water use records. These records generally contained an approved maximum daily amount and a reported amount averaged based on actual days used. Reported amounts served as approved amounts when approvals did not exist. CU coefficients were applied to Commission and member state withdrawal data where necessary.
- Estimated unregulated CU refers to livestock, irrigation, and self-supplied residential water use. Actual CU for these categories is typically either grandfathered or does not trigger agency regulatory thresholds. Therefore, estimates were developed to provide a comprehensive assessment of Basinwide CU.
- Total CU refers to the sum of regulated CU, either approved or reported, and estimated unregulated CU.
- Projected CU refers to the sum of forecasted estimates for regulated, either approved or reported, and unregulated CU in 2030.

2.1 Previous Consumptive Use Estimates

In 1996, the Commission partnered with the United States Army Corps of Engineers (USACE) on a study entitled “Assessment of Consumptive Water Use and the Availability of Make-up Water from Storage in the Susquehanna River Basin” (SRBC, 1996). Water use information from the Commission, Pennsylvania Department of Environmental Protection (PADEP), and the United States Census of Agriculture were compiled to estimate CU in 1970 and 1990, and project CU in 2020, for six major water use sectors including public water supply (PWS), industrial, irrigation, livestock, power, and other. The Basinwide CU in 1970, 1990, and 2020 was estimated to be 270, 447, and 656 mgd, respectively. An expanded effort was made as part of the Conowingo Pond Management Plan (SRBC, 2006) to revisit and update the CU estimates and projections from the 1996 study. Based on revised assumptions and additional data not available in 1996, the 1970, 2000, and 2025 CU totals were determined to be 270.6, 456, and 641.7 mgd, respectively. It should be noted that for both evaluations, the City of Baltimore and Chester Water Authority (CWA) diversions were not included due to uncertainty and variation in water use. Since the 1996 assessment provided a more thorough evaluation of CU by subbasin and industry sector, it allowed for a more analogous comparison with updated CU quantities from this study. Additionally, approved diversion quantities for Baltimore (107 mgd for 1970 and 1990, and 250 mgd for 2020, due to a 2001 approval increase) and CWA (60 mgd) were added to the data presented in Figure 2 and Table 1, which summarize CU by subbasin and sector, respectively.

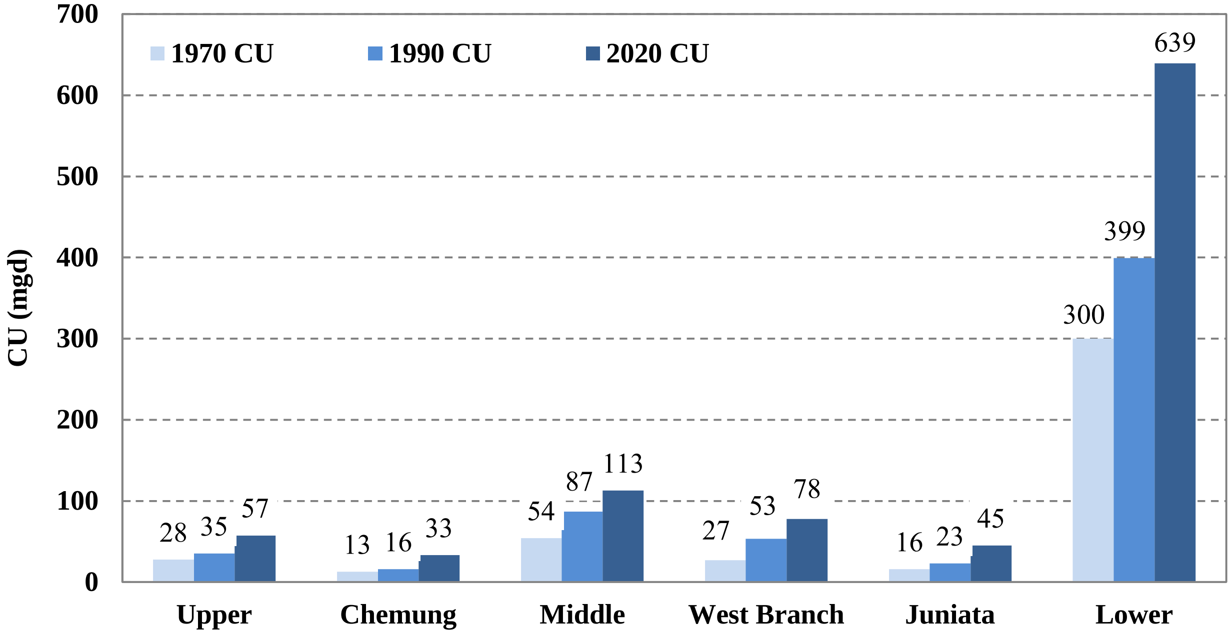


Figure 2. ***Estimated CU by Subbasin for 1970, 1990, and 2020 from 1996 Assessment of CU and Availability of Make-up Water from Storage in the Basin***

Table 1. ***Estimated CU by Sector for 1970, 1990, and 2020 from 1996 Assessment of CU and Availability of Make-up Water from Storage in the Basin***

	Public Water Supply	Industrial	Irrigation	Livestock	Electric Generation	Other	Total
1970 CU (mgd)	288	23	35	24	30	37	438
1990 CU (mgd)	303	50	54	25	134	48	614
2020 CU (mgd)	490	162	83	26	141	63	966

An assessment of Commission approved CU was completed during the development of the Consumptive Use Mitigation Plan (CUMP) (SRBC, 2008). The plan presented updated estimates of current and projected CU, low flow mitigation needs, and a series of recommendations for meeting mitigation needs. At the time of the evaluation, 2005 was the most recent year in which complete water use data were available. The characterization of CU indicated that approved CU for the Basin totaled 563 mgd, which was broken down into seven use sectors, including public water supply, electric generation, mining, manufacturing, recreation, education, and other (Table 2). An attempt was also made to establish baseline 2005 CU conditions that considered unregulated CU, including agricultural, grandfathered, and small projects. Assuming maximum usage for all projects, the 2005 CU for the Basin was estimated at 882.5 mgd. Projected 2025 CU quantities were also developed based on population projections and anticipated project expansions, which totaled 1,202.2 mgd. A breakdown of 2005 CU and projected 2025 CU by subbasin is depicted in Figure 3.

Table 2. Approved CU by Sector for 2005 from 2008 CUMP

	Public Water Supply	Electric Generation	Mining	Manufacturing	Recreation	Education	Other	Total
2005 CU (mgd)	324.8	148.4	7.8	21.2	47.8	4.6	8.4	563.0

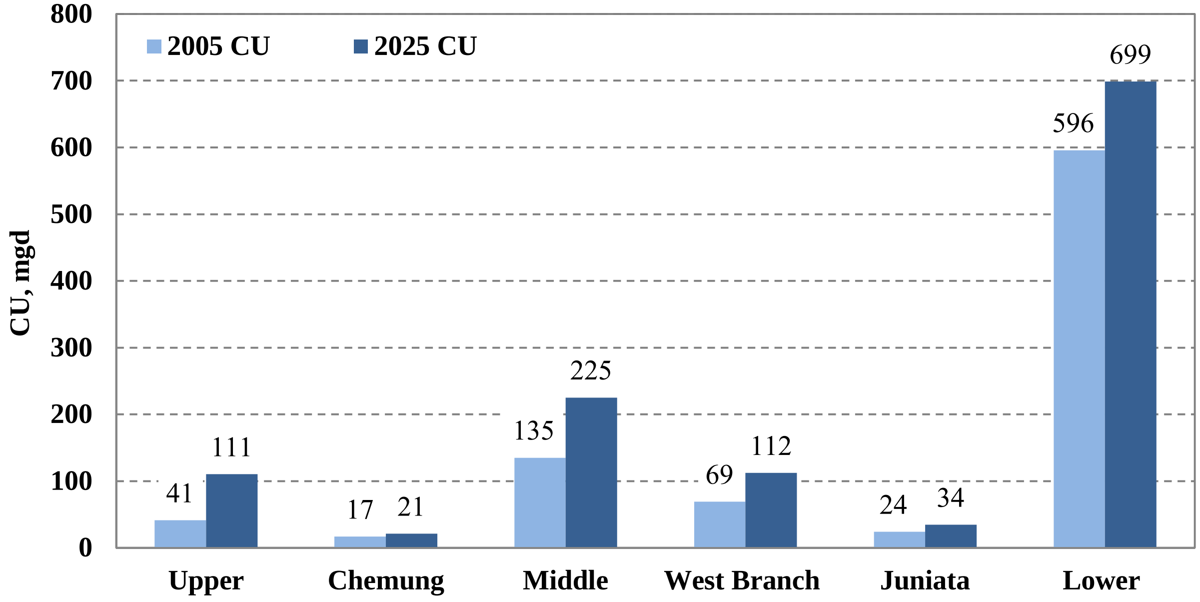


Figure 3. Approved and Unregulated CU by Subbasin for 2005 and 2025 from 2008 CUMP

2.2 Regulated Consumptive Use

In 2014, Commission staff developed a comprehensive Basinwide water use database by integrating Commission and member state water use records. The initial approach attempted to use source-based withdrawal and discharge data to estimate CU in the Basin. This method required the compilation of a comprehensive discharge database. During the early phases of water use data collection, it became apparent that updated, inclusive discharge data were not readily available Basinwide. This constraint necessitated the development of an alternate methodology that relied primarily on Commission CU records supplemented with Commission and member state withdrawal records translated to CU by applying published CU coefficients. Appendix A contains a list of CU coefficients by North American Industry Classification System (NAICS) code.

The Commission, along with New York State Department of Environmental Conservation (NYSDEC, 2014) and New York State Department of Health (NYSDOH, 2014), Pennsylvania Department of Environmental Protection (PADEP, 2015a), and Maryland

Department of the Environment (MDE, 2015) maintains permitted and/or registered water use data. The Commission has Basinwide regulatory authority over water withdrawals of 100,000 gallons per day (gpd) and greater. Additionally, the Commission has unique regulatory authority over CU beginning at 20,000 gpd. However, given these regulatory thresholds and effective dates of CU (1971), groundwater and surface water withdrawal regulations (1978/1995), many water uses are currently considered grandfathered or exempt by quantity. Fortunately, each member state has regulatory authority or water use registration and reporting requirements generally beginning at 10,000 gpd, supplementing this data gap. Even though different regulatory thresholds exist for the Commission and its member states, it is generally required that all water users using 10,000 gpd or more register with the appropriate state agency. This stipulation leads to the occurrence of similar water use records in multiple agency databases.

To avoid double-counting water use, and better align the various databases, a data hierarchy was established for consolidating the comprehensive water use database. The standard protocol was for Commission data to take precedence over identical member state records due to facility-based CU approvals, accessibility of records, and accountability of in-house data. This is not meant to imply a greater level of accuracy of Commission data. If a member state record was determined to have more reliable location or attribute information, this rule was overridden.

Multiple permit approval types have been utilized within the CWUAS database. These include facility-based, system-wide water use limits, and specific, source-based approvals. Facility-based and system-wide water use limit data often encompass multiple withdrawal approvals or individual sources. Therefore, facility-based and system-wide water use limits supersede individual source-based or withdrawal approvals. This rule demanded that facility-based NYSDEC records supersede NYSDOH source-based public water supply (PWS) records. Table 3 describes various sources of water use data and associated permitting criteria that have been incorporated into the comprehensive water use database.

Table 3. Water Use Permitting/Reporting Requirements of Agency Datasets Used in the Comprehensive Water Use Database

Agency	Water Use Type	Water Use Threshold (gpd)	Water Use Sector	Recording Method	Reporting Location	Record Type	System Limits	Record Count
SRBC	GW, SW	>100,000	All	Peak Day, 30-Day Average, Averaged by Days Used	Source	Approved, Reported	Yes	1,224
	CU	>20,000	All (Excluding Agriculture)	Peak Day, 30-Day Average, Averaged by Days Used	Facility	Approved, Reported	Yes	311
PADEP	GW, SW	>10,000	All	Averaged by Days Used	Source	Approved, Reported	Yes	3,401
NYSDEC	GW, SW	>100,000	All	Average & Maximum Daily, Averaged by Days Used	Facility	Approved, Reported	No	146
NYSDOH	GW, SW	>0	Public Water Supply	Average Daily	Source	Reported	No	1,485
MDE	SW	>10,000	All	Average & Maximum Daily	Source	Approved	No	24
	GW	>5,000	All	Average & Maximum Daily	Source	Approved	No	338

2.3 Estimated Unregulated Consumptive Use

One limitation of the comprehensive water use database is that it captures only the water uses that trigger the various agencies' regulatory thresholds. Self-supplied residential and some agricultural water uses, not regulated by the Commission, are generally undocumented and not monitored, but collectively can significantly impact water resources in an area. Therefore, an attempt was made to estimate CU for these selected smaller-scale use sectors. Detailed methodologies used to develop estimated unregulated CU by sector are included in Appendix B.

2.3.1 Self-Supplied Residential

CU estimates of self-supplied residential water use were derived from a GIS analysis of Census Block Groups (US Census Bureau, 2010) and PWS service areas. PWS service area GIS data were acquired from PADEP (2012), Cecil County, Maryland (2012), and Harford County, Maryland (2012). PWS service areas do not exist in the Baltimore and Carroll County, Maryland portions of the Basin. Since PWS service area GIS data are not available in New York, NYSDOH (2014) records aligned with minor civil division boundaries were used as a supplement and PWS population served estimates were subtracted from census block group populations within respective minor civil divisions. Areas not covered by PWS service areas were considered to be self-supplied residential water use areas.

Assuming an equal population distribution within each block group, population estimates for the self-supplied residential water use areas were derived by calculating a change-in-area ratio of the census block groups contained within the self-supplied area and multiplying the ratio by the population of the block group. The self-supplied population was then multiplied by a 75 gallon per capita per day (gpcd) average residential water demand (PADEP, 2006) and a 15 percent CU factor (Shaffer and Runkle, 2007) to determine the total estimated CU for the self-supplied residential population. Self-supplied residential CU was further derived for each HUC-10 watershed using an additional change-in-area calculation.

2.3.2 Livestock

Tabular data for head of livestock by county were acquired from the United States Department of Agriculture (USDA) Census of Agriculture (USDA, 2012) for seven major categories of livestock. For each livestock category, a CU factor (gpd/animal) was used to calculate average water use in gpd (Jarrett, 2002) within each county in the Basin. The proportion of county area within the Basin versus the entire county area was used to estimate livestock populations specific to the Basin. The Pennsylvania State Water Plan (PA SWP) effort found that locations of Concentrated Animal Feeding Operations (CAFOs) coincided with cultivated crop land use (Stuckey, 2008). More recent CAFO locations and land use data (USGS, 2006) illustrated that more than 70 percent of CAFOs and 60 percent of livestock-related water use permits were located in cultivated crop and pasture/hay land use classes. These two land use classes were reclassified as livestock areas and further divided by county boundaries. Assuming equal distribution of livestock populations within these county livestock areas, livestock CU was derived within each HUC-10 watershed using a change-in-area ratio calculation.

2.3.3 Irrigation

The quantity of water applied by crop, in average acre-feet applied per acre of land, was retrieved for each state using the Census of Agriculture, Farm, and Ranch Irrigation Surveys (USDA, 2013). Irrigated land by crop, in acres, was retrieved for each county in the Basin using the Census of Agriculture (USDA, 2012). Additionally, the Cropland Data Layer (USDA, 2014), a crop-specific land cover dataset, was used to determine the spatial distribution of irrigated land for each county. Assuming equal distribution of irrigated land across each respective Cropland Data Layer class, irrigation CU for each HUC-10 watershed was derived using a change-in-area ratio multiplied by crop-specific average acre-feet of water applied per acre. Assuming that the growing season throughout the Basin generally lasts from May to October, and on average 77 percent of irrigation occurs between June and September, the resultant acre-feet applied value was multiplied by 0.77 and converted to mgd using a 120-day irrigation period. Irrigated water use was considered to be 100 percent consumptively used.

2.4 Projected Consumptive Use

Projections of future water use in the Basin were developed to provide insight into prospective water availability conditions and potential management actions that could be taken to avoid imminent water supply and demand conflicts. Projections of 2030 CU in the Basin were developed for the electric power generation, natural gas, PWS, agriculture, and other sectors based on published forecast information. The detailed procedures used to project 2030 CU are included in Appendix C. Baseline 2014 CU for each sector was determined using the comprehensive water use database, estimated self-supplied residential and agricultural use, and county census data (US Census Bureau, 2010). Proposed water uses, associated with new or planned expansion projects known to Commission staff and/or documented in industry-specific reports, were represented as pending projects and were not reflected in the CU projections. Growth in CU for PWS, self-supplied residential, and other use was assumed to follow projected population growth. Similarly, water use for the agricultural industry was assumed to follow past trends in irrigated acres and livestock populations. Growth in CU for electric power generation and natural gas is subject to specific development of upgraded systems and/or new facilities. Because the location and water use quantity drivers for these sectors are not easily predicted, past water use trends, existing electric power generation facility locations, and developable natural gas areas were considered in developing CU projections.

2.4.1 Electric Power Generation

The 2030 CU projections for thermoelectric power generation facilities were based upon electric generation projections identified in the United States Energy Information Administration's (EIA's) Annual Energy Outlook for 2015. The EIA electric generation projections were issued for two separate Electric Market Module (EMM) regions. The Basin is divided between the Reliability First Corporation/East EMM region for Pennsylvania and Maryland and the Northeast Power Coordinating Council/Upstate New York EMM region for New York. Both approved and reported CU for thermoelectric cooling was related to the observed and predicted generating capacity (megawatt, MW) of each facility, per fuel source, to determine an average approved and reported CU per capacity relationship for each fuel type. Fuel types represented include nuclear, coal, natural gas, petroleum, and renewables. Using the 2014 approved and reported CU per fuel source relationships, 2030 approved and reported CU was estimated based upon projected 2030 capacities of each facility per EMM region. The distribution of projected growth or decrease in CU was classified according to the Commission's Aquatic Resource Class (ARC) scheme (SRBC, 2012). Projected growth or decrease in CU, separate from 2014 baseline conditions, was applied to ARC segments in proportion to the current 2014 facility distribution within each ARC setting.

2.4.2 Natural Gas

The projected rate of annual unconventional natural gas well development in 2030 was extrapolated from PADEP (2015b) well development data for calendar years 2010-2014. A linear regression trend line analysis indicated that a total of 787 wells could be fractured annually within the Basin by 2030. In 2014, approximately 568 wells were fractured and a total of 4,065.0 million gallons (MG) of water was reportedly withdrawn and consumptively used. From 2010-2014, the occurrence of natural gas-related water withdrawals ranged from 93 to 150 days per year. The reported water use in 2014 was reflective of withdrawals occurring 131 days a year, as opposed to a full 365 days a year. A 2030 reported CU rate of 7.16 MG per well was developed from the 2014 reported CU versus number of fractured wells relationship. This rate was applied to the 787 fractured wells projected in 2030, which resulted in 5,634.9 MG of CU or 42.265 mgd assuming 131 days of water use. A projected 2030 approved CU total of 152.137 mgd was derived by multiplying the projected 2030 reported CU by the 2014 approved/reported CU relationship.

The projected increase in 2030 approved and reported CU was distributed among separate geographic regions to portray two potential natural gas development scenarios. These included the (1) Pennsylvania portion and (2) Pennsylvania and New York portions of the Basin underlain by Marcellus Shale. The latter scenario illustrates a potential increase in CU for the New York portion of the Basin, should the current moratorium on unconventional natural gas development be lifted by 2030. The distribution of projected increases in natural gas industry CU, separate from 2014 baseline conditions, was applied to ARC stream segments in proportion to 2014 source water locations and CU quantities within each ARC setting. Projected CU for 2030 accounts solely for Marcellus Shale natural gas development, with the assumption that any additional CU is sourced within the area of the Basin underlain by Marcellus Shale.

2.4.3 Public Water Supply

Projected CU for the PWS sector was based on projected population growth from 2010 to 2030. The Microsoft Excel FORECAST function, a least squares trending/regression function, was used to project 2030 county population data from U.S. Census Bureau records for 1980, 1990, 2000, and 2010 (U.S. Department of Commerce, 2014). The 2030/2010 county-based population growth ratios were applied to 2014 approved and reported PWS CU depending upon the source location within the representative county. The 2030 approved and reported PWS use estimates were then multiplied by a CU factor of 0.15 (Shaffer and Runkle, 2007) to calculate the total projected 2030 increase in CU. Estimated self-supplied residential CU was also projected based upon 2030/2010 county-based population growth ratios.

Areas not covered by PWS service areas were considered to be self-supplied residential water use areas, as noted in Section 2.3.1. For these areas, census block groups were used to estimate population in 2030 based upon 2030/2010 county-based population growth ratios, with the assumption of equal population distribution within each block group. The 2030 population estimate within the self-supplied areas was multiplied by a 75 gallon per capita per day (gpcd) average residential water demand (PADEP, 2006) and a 15 percent CU factor (Shaffer and Runkle, 2007) to determine the total estimated CU for the projected 2030 self-supplied residential population.

2.4.4 Agriculture

County-based Agricultural Census datasets from 1997, 2002, 2007, and 2012 (U.S. Department of Agriculture, 2014) were analyzed using Microsoft Excel's FORECAST function to project livestock populations and irrigated crop acres in 2030. CU coefficients for specific livestock species and irrigated crops (Jarret, 2002) were applied to projected 2030 livestock numbers and irrigated crop acres to estimate agricultural CU in 2030. Projected CU for livestock and irrigation was then distributed spatially using similar methods described in Sections 2.3.2 and 2.3.3, respectively.

2.4.5 Other Sectors

For other CU records included in the comprehensive water use database, for which sector-specific projections were not developed, county population projections were used to project the associated 2014 CU to 2030. The other sectors incorporated within this projection included uses for manufacturing, education, water treatment, military, and recreation. These sectors coincide with NAICS codes ranging from 311000-928110. Depending on the source location of these facilities, 2014 approved and reported CU was adjusted based upon projected 2030 county population estimates.

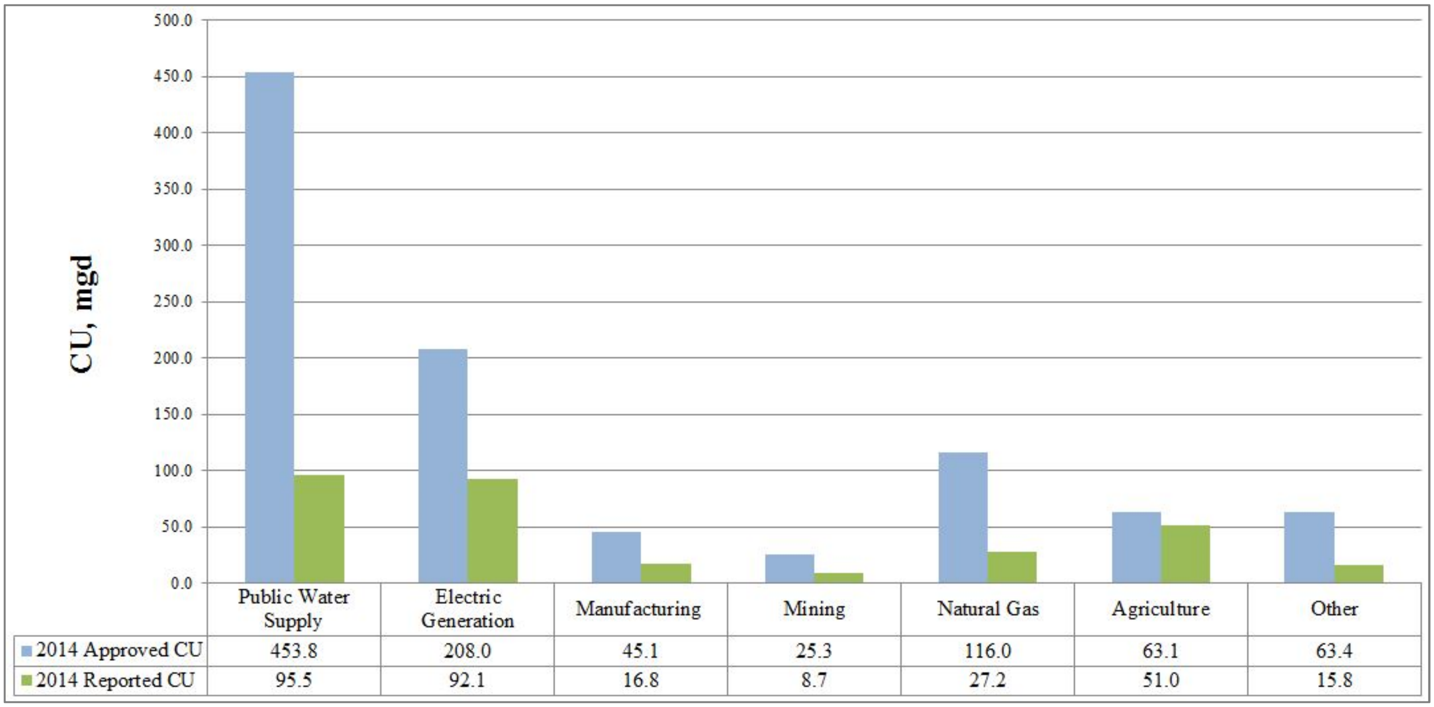
2.5 Consumptive Use Results

The CU results presented below represent current, non-duplicative, Basinwide water use records from the Commission and member state databases. In addition to regulated CU data, estimated CU results based on methods described previously have been incorporated to calculate total CU. A total of 5,165 water use records were compiled and analyzed to arrive at approved and reported CU totals. The composition of those records included 1,055 from the Commission, 2,411 from PADEP, 1,245 from NYSDOH, 103 from NYSDEC, and 351 from MDE. Of those, approximately 41 percent were reported quantities being supplemented as approved CU. The remainder was comprised of approved peak day, 30-day average, or average daily uses depending on data availability. It is important to note that approved CU totals reflected a scenario where all water users are operating simultaneously at maximum capacity.

Reported CU quantities for specific sectors and projects can vary substantially due to the frequency in which water is withdrawn, used, and subsequently reported. The Commission, NYSDEC, and PADEP records indicate reported CU quantities based on days used or average daily use. The frequency of withdrawal occurrence is largely a function of industry type, project configuration, source characteristics, hydrologic conditions, and a variety of external factors including socioeconomics. For example, the electric generation sector reported CU values were not considerably different from a 365-day average due to water use for that industry occurring consistently year-round. Conversely, reported CU for the natural gas industry reflected intermittent water use and could vary from 11.1 mgd to 27.2 mgd in 2014, depending on water use reported by average daily use or actual days used, respectively. Where possible, water use reported by days used was preferable since it reflected a more conservative and realistic impact on water resources.

2.5.1 Baseline 2014 Consumptive Use

From an analysis of the comprehensive water use database, it was estimated that 974.9 mgd of approved, and 307.1 mgd of reported, regulated CU existed within the Basin in 2014. Figure 4 shows a breakdown of approved and reported regulated CU by sector. Total approved CU for the Basin, including estimated unregulated CU, was 1,034.8 mgd. Total reported CU was markedly less at 367.0 mgd. Commission CU dockets are approved based on a peak day rate, to allow for operating demand fluctuations, which may not be consistently required to meet normal or average daily demands. In 2014, on average, water users only required 60 percent of their approved CU quantity. Some of the difference can also be attributed to seasonal and intermittent activities, such as skiing, golfing, irrigation, and hydraulic fracturing. Of particular note is the City of Baltimore's approved diversion of 250 mgd, which was not utilized in 2014 and was accountable for almost 40 percent of the difference in Basinwide approved versus reported CU.

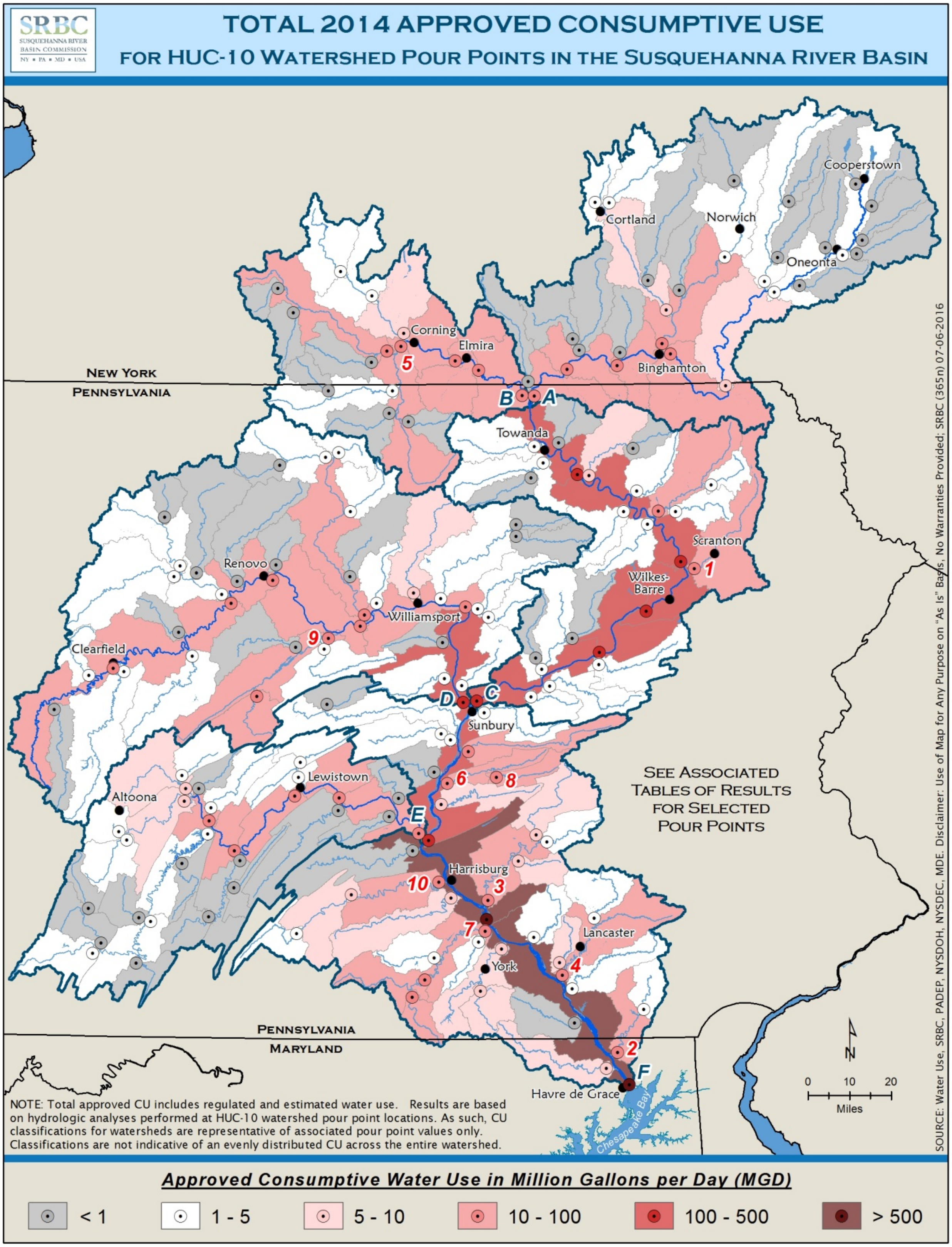


	Public Water Supply	Electric Generation	Manufacturing	Mining	Natural Gas	Agriculture	Other
🟦 2014 Approved CU	453.8	208.0	45.1	25.3	116.0	63.1	63.4
🟩 2014 Reported CU	95.5	92.1	16.8	8.7	27.2	51.0	15.8

Figure 4. Baseline 2014 Approved and Reported Regulated CU by Sector

Figure 4 shows that PWS and electric generation accounted for the highest approved regulated CU by sector, at 47 and 21 percent, respectively. These industries also reported the most CU in 2014. The natural gas industry was approved for 116 mgd or 12 percent of the regulated CU in the Basin. These three industries were approved for significantly more CU than the manufacturing, mining, agriculture, and other sectors, which included recreational facilities such as golf courses and ski resorts. The CU totals for agriculture, the third highest reported CU sector, may appear skewed as they were based largely on reported CU by actual days used. However, during dry periods and low flow conditions, it was valid to assume that extensive irrigation could be occurring and therefore, the associated CU needed to be considered when evaluating cumulative water use and availability for Basin watersheds.

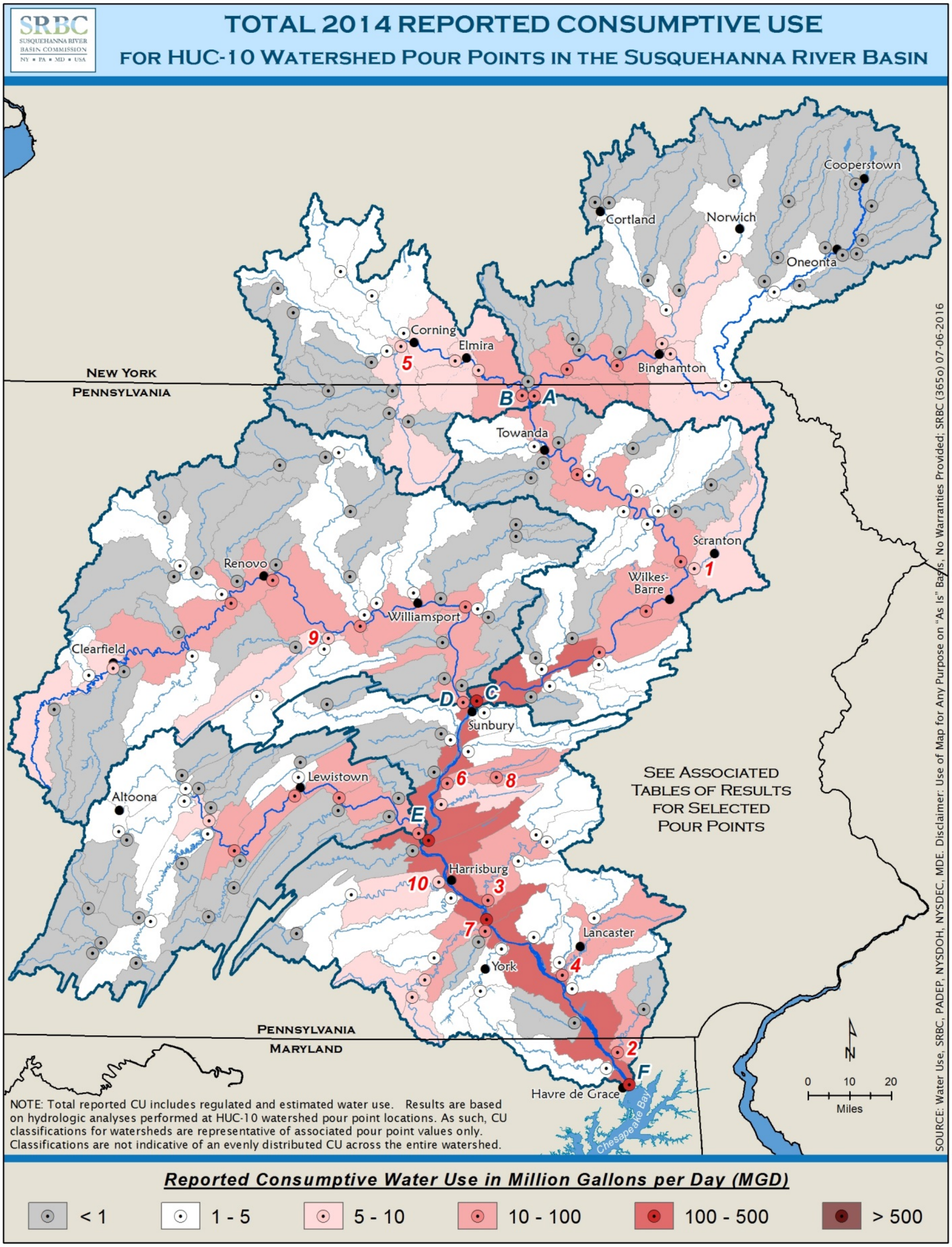
Figures 5 and 6 depict total 2014 approved and reported CU, respectively, for HUC-10 watersheds in the basin. Tabular data are also summarized in Appendix D. Results were representative of calculations performed at HUC-10 pour point locations and should not be construed as representative of uniform conditions throughout each respective watershed. Due to the cumulative nature of the analysis, CU was greatest in mainstem river watersheds with the largest drainage area (DA), including the Lower Susquehanna, Middle Susquehanna, and West Branch Susquehanna River segments. This was also where the more significant population centers in the Basin exist, contributing to increased water demand. These results are evident in Table 4, which lists total approved and reported CU by subbasin pour point. Total approved/reported CU for the Middle Susquehanna and West Branch Susquehanna subbasin pour points were particularly notable at 262.6/103.2 mgd and 125.3/52.1 mgd, respectively.



NOTE: Total approved CU includes regulated and estimated water use. Results are based on hydrologic analyses performed at HUC-10 watershed pour point locations. As such, CU classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of an evenly distributed CU across the entire watershed.

SOURCE: Water Use, SRBC, PADEP, NYSDOH, NYSDEC, MDE. Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (365n) 07-06-2016

Figure 5. Total 2014 Approved CU for HUC-10 Watershed Pour Points



NOTE: Total reported CU includes regulated and estimated water use. Results are based on hydrologic analyses performed at HUC-10 watershed pour point locations. As such, CU classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of an evenly distributed CU across the entire watershed.

SOURCE: Water Use, SRBC, PADEP, NYSDOH, NYSDEC, MDE. Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (3650) 07-06-2016

Figure 6. Total 2014 Reported CU for HUC-10 Watershed Pour Points

Table 4. *Total 2014 Approved and Reported CU by Subbasin Pour Point*

Map ID	Subbasin Name	DA (mi^2)	Approved CU (mgd)	Reported CU (mgd)
A	Upper Susquehanna	4,945.0	53.0	18.7
B	Chemung	2,595.5	37.4	12.4
C	Middle Susquehanna	11,310.5	262.6	103.2
D	West Branch Susquehanna	6,978.7	125.3	52.1
E	Juniata	3,403.5	23.5	15.9
F	Lower Susquehanna	27,501.7	1,034.8	367.0

Table 5 lists the tributary HUC-10 watershed pour points with the highest total 2014 approved CU. Several of these watersheds, including the Lackawanna River, Octoraro Creek, Mahantango Creek, and Deep Creek, exhibited approved CU greater than or equal to 0.1 mgd per square mile of DA. Water use in the Lackawanna River Watershed was dominated by the large (37.6 mgd) Pennsylvania American Water Scranton and Springbrook regional PWS systems. The next three tributary watersheds also contained public water supplies for large population centers, including Chester in the Octoraro Creek, Lebanon and Harrisburg suburbs in the Lower Swatara Creek, and Lancaster in the Conestoga River, which contributed to higher CU demands. At first glance, the Tioga River, being more than half the size of the Chemung subbasin, seemed to have such a high approved CU value simply because of the cumulative effect of large drainage areas. However, in actuality, two agricultural operations (8 mgd) and 16 natural gas withdrawals (8 mgd in total) combined to make up almost 70 percent of the CU. Both of these industries operated infrequently, causing the large disparity between approved and reported CU.

Table 5. *Tributary HUC-10 Watershed Pour Points with Highest Total 2014 Approved CU*

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	Approved CU (mgd)	Reported CU (mgd)
1	Lackawanna River	0205010701	347.7	44.4	9.6
2	Octoraro Creek	0205030615	210.3	35.6	24.8
3	Lower Swatara Creek	0205030509	571.2	32.0	16.9
4	Conestoga River	0205030611	474.8	23.4	14.2
5	Tioga River	0205010409	1,383.1	23.3	5.0
6	Mahantango Creek	0205030108	164.6	20.5	20.1
7	Lower Conewago Creek	0205030605	515.6	20.4	10.5
8	Deep Creek	0205030107	77.0	17.3	16.8
9	Bald Eagle Creek	0205020404	773.2	16.9	6.6
10	Lower Conodoguinet Creek	0205030504	506.3	15.1	8.8

For Mahantango and Deep Creek Watersheds, CU was influenced by regional irrigation operations (18.1 mgd) that were intensive only during the summer months. Since data for these systems were limited to reported water use, the small number of actual days used inflated the reported use and was the main reason for these watersheds having some of the highest reported CU in the Basin. Total CU for the Lower Conewago Creek Watershed was influenced by PWS use (10.1 mgd) associated with the Borough of Hanover, which diverted water out of the local watershed. Bald Eagle Creek, one of the larger tributary watersheds and inclusive of State College, had 40 percent of its water use devoted to a large manufacturing facility and three PWSs including State College Borough, Bellefonte Borough, and the Pennsylvania State University. Total approved CU was greater than 10 mgd for several other mid-sized watersheds including the Lower Chenango River, Tunkhannock Creek, Lower Pine Creek, Spring Creek, Lower Conodoguinet Creek, Mahanoy Creek, and Canisteo River. Of these, watersheds in the northern portion of the Basin have experienced increased water demand associated with natural gas development, whereas watersheds in the southern region were host to PWS and industrial uses that support some of the most densely populated areas of the Basin.

There were also watersheds in the Basin with very little total 2014 approved CU. Most notable were the headwater systems scattered across the Upper, northern West Branch, and Juniata subbasins with total approved CU of less than 1 mgd. Watersheds including Schrader Creek, Upper Loyalsock Creek, and Young Woman's Creek were estimated to have less than 0.05 mgd of total approved CU. The majority of watersheds in the Basin, 126 out of 170 (74 percent), were estimated to have total approved CU less than 10 mgd. Of these watersheds, 110 (65 percent) had total approved CU less than 5 mgd, and 54 (32 percent) had less than 1 mgd. Overall, there were 143 (84 percent) watersheds with less than 10 mgd of reported CU.

When compared to previous Basinwide CU estimates presented in Section 2.1, total 2014 approved CU (1,034.8 mgd) was slightly higher than the prior 2020 projection of 966 mgd (SRBC, 1996). The CUMP (SRBC, 2008) estimated maximum CU at 882.5 mgd for 2005. Since then, CU increased by over 150 mgd, but has not exceeded the CUMP 2025 projection. Withdrawals by the natural gas industry began in 2008 and accounted for much of the increase. Subbasin comparisons between the 1996 study (Figure 2) and 2014 results (Table 4) also aligned reasonably well. It should be noted that Table 4 presents cumulative subbasin totals, whereas Figure 2 is specific to each subbasin. Elevated CU in 2014 in the West Branch and Middle Susquehanna subbasins can be accounted for by the increased demand in the electric generation and natural gas industry sectors. The CUMP subbasin totals (Figure 3) generally matched up well with the 2014 CU distributions. The CU was higher in 2014 than was estimated in 2005 in all subbasins except the Juniata. The 2014 CU by subbasin was higher than the CUMP 2025 projections for the Chemung and West Branch Susquehanna subbasins, again due to the emergence of natural gas industry water use.

Regarding the comparisons of CU by sector in Section 2.1, 2014 CU totals were generally trending below projected 2020 CU presented in the 1996 study, except for electric generation which had already surpassed the projection by over 60 mgd. Although 2020 is six years away, current approved CU from all other sectors were noticeably lower than the 2020 projections. PWS was 36 mgd less. A combination of current approved CU from both manufacturing and mining (70 mgd) made for a more accurate comparison against 2020 industrial CU (162 mgd). Conversely, current approved CU for agriculture (63 mgd) was lower than both 2020 projections for irrigation and livestock (109 mgd). Sector totals for 2005 from the CUMP (SRBC, 2008) (Table 2) were all lower than the 2014 totals (Figure 4). Although this comparison showed an accurate increasing trend over the last ten years, it was important to note that Table 2 was solely comprised of Commission CU data whereas Figure 4 results contained additional member state water use data. This accounted for the seemingly large increases in the PWS, manufacturing, mining, and other categories where use generally fell below the Commission's regulatory thresholds.

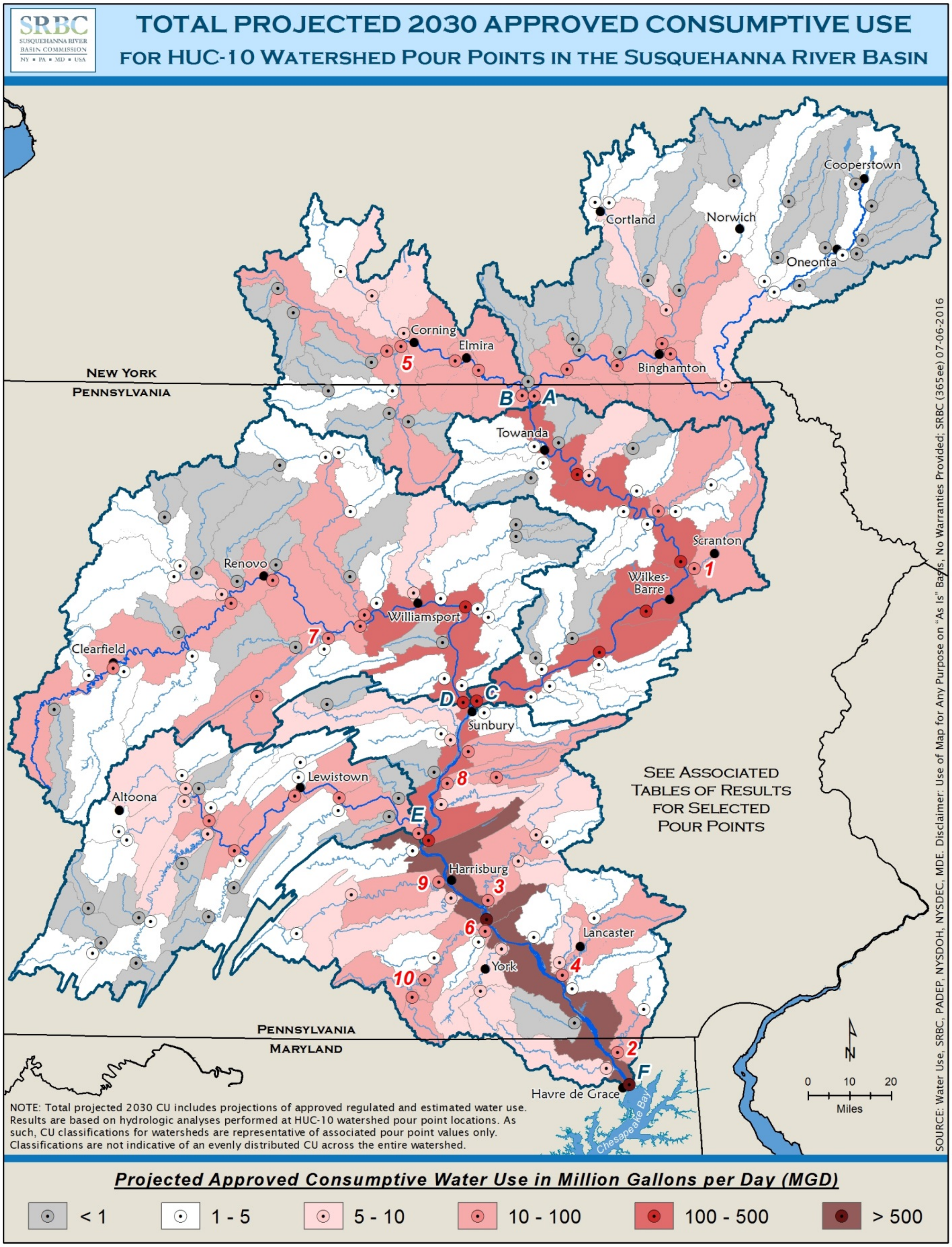
2.5.2 Projected 2030 Consumptive Use

Total projected 2030 approved and reported CU for the Basin was estimated at 1,203.3 and 405.4 mgd, respectively. This represented a 16 percent increase in approved CU, and a 10 percent increase in reported CU from 2014. These projections continued to reflect the current trend of reported CU being about 60 percent less than approved CU. Figure 7 illustrates total projected 2030 approved CU for HUC-10 watersheds in the Basin. Tabular data are also summarized in Appendix D.

Although Figure 7 does not differ greatly from Figure 5 in Section 2.5.1, Tables 4 and 5 show gains in CU across both subbasin and tributary watershed pour points. The Juniata and West Branch Susquehanna subbasins were projected to increase the most, at 57 and 20 percent, respectively, with the major driver being increases in natural gas industry approved CU. Reported CU was projected to increase by 27 percent for the Juniata subbasin and 16 percent for the West Branch Susquehanna subbasin. Tributary HUC-10 watershed pour points with the highest projected approved CU in 2030 did not show very large increases from the 2014 approved CU totals (Table 6). The largest CU increases in the Basin were forecasted in the Octoraro Creek (8.1 mgd), Bald Eagle Creek (4.6 mgd), Conestoga River (4.1 mgd), and Lower Conewago Creek (3.8 mgd) Watersheds. These increases were directly related to higher PWS demand forecasted in 2030 for Chester, State College, Lancaster, and Hanover, respectively. Of the 170 HUC-10 watersheds, 28 were projected to have less approved CU in 2030. The majority of these watersheds were in the New York portion of the Basin where population was declining and natural gas industry water use was not anticipated to occur.

Table 6. Total Projected 2030 Approved CU by Subbasin Pour Point

Map ID	Subbasin Name	DA (mi^2)	2030 Approved CU (mgd)	2014 Approved CU (mgd)
A	Upper Susquehanna	4,945.0	53.4	53.0
B	Chemung	2,595.5	40.2	37.4
C	Middle Susquehanna	11,310.5	277.3	262.6
D	West Branch Susquehanna	6,978.7	150.5	125.3
E	Juniata	3,403.5	36.9	23.5
F	Lower Susquehanna	27,501.7	1,203.3	1,034.8



NOTE: Total projected 2030 CU includes projections of approved regulated and estimated water use. Results are based on hydrologic analyses performed at HUC-10 watershed pour point locations. As such, CU classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of an evenly distributed CU across the entire watershed.

SOURCE: Water Use, SRBC, PADEP, NYSDOH, NYSDEC, MDE. Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (365ee) 07-06-2016

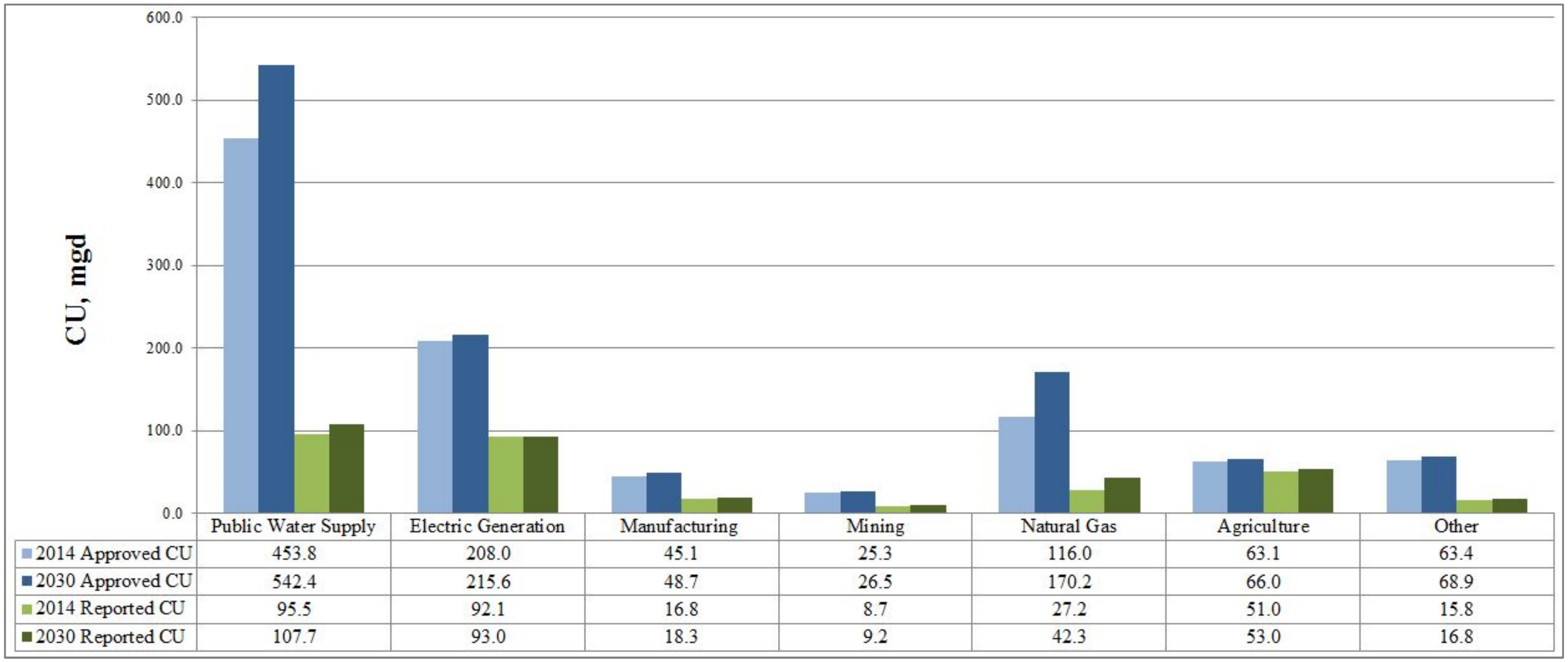
Figure 7. Total Projected 2030 Approved CU for HUC-10 Watershed Pour Points

Table 7. Tributary HUC-10 Watershed Pour Points with Highest Total Projected 2030 Approved CU

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	2030 Approved CU (mgd)	2014 Approved CU (mgd)
1	Lackawanna River	0205010701	347.7	44.0	44.4
2	Octoraro Creek	0205030615	210.3	43.7	35.6
3	Lower Swatara Creek	0205030509	571.2	35.3	32.0
4	Conestoga River	0205030611	474.8	27.5	23.4
5	Tioga River	0205010409	1,383.1	24.7	23.3
6	Lower Conewago Creek	0205030605	515.6	24.3	20.4
7	Bald Eagle Creek	0205020404	773.2	21.5	16.9
8	Mahantango Creek	0205030108	164.6	20.9	20.5
9	Lower Conodoguinet Creek	0205030504	506.3	18.6	15.1
10	Upper Conewago Creek	0205030602	219.7	17.6	14.6

Figure 8 summarizes baseline 2014 and projected 2030 approved and reported CU by major use sector. The most notable increases in CU for the Basin were observed for the PWS and natural gas sectors. PWS use was projected to grow by 20 percent for approved CU and 13 percent for reported CU. Natural gas use was projected to increase by 47 percent for approved CU and 56 percent for reported CU. The PWS projection did include the 250 mgd diversion for the City of Baltimore, which skewed the approved CU projection for this sector. However, the diversion needed to be accounted for to simulate a worst case future CU scenario. The reported PWS projection may provide a more average or realistic account of projected CU for this sector. The natural gas CU projection, as explained in Section 2.4.2 and Appendix C, was based on observed rates of fractured wells and approved and reported CU during calendar years 2010 through 2014. During the buildup of natural gas assets in Pennsylvania, the industry was focused on maximizing surface water withdrawal sources both in terms of quantity and spatial distribution. Although 2030 projections indicated an increase in approved CU for the natural gas sector, there is still great uncertainty regarding future development due to current moratoriums and long-term realizations of a regional infrastructure. Once again, the reported 2030 projection offered a more conservative or realistic view of future CU for this industry.

Projected electric generation CU increases were relatively low considering the historical significance of the industry's CU in the Basin. Although EIA (2014) showed increases in electric generation from coal, natural gas, and renewable fuel sources in Pennsylvania and Maryland, a projected decrease by 3.9 percent for nuclear fuel sources could offset projected increases in CU as nuclear energy supplies up to 24 percent more power and requires up to 44 percent more water, per unit energy, than coal or natural gas fuel sources in the Susquehanna River Basin (Appendix C). Additionally, this projection did not account for proposed development of new power plants in the Basin, but was based solely on EIA (2014) electric generation trends for fuel sources utilized by existing facilities within specific drainage area (ARC) settings. Projected 2030 CU for the other sector was based on population and agriculture projections, and indicated only slight increases beyond 2014 CU.



	Public Water Supply	Electric Generation	Manufacturing	Mining	Natural Gas	Agriculture	Other
■ 2014 Approved CU	453.8	208.0	45.1	25.3	116.0	63.1	63.4
■ 2030 Approved CU	542.4	215.6	48.7	26.5	170.2	66.0	68.9
■ 2014 Reported CU	95.5	92.1	16.8	8.7	27.2	51.0	15.8
■ 2030 Reported CU	107.7	93.0	18.3	9.2	42.3	53.0	16.8

Figure 8. Baseline 2014 and Projected 2030 Approved and Reported CU by Sector

3.0 HYDROLOGIC ANALYSES

To establish a basis for assessing water availability for Basin watersheds, it was critical to conduct hydrologic analyses to estimate streamflow statistics for both gaged and ungaged watersheds. Hydrologic analyses performed in the study were grouped into two distinct methods. The first was applicable to gaged stream reaches for which USGS gage data were leveraged to compute specified streamflow statistics for use in assessing water capacity. The second was pertinent to ungaged reaches, where USGS reference gages and associated data were utilized to develop regional regression equations to estimate designated streamflow statistics. The overall approach prioritized use of stream gage data to calculate hydrologic indices for gaged reaches and filled data gaps in ungaged reaches using regression based estimates of target streamflow statistics. Figure 9 shows Basin stream segments classified during the study as either gaged or ungaged reaches for use in performing hydrologic analyses. Note that stream segments with drainage areas less than 10 square miles were called out separately since hydrologic analyses were not performed for these systems as they were outside the minimum spatial scale established. The following criteria were applied to delineate gaged and ungaged reaches for the study:

- A USGS stream gage (active or inactive) with at least 10 years of continuous post-1970 record must be present on the stream segment for it to be designated as a gaged reach.
- Gaged reaches should not extend beyond points along the stream at which the drainage area ratio would fall outside the target range of 0.33 to 3.0 (Ries and Friesz, 2000).
- Breakpoints in the Northeast Aquatic Habitat Classification System (Olivero, et al., 2008) stream size classes may be used to demarcate limits of gaged reaches, particularly downstream of an equivalent or larger drainage area stream that joins the gaged reach.
- Gaged reaches can only be designated for stream segments located on the same upstream or downstream reach of a reservoir as the applicable gage.
- Streamflow statistics calculated from stream gage data may not be applied to ungaged reaches.
- Ungaged reaches for applying regression equations should only be defined for stream segments with drainage areas between 10 and 1,000 square miles, as a function of reference gage watershed characteristics used in the regional regression analyses.

Site specific discrepancies in application of these criteria were addressed through institutional knowledge and professional judgment regarding stream reaches affected by regulation, diversions, or other significant human-influenced alterations.

3.1 Gaged Reaches

A GIS coverage of USGS stream gages was evaluated to identify a comprehensive list of stations, in accordance with the above criteria. This culminated in the identification of 102 stream gages depicted in Figure 9. These gages were then assigned to specific gaged reaches, as shown, in accordance with the defined criteria. Streamflow data from the designated USGS gages were used to compute a suite of streamflow statistics to facilitate the assessment of water capacity for gaged reaches throughout the Basin.

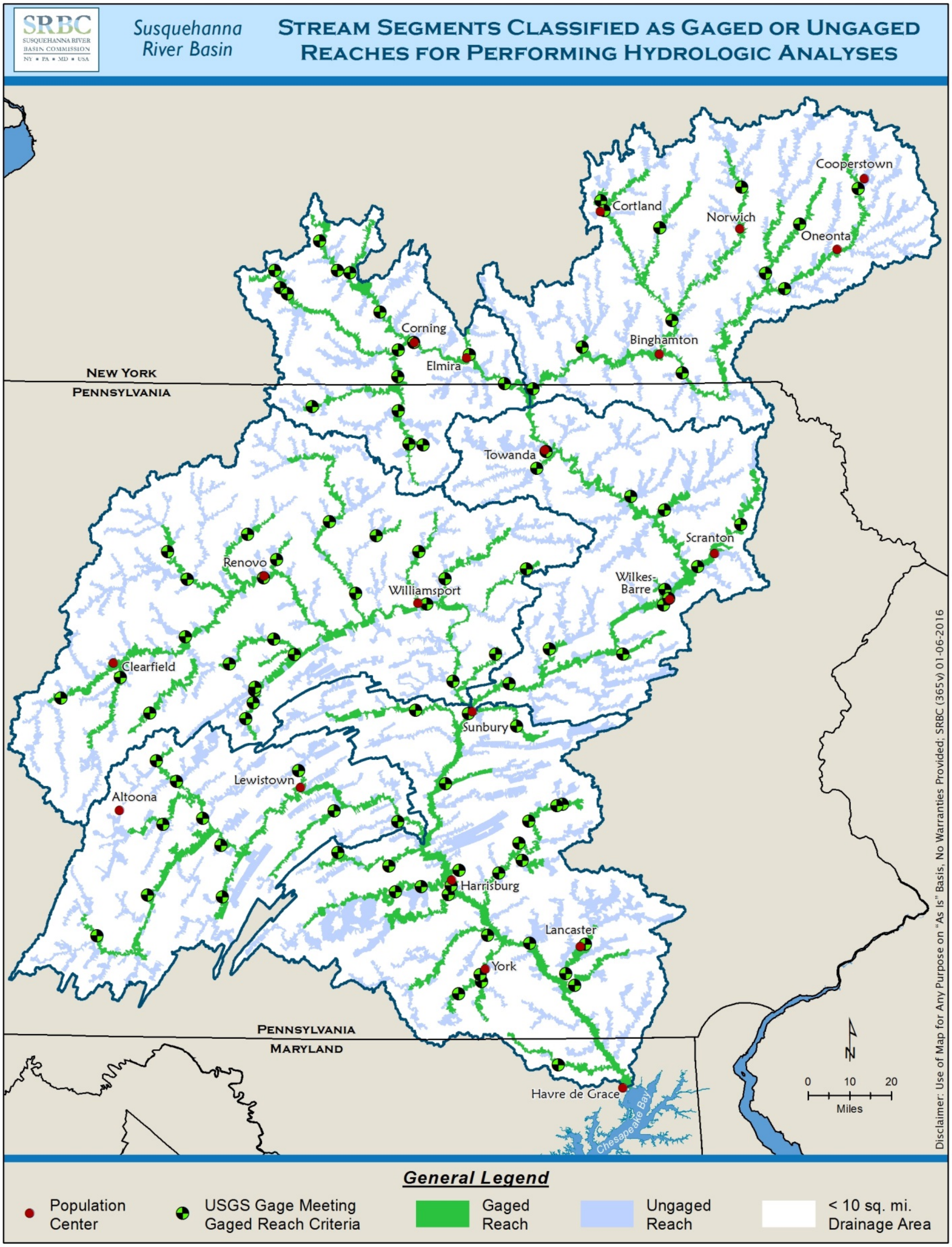


Figure 9. *Stream Segments Classified as Gaged or Ungaged Reaches for Performing Hydrologic Analyses*

3.1.1 Flow Frequency Analysis

Daily flow time series data for the 102 stream gages were downloaded for use in calculating various streamflow statistics. The collection of low flow, baseflow, mean flow, and monthly percent exceedance flow statistics generated for the study is listed in Table 8. The various statistics were computed from daily streamflow data via frequency analysis using the Statistical Analysis System (SAS®), version 9.3 software package (SAS Institute, Inc., 2012). The objective of flow frequency analysis is to relate the magnitude of streamflow events to their frequency of occurrence through probability distribution. Calculations were based on the climatic year, which starts April 1 and ends March 31, and the entire period of record for each gage. These computed flow statistics served as the foundation for evaluating water capacity and water availability throughout the study process.

Table 8. Low Flow, Baseflow, Mean Flow, and Monthly Percent Exceedance Flow Statistics

Low Flow		**Baseflow**		**Mean Flow**	
Statistic	**Abbreviation**	**Statistic**	**Abbreviation**	**Statistic**	**Abbreviation**
7-Day, 10-Year Low Flow	7Q10	Average Baseflow	BF_Avg	Average Daily Flow	ADF
		2-Year Baseflow	BF2		
		5-Year Baseflow	BF5		
		10-Year Baseflow	BF10		
		25-Year Baseflow	BF25		
		50-Year Baseflow	BF50		
Monthly Percent Exceedance Flow					
Statistic	**Abbreviation**	**Statistic**	**Abbreviation**	**Statistic**	**Abbreviation**
January 95 Percent Exceedance Flow	P95_1	January 75 Percent Exceedance Flow	P75_1	January 50 Percent Exceedance Flow	P50_1
February 95 Percent Exceedance Flow	P95_2	February 75 Percent Exceedance Flow	P75_2	February 50 Percent Exceedance Flow	P50_2
March 95 Percent Exceedance Flow	P95_3	March 75 Percent Exceedance Flow	P75_3	March 50 Percent Exceedance Flow	P50_3
April 95 Percent Exceedance Flow	P95_4	April 75 Percent Exceedance Flow	P75_4	April 50 Percent Exceedance Flow	P50_4
May 95 Percent Exceedance Flow	P95_5	May 75 Percent Exceedance Flow	P75_5	May 50 Percent Exceedance Flow	P50_5
June 95 Percent Exceedance Flow	P95_6	June 75 Percent Exceedance Flow	P75_6	June 50 Percent Exceedance Flow	P50_6
July 95 Percent Exceedance Flow	P95_7	July 75 Percent Exceedance Flow	P75_7	July 50 Percent Exceedance Flow	P50_7
August 95 Percent Exceedance Flow	P95_8	August 75 Percent Exceedance Flow	P75_8	August 50 Percent Exceedance Flow	P50_8
September 95 Percent Exceedance Flow	P95_9	September 75 Percent Exceedance Flow	P75_9	September 50 Percent Exceedance Flow	P50_9
October 95 Percent Exceedance Flow	P95_10	October 75 Percent Exceedance Flow	P75_10	October 50 Percent Exceedance Flow	P50_10
November 95 Percent Exceedance Flow	P95_11	November 75 Percent Exceedance Flow	P75_11	November 50 Percent Exceedance Flow	P50_11
December 95 Percent Exceedance Flow	P95_12	December 75 Percent Exceedance Flow	P75_12	December 50 Percent Exceedance Flow	P50_12

The 7-day, 10-year low flow (7Q10) flow statistic represents the annual 7-day minimum flow with a 10-year recurrence interval. This value has a long history of being an important low flow statistic used in water quality management throughout the United States. The 7Q10 flow statistic has historically served as a key threshold in the Commission's CU mitigation and passby flow programs. It was also predominantly used to define screening criteria for assessing water use and availability as part of the updated PA State Water Plan (PADEP, 2009). Accordingly, the 7Q10 flow statistic was computed as part of the hydrologic analyses and evaluated with other water capacity metrics described in Section 4.

The mean flow statistic computed for the study was average daily flow (ADF). The ADF is the average of all daily streamflows for the year, and often used to describe "normal" streamflow conditions. It was utilized extensively by the Commission while conducting the Instream Flow Studies, Pennsylvania and Maryland (SRBC, 1996), and in administering its previous passby flow policy (SRBC, 2003). It is also often used by water management agencies in the United States as a benchmark statistic for prescribing environmental flow protection requirements associated with water use permits (Tennant, 1976).

Baseflow is the portion of streamflow typically attributed to groundwater discharge, which can sustain streamflow over long-term periods of dry conditions (USGS, 1989). Baseflow is often estimated from streamflow data using hydrograph separation techniques. Several methods are available for performing baseflow separations, each of which can produce different results. User discretion is required to determine which method is most representative of the component of streamflow sustained solely by groundwater inputs. The study utilized the PART computer program (USGS, 1998) to separate baseflow from surface runoff using gaged streamflow records. PART has been widely applied to determine baseflow in the eastern United States (Risser et al., 2008). The program identifies the days that meet the requirement of antecedent recession and, thus, are deemed to have negligible surface runoff. For days that have significant surface runoff, baseflow is estimated via linear interpolation (Rutledge, 2007). Rutledge (1998) provides a detailed description of the streamflow partitioning algorithm. A range of baseflow return periods were estimated for the study, including 2-, 5-, 10-, 25-, and 50-year baseflow. Average baseflow was also quantified, as it represents the long-term mean baseflow and groundwater recharge rate for a given watershed.

Contemporary environmental flow science has advocated a transition from annual- to monthly-based streamflow statistics that better represent variability in natural flow regimes. TNC's Ecosystem Flow Recommendations for the Susquehanna River Basin (DePhilip and Moberg, 2010) presented a set of flow recommendations for the high, seasonal, and low flow components, expressed in terms of acceptable deviation from reference values. These recommendations were also presented in the Commission/USACE Ecological Flow Management Study, Phase I Report (USACE, 2013). The establishment of flow components and associated recommendations were based upon monthly percent exceedance flow statistics. The approach leverages flow duration curves to statistically characterize monthly streamflow data by the percentage of time that specified discharges were exceeded during a given period. For example, a June 95 percent exceedance (P95) flow represents a low flow that has been exceeded 95 percent of all days in June over the period of record. The TNC study featured monthly P50, P75, and P95 as key flow statistics for defining the seasonal and low flow components and associated flow recommendations for each. As such, this study computed the same monthly flow statistics for use in evaluating water capacity for Basin watersheds.

3.1.2 Flow Statistics for Gaged Reaches

The computed low flow, baseflow, mean flow, and monthly percent exceedance flow statistics were incorporated into a stream gage geodatabase and assigned to the respective gaged reaches. The drainage area ratio method was used to adjust computed flow statistics for a given stream gage site to other points along the assigned gaged reach. The method is based on the assumption that streamflow for a site of interest can be estimated by multiplying the ratio of the drainage area for the site of interest and the drainage area for a nearby stream gage by the streamflow for the nearby stream gage (Emerson, 2005). Hirsch (1979) noted that the drainage area ratio method is most valid in situations where watersheds are of similar size, land use, soil type, and experience similar precipitation patterns. The method is generally as accurate as, or more accurate than, regression estimates when the drainage area ratio for the ungaged and gaged sites is between 0.3 and 1.5 (Ries and Friesz, 2000). Computed flow statistics for selected stream gages were applied to sites along designated gaged reaches using the drainage area ratio method in accordance with the following equation:

$$Qstat_{site} = \frac{DA_{site}}{DA_{gage}} xQstat_{gage} \tag{1}$$

where:

$Qstat_{site}$ is the estimated flow statistic (cfs) for the site of interest;
DA_{site} is the drainage area (mi^2) for the site of interest;
DA_{gage} is the drainage area (mi^2) for the selected stream gage; and
$Qstat_{gage}$ is the computed flow statistic (cfs) for the selected stream gage.

3.2 Ungaged Reaches

Regional regression analysis was conducted as part of the hydrologic analyses to fill data gaps associated with ungaged reaches delineated throughout the Basin. Regression equations have been developed by other agencies for estimating various streamflow statistics for certain portions of the Basin (Lumia et al., 2006; Mulvihill et al., 2009; Stuckey, 2006; Roland and Stuckey, 2008; Thomas et al., 2010; Carpenter et al., 1996). However, these equations do not provide Basinwide coverage for estimating a consistent set of low and mean flow statistics for ungaged reaches. Furthermore, regression equations for estimating monthly percent exceedance flow statistics, relevant to contemporary environmental flow criteria, were not available from these investigations. As such, a significant effort was made in developing a consistent, comprehensive set of regression equations for estimating low flow, baseflow, mean flow, and monthly percent exceedance flow statistics at ungaged sites throughout the Basin.

3.2.1 Reference Gages

To initiate development of regression equations for estimating streamflow statistics at ungaged sites throughout the Basin, a network of USGS reference stream gages was selected based on the following criteria: (1) location within or adjacent to the Basin; (2) long-term (10-year minimum) continuous daily streamflow record; (3) unregulated conditions with minimal hydrologic alteration; and (4) drainage areas less than 1,000 square miles (covers most/all unregulated reference gages in Basin). A GIS coverage of USGS stream gages was evaluated to ascertain a list of reference stations that conformed to these standards. The selected reference gages were cross-checked with various USGS publications and related reports (Stuckey, 2006; Stuckey et al., 2012; Stuckey and Roland, 2011; Zhang et al., 2010) to confirm their suitability for regional regression analysis. The process resulted in the identification of 72 reference gages shown in Figure 10 and listed with pertinent attribute information in Table 9.

3.2.2 Flow Statistics

The next step in the regional regression analysis was to download daily flow time series data for the 72 reference gages for use in computing specific streamflow statistics to facilitate the development of the regression equations. The same target streamflow statistics listed in Table 8 were required to be computed for the reference gage network. Many of the 72 selected reference gages overlapped with the 102 stream gages assigned to gaged reaches according to methods outlined previously. As such, the computed flow statistics for common gages were able to be leveraged for the regression analysis. Streamflow statistics for the other reference gages, typically located adjacent to the Basin, were calculated from retrieved daily streamflow data via the procedures described in Section 3.1.1. These computed reference gage streamflow statistics are referred to as observed flow statistics for purposes of describing the regional regression analysis methodology.

3.2.3 Watershed Characteristics

The underlying approach to performing the regional regression analysis was based on evaluating observed flow statistics and derived watershed characteristics for the reference gage network to assess the effectiveness of various characteristics in predicting streamflow statistics for ungaged reaches. A comprehensive list of hydrologically-relevant characteristics was compiled based on a literature review of various publications related to the development of regression equations for estimating streamflow statistics for states within or adjacent to the Basin (Lumia et al., 2006; Mulvihill et al., 2009; Stuckey, 2006; Roland and Stuckey, 2008; Thomas et al., 2010; Carpenter et al., 1996; NJ, OH, WV). The list included a variety of climatologic, topographic, land use, hydrologic, and geologic characteristics with potential influences on observed low flow, baseflow, mean flow, and monthly percent exceedance flow statistics. The list was then evaluated to determine whether or not publically available, well-documented, Basinwide GIS coverages could be obtained, or easily generated, for use in extracting watershed characteristics for the 72 reference gages. Appendix E contains the watershed characteristics used in the regional regression analysis, and the associated minimum, mean, and maximum values associated with the reference gage network. Appendix F provides definitions, data sources, scale, time period, and URL addresses for each of the characteristics.

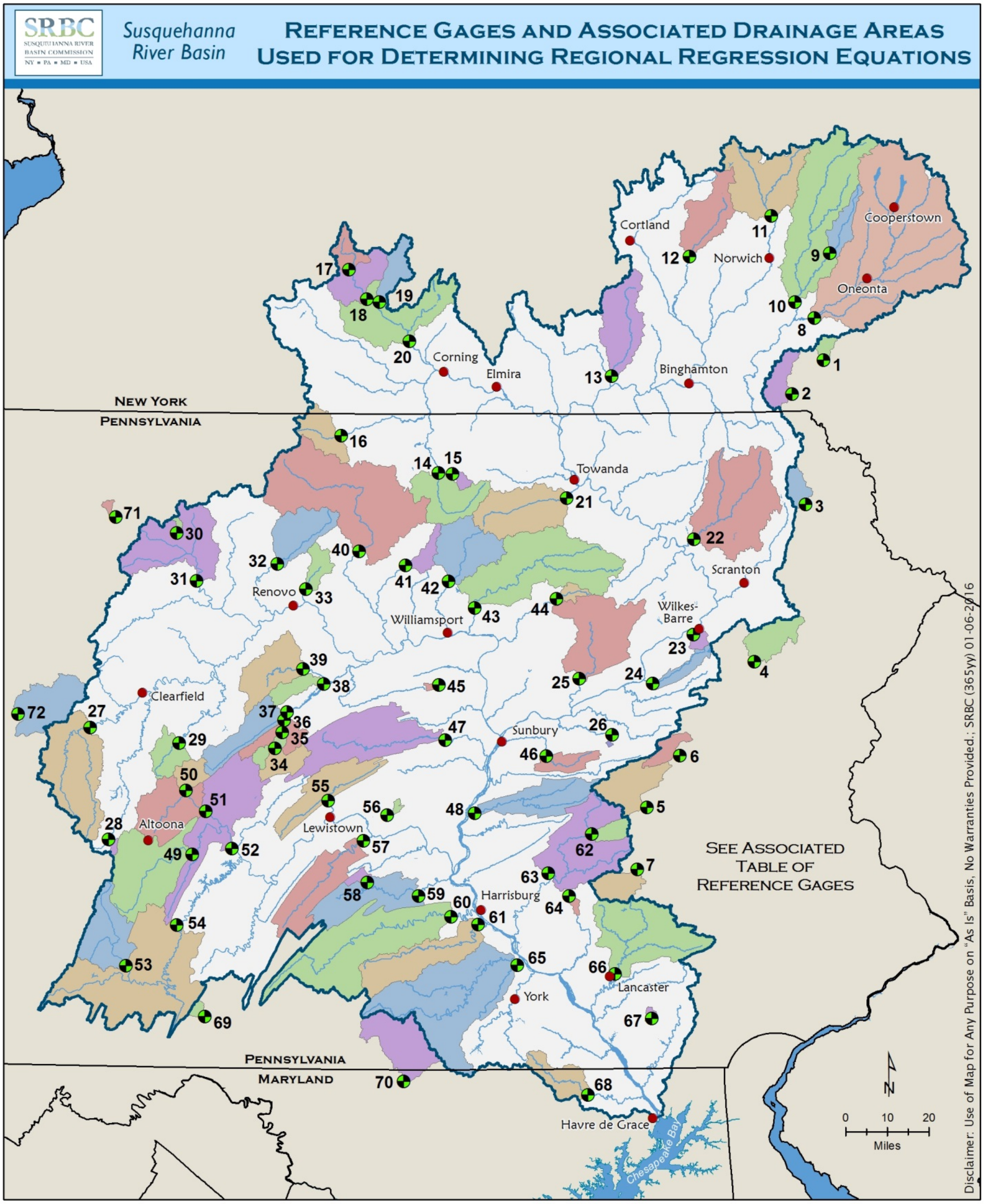


Figure 10. Reference Gages and Associated Drainage Areas Used for Determining Regional Regression Equations

Table 9. Attributes of Reference Gages Used in the Regional Regression Analysis

Map ID	USGS Station Number	Gage Name	Period of Record	DA (mi^2)
1	0142400103	Trout Creek near Trout Creek, NY	1953-1966	20.2
2	01426000	Oquaga Creek at Deposit, NY	1941-1973	67.5
3	01428750	West Branch Lackawaxen River near Aldenville	1987-2012	40.6
4	01447500	Lehigh River at Stoddartsville	1944-2012	91.8
5	01468500	Schuylkill River at Landingville	1948-2012	133.1
6	01469500	Little Schuylkill River at Tamaqua	1920-2012	43.9
7	01470779	Tulpehocken Creek near Bernville	1976-2012	70.5
8	01500500	Susquehanna River at Unadilla	1939-2008	985.3
9	01502000	Butternut Creek at Morris	1939-1994	59.9
10	01502500	Unadilla River at Rockdale	1931-2011	520.3
11	01505000	Chenango River at Sherburne	1939-2011	262.3
12	01510000	Otselic River at Cincinnatus	1939-2012	147.1
13	01514000	Owego Creek near Owego, NY	1931-1978	186.6
14	01516350	Tioga River near Mansfield	1977-2012	152.6
15	01516500	Corey Creek near Mainesburg	1955-2012	12.1
16	01518862	Cowanesque River at Westfield	1984-2012	90.0
17	01527000	Cohocton River at Cohocton	1951-1981	52.0
18	01527500	Cohocton River at Avoca	1939-2011	155.9
19	01528000	Fivemile Creek near Kanona	1938-1994	66.9
20	01529500	Cohocton River near Campbell	1919-2012	467.4
21	01532000	Towanda Creek near Monroeton	1915-2012	216.2
22	01534000	Tunkhannock Creek near Tunkhannock	1915-2012	393.0
23	01537500	Solomon Creek at Wilkes-Barre	1941-1990	15.5
24	01538000	Wapwallopen Creek near Wapwallopen	1920-2012	42.0
25	01539000	Fishing Creek near Bloomsburg	1939-2012	271.6
26	01540200	Trexler Run near Ringtown	1964-1980	1.8
27	01541000	West Branch Susquehanna River at Bower	1914-2012	315.2
28	01541308	Bradley Run near Ashville	1968-1979	6.8
29	01542000	Moshannon Creek at Osceola Mills	1941-1993	68.8
30	01542810	Waldy Run near Emporium	1965-2012	5.2
31	01543000	Driftwood Br Sinnemahoning Cr at Sterling Run	1914-2012	272.0
32	01544500	Kettle Creek at Cross Fork	1941-2012	137.1
33	01545600	Young Womans Creek near Renovo	1966-2012	46.2
34	01546400	Spring Creek at Houserville	1986-2012	58.0
35	01546500	Spring Creek near Axemann	1941-2012	85.9
36	01547100	Spring Creek at Milesburg	1968-2012	145.4
37	01547200	Bald Eagle Creek below Spring Creek at Milesburg	1956-2012	267.4
38	01547700	Marsh Creek at Blanchard	1956-2012	44.1

Map ID	USGS Station Number	Gage Name	Period of Record	DA (mi^2)
39	01547950	Beech Creek at Monument	1969-2012	152.6
40	01548500	Pine Creek at Cedar Run	1919-2012	601.4
41	01549500	Blockhouse Creek near English Center	1941-2011	37.9
42	01550000	Lycoming Creek near Trout Run	1915-2012	172.9
43	01552000	Loyalsock Creek at Loyalsockville	1926-2012	436.7
44	01552500	Muncy Creek near Sonestown	1941-2012	23.4
45	01553130	Sand Spring Run near White Deer	1969-1980	4.6
46	01554500	Shamokin Creek near Shamokin	1941-1993	54.5
47	01555000	Penns Creek at Penns Creek	1930-2012	305.8
48	01555500	East Mahantango Creek near Dalmatia	1930-2012	162.4
49	01556000	Frankstown Br Juniata River at Williamsburg	1917-2012	289.3
50	01557500	Bald Eagle Creek at Tyrone	1945-2012	44.6
51	01558000	Little Juniata River at Spruce Creek	1939-2012	220.4
52	01559000	Juniata River at Huntingdon	1942-2012	816.6
53	01560000	Dunning Creek at Belden	1940-2012	171.7
54	01562000	Raystown Branch Juniata River at Saxton	1912-2012	753.7
55	01565000	Kishacoquillas Creek at Reedsville	1940-2012	163.0
56	01565700	Little Lost Creek at Oakland Mills	1964-1980	6.6
57	01566000	Tuscarora Creek near Port Royal	1912-1958	209.9
58	01567500	Bixler Run near Loysville	1955-2012	15.0
59	01568000	Sherman Creek at Shermans Dale	1930-2012	206.7
60	01570000	Conodoguinet Creek near Hogestown	1912-2012	466.4
61	01571500	Yellow Breeches Creek near Camp Hill	1911-2012	212.7
62	01572000	Lower Little Swatara Creek at Pine Grove	1920-1984	34.1
63	01573000	Swatara Creek at Harper Tavern	1920-2012	336.1
64	01573086	Beck Creek near Cleona	1964-1980	7.9
65	01574000	West Conewago Creek near Manchester	1929-2012	512.4
66	01576500	Conestoga River at Lancaster	1929-2011	322.0
67	01578400	Bowery Run near Quarryville	1963-1980	6.0
68	01580000	Deer Creek at Rocks	1927-2012	94.4
69	01613050	Tonoloway Creek near Needmore	1966-2012	10.7
70	01639000	Monocacy River at Bridgeport	1943-2012	173.2
71	03026500	Sevenmile Run near Rasselas	1953-2011	7.9
72	03034000	Mahoning Creek at Punxsutawney	1939-2012	157.5

3.2.4 Regional Regression Analysis

The observed flow statistics for the 72 reference gages were related to the GIS-derived watershed characteristics using the ordinary least squares (OLS) regression technique. The watershed characteristics are referred to as explanatory variables for purposes of describing the regression analysis methodology. The OLS method estimates regression parameters by minimizing the sum of the squares of differences between observed and predicted responses. OLS regression is based on the assumption that the errors of the regression equations have a mean of 0 and constant variance, and errors are uncorrelated. The streamflow statistics and watershed characteristics were log transformed to form a near-linear relation. For watershed characteristics with units of percentages, 1.0 was added to the decimal form of the percentages to avoid the occurrence of zero values before they were transformed. The streamflow statistics estimated using the regression equations are referred to as predicted flow statistics.

The regression equation in log-space is:

$$Logy = \beta_0 + \beta_1 Logx_1 + \beta_2 Logx_2 + \beta_3 Logx_3 + \ldots \tag{2}$$

The regression equation in real-space is:

$$y = 10^{\beta_0} {x_1}^{\beta_1} {x_2}^{\beta_2} {x_3}^{\beta_3} \ldots \tag{3}$$

where:

Log is log to base 10;

y is the flow statistic of interest;

x_1 ,x_2 ,x_3… are watershed characteristics; and

β_0, β_1, β2, β_3… are coefficients of regression.

Step-wise regression was used to reduce the number of explanatory variables to those significant at the 95 percent confidence level. Regression analyses were conducted using the SAS®, version 9.3 software package. The preliminary results of the regression equations for 7Q10, monthly P75, and monthly P95 demonstrated that the standard errors of prediction were not satisfactory. As such, regression equations were developed for two distinct regions of the Basin defined as either glaciated or non-glaciated. Graphic relations were used to examine outliers and the overall validity of the regression equations. The residuals were then checked against the assumptions of OLS (e.g., uncorrelated errors with a mean of 0 and constant variance). The prediction error sum of squares (PRESS) was explored to show how well the regression model performed in predicting new observations. R-squared and adjusted R-squared were used to check the fit of the model. Variance inflation factors (VIF) were also used to explore multi-colinearity problems. Cook's D was used to check high leverage and influence of observations. Mallow's Cp values were used to examine the fit of the model and selection of variables. The suite of regression equations developed during the hydrologic analyses phase of the study, for use in evaluating water capacity in ungaged reaches, are included in Appendix G.

4.0 WATER CAPACITY

Water capacity is the natural ability of a watershed to sustainably support streamflow over time, during varied climatic conditions (NJ Highlands Council, 2008). It can be thought of as the natural yield of a watershed. As such, it is a critically important component to quantify for evaluating water availability. Water capacity is usually considered in the context of baseflow or low flow conditions to ensure sustainable water resources. Typically, only a portion of estimated water capacity is intended for development, while the remainder serves as reserved capacity to avoid ecologic impacts or conflicts among water users. It is a metric typically defined relative to a benchmark streamflow statistic or set of statistics. This was the impetus for performing the hydrologic analyses described in Section 3. The ability to estimate a suite of streamflow statistics for both gaged and ungaged reaches provided a framework for performing an in-depth evaluation of water capacity for Basin watersheds.

4.1 Quantitative Approaches

To initiate the assessment of water capacity for Basin watersheds, a literature review was performed to provide insight into various approaches and metrics implemented by water resources managers. The quantitative approaches uncovered during the process were grouped into four general categories, including the baseflow recurrence interval, low flow margin, ecological limits of hydrologic alteration (ELOHA), and other methods.

4.1.1 Baseflow Recurrence Interval

Baseflow is the portion of streamflow typically attributed to groundwater discharge. It is sometimes used as an approximation of recharge when losses of groundwater from the watershed are thought to be minimal. When used as a proxy for recharge, baseflow has been referred to as "effective recharge" (Daniel, 1996), "base recharge" (Szilagyi and others, 2003), or "observable recharge" (Holtschlag, 1997) to acknowledge that it likely represents some amount less than what recharges the aquifer. The main assumptions in using baseflow to estimate recharge are that baseflow equals groundwater discharge and that groundwater discharge is approximately equal to recharge. Implicit is the assumption that groundwater losses from the gaged watershed caused by underflow, groundwater evapotranspiration, and exports of groundwater are minimal. During extended low flow periods and droughts, natural streamflow is comprised entirely of baseflow. This method estimates the amount of baseflow during a specific drought recurrence interval as an indicator of the amount of water capacity when water resources are under varied levels of stress.

A variety of baseflow statistics have been used to estimate water capacity and availability in the mid-Atlantic region (Delaware River Basin Commission (DRBC), 1999; SRBC, 2005; NJ Highlands Council, 2008). The DRBC Groundwater Protected Area Regulations for Southeastern PA (DRBC, 1999) state that the 1-in-25 year average annual baseflow rate shall serve as the maximum withdrawal limit for net annual groundwater withdrawals for subbasins. The Commission's Groundwater Management Plan (SRBC, 2005) defined the sustainable limit of water resource development as the average annual baseflow (recharge) available in the "local" watershed during a 1-in-10 year average annual drought. The Interstate Commission on the Potomac River Basin (ICPRB) report titled Water Resources Sustainability and Safe Yield in West Virginia (ICPRB, 2013) explored the baseflow method, including the DRBC and Commission thresholds, as a means of calculating groundwater availability for safe yield determinations. The NJ Highlands Council Water Use and Availability Technical Report (NJ Highlands Council, 2008) evaluated a number of methods for use in determining available water supplies, including a range of baseflow recurrence interval statistics.

4.1.2 Low Flow Margin

The low flow margin method was developed by the New Jersey Department of Environmental Protection (NJDEP) for the purpose of defining water capacity based on a margin between two low flow statistics (NJDEP, 2013). Specifically, the low flow margin was defined as the difference between a normal dry-season flow (September P50) and a drought flow (7Q10). A typical, dry season flow regime for aquatic ecology is the lowest monthly flow, which, for New Jersey, occurs in September. This prompted the selection of September median (P50) flow for defining the upper margin boundary. The drought flow statistic traditionally used by New Jersey water supply planners is 7Q10, which drove its selection for defining the lower margin boundary. The low flow margin is essentially an estimate of water in a stream during critical low flow conditions. The method assumes that part of the margin can be continuously removed from the stream without creating unacceptable ecological impacts. However, if the entire margin is removed continuously, normal low flows would become drought flows and drought flows would become even more extreme low flows. Defining what percentage of the low flow margin may be removed without unacceptable impacts is based on sensitivity of the resource and policy decisions regarding acceptable impacts (NJDEP, 2013).

4.1.3 Ecological Limits of Hydrologic Alteration

Poff et al. (2010) developed the ELOHA framework as a way to further the implementation of regional environmental flow standards. The scientific process in the ELOHA framework consists of four primary steps, which include: (1) building a hydrologic foundation; (2) classifying rivers according to flow regimes and geomorphic features; (3) computing flow alteration; and (4) formulating flow alteration-ecological response relationships for environmental flows. The framework is flexible and allows scientists, water resources managers, and stakeholders to develop ecologically-based criteria for environmental flow management. The Ecosystem Flow Recommendations for the Susquehanna River Basin (DePhilip and Moberg, 2010) were developed based on the ELOHA framework and intended to inform: (1) establishment of conditions or limitations on water withdrawals; (2) management of reservoir releases for CU mitigation and low flow protection; and (3) future water planning within the major subbasins. These recommendations could be leveraged to derive an ELOHA-based method of quantifying water capacity for Basin watersheds.

4.1.4 Other Methods

Other methods encountered for assessing water availability included the Tennant method (Tennant, 1976), Aquatic Base Flow (ABF) method (Annear et al., 2004), Wetted Perimeter Method (WPM) (Gippel and Stewardson, 1998), Instream Flow Incremental Methodology (IFIM) (Stalnaker et al., 1995), R2Cross method (Parker et al., 2004), Range of Variability Approach (RVA) (Morgan et al., 1994; Richter et al., 1997), and groundwater or aquifer models. The Tennant method uses empirical hydraulic data from channel transects and habitat assessments to define relationships between flow and aquatic habitat. The method recommends instream flow needs based on percentages of mean annual flow, specifically 20 percent of ADF during the wet season, and 40 percent of ADF during the dry season, to maintain suitable aquatic habitat. The ABF method was developed by U.S. Fish and Wildlife Service (USFWS) and is currently used in the New England Flow Policy (1981). According to the policy, the ABF describes a set of chemical, physical, and biologic conditions that represent limiting conditions for aquatic life in stream environments. As low flow conditions occurring in August typically result in the most metabolic stress to aquatic organisms, August median flow was designated as the ABF in the policy. In the absence of flow data, or if the drainage area exceeds 50 square miles, the policy designates default instream flow criteria of 0.5, 1.0, and 4.0 cfs/mi^2 for summer, fall/winter, and spring months, respectively.

The WPM assumes there is a direct relation between the wetted perimeter in a riffle and fish habitat in streams (Annear and Conder, 1984; Lohr, 1993). The method is based on a plot of the relation between wetted perimeter and discharge. The point of maximum curvature in this relation is used to determine the streamflow required for habitat protection (Annear and Conder, 1984; Nelson, 1984).

The IFIM was developed in the 1970s by the USFWS as a way to demonstrate relationships between streamflow and aquatic habitat, focused on fish and benthic macroinvertebrate habitat requirements. A major component of IFIM is the Physical Habitat Simulation Model (PHABSIM), which simulates habitat relations for various species and life stages and allows quantitative habitat comparisons at different streamflows.

The R2Cross method requires selection of a critical riffle along a stream reach and assumes that a discharge chosen to maintain habitat in the riffle is sufficient to maintain habitat for fish in nearby pools and runs (Nehring, 1979). Streamflow requirements for habitat protection in riffles are determined from flows that meet criteria for three hydraulic parameters including mean depth, percent of wetted perimeter, and average velocity. The hydraulic criteria were developed in Colorado to quantify the amount of streamflow required to "preserve the natural environment to a reasonable degree" (Espegren, 1996).

The RVA was introduced for setting streamflow-based ecosystem management targets derived from aquatic ecology theory concerning the key role of hydrological variability, and associated characteristics of timing, frequency, duration, and rates of change, in sustaining aquatic ecosystems (Richter et al., 1997). The RVA requires a measured or synthesized baseline daily streamflow record reflective of minimally altered hydrologic conditions. The record is then characterized using a composite of 32 ecologically relevant indices used to assess the degree of hydrologic alteration (Richter et al., 1996, 1997). These indices fall into non-parametric (percentile values) or parametric (1-2 standard deviations from mean) statistics related to streamflow magnitude, frequency, duration, timing, and rate of change. Applications of the RVA for determining water availability are less defined, as the RVA does not specify acceptable limits of hydrologic alteration.

Additionally, groundwater or aquifer models can also provide insight into assessing water capacity and availability as aquifers are often highly connected to stream discharge during low flow periods (Faunt, 2009). However, it can be very costly and labor intensive to construct and perform simulations using groundwater models due to the detailed input and calibration requirements. In addition, while they are generally robust, many groundwater and aquifer models only consider the physical impact of water use on groundwater and not streamflow.

4.2 Water Capacity Metrics

As many of the other methods described above for evaluating water capacity, including IFIM, WPM, and R2Cross, relied on site-specific field data, they were eliminated from further consideration in favor of desktop methods more feasible to implement Basinwide for the 170 HUC-10 watersheds evaluated in the study. In formulating water capacity metrics for analysis, a set of overarching criteria was established based on the objectives of the study. These included: (1) consistent Basinwide applicability; (2) derivation via desktop methods; (3) reasonable estimation accuracy; (4) ability to regionalize; (5) conformance with existing policies and plans; (6) consideration of human and ecosystem needs; (7) differentiation against total approved CU; and (8) ease of communication. Based on the quantitative approaches identified during the literature review, and criteria previously discussed, a suite of water capacity metrics was developed and carried forward for analysis.

4.2.1 Previous Commission Metrics

Previous metrics used by the Commission and other regional water management agencies for regulatory and planning purposes were grounded on the 7Q10 flow statistic. The Commission's early CU regulations specified mitigation requirements based on the 7Q10 threshold. The Commission's previous passby flow policy (SRBC, 2003) specified that if withdrawal impacts were 10 percent or less of the 7Q10 flow for the stream, no passby flow would be required. As discussed previously, the Pennsylvania State Water Plan watershed screenings were performed using criteria based on the 7Q10 threshold, specifically 50 percent of 7Q10 for most streams and 30 percent of 7Q10 for Class A trout streams in carbonate areas. As 7Q10 has been entrenched as a threshold for water management in the Basin, this study examined 7Q10 as part of the early evaluation of water capacity metrics. As described previously, ADF was utilized extensively in the Commission's Instream Flow Studies, Pennsylvania and Maryland (SRBC, 1996) and its previous passby flow policy (SRBC, 2003). As such, it was also considered during the preliminary assessment of water capacity metrics.

4.2.2 Baseflow Recurrence Interval Metrics

Considering the Commission's and DRBC's use of the 10-year and 25-year baseflow for limiting groundwater development, both statistics were incorporated in the evaluation of water capacity metrics. To cover a broader range of climatic scenarios, the average, 2-, 5-, and 50-year recurrence interval baseflows, which span from normal to very dry conditions, were also considered. The long-term mean (average) baseflow is representative of a 1-year annual base flow recurrence interval. The 5-, 10-, 25- and 50-year baseflows have probabilities of 20 percent, 10 percent, 4 percent, and 2 percent of occurring every year, respectively. It should be noted that the probability of a specified baseflow event does not exclude the chance for a similar probability baseflow event to occur during the following year. Instead, severe droughts tend to occur after other drought events, which demonstrates the hydrologic persistence of low flow occurrences.

4.2.3 Low Flow Margin Metrics

Building on the work done by NJDEP regarding the low flow margin method, several related metrics were formulated for analysis as part of the study. These included (1) 10-year baseflow (BF10) minus 7Q10; (2) BF10 minus annual 95 percent exceedance (P95) flow; (3) BF10 minus September P75/P95; (4) September P50 minus 7Q10; and (5) September P50 minus September P75/P95. Hydrologic analysis regarding the timing of critical low flow events indicated that September is also the lowest flow month for the Susquehanna River Basin. Following suit with the NJ-based low flow margin, September P50 flow was selected as the upper margin for a pair of water capacity metrics evaluated. Similarly, 7Q10 was chosen as the lower margin for two of the metrics. For the others, BF10 was designated as the upper margin given it's lineage to the Commission's Groundwater Management Plan (SRBC, 2005) sustainable limit of water resource development. Likewise, September P75 or P95 was established as the lower margin for two of the metrics analyzed due to their relevance to the "no change" low flow recommendations in Ecosystem Flow Recommendations for the Susquehanna River Basin (DePhilip and Moberg, 2010). September P75 was applied for ARCs 1-3 while September P95 was applied for ARCs 4-6 based on the Commission's current Low Flow Protection Policy (LFPP) (SRBC, 2012). One of the identified metrics also utilized annual P95 flow as the lower margin.

4.2.4 Ecological Limits of Hydrologic Alteration Metric

The above methods and resultant metrics assume some minimum instream flow is needed for maintaining water quality and aquatic communities, but do not explicitly examine the impact of hydrologic alteration on aquatic ecosystems. An attempt was made to do so through derivation of an ELOHA-based water capacity metric that leveraged environmental flow standards in TNC's Ecosystem Flow Recommendations for the Susquehanna River Basin (DePhilip and Moberg, 2010). These recommendations cover three primary flow components including high, seasonal, and low flow, and are defined based on monthly percent exceedance flow statistics to represent seasonal variation in streamflow and ecologic processes. The flow standards address limits of hydrologic alteration over the entire flow regime and are summarized in Table 10.

Table 10. Environmental Flow Standards for the Susquehanna River Basin

	Low Flow Magnitude		**Low Flow Range**	**Seasonal Median**	**Seasonal Range**	**High Flow**
Flow statistics	Monthly P75	Monthly P95	Area under curve between P75 and P99	Monthly P50	Area under curve between P10 and P75	Monthly P10
Watersheds <50 sq mi	No change	N/A	No change	Between P45 and P55	<=10% change	<=10% change
Watersheds >50 sq mi	N/A	No change	<=10% change	Between P45 and P55	<=10% change	<=10% change

The process for developing the ELOHA metric involved two primary components, including iterative withdrawal simulations for selected unregulated USGS reference stream gages and regional regression analysis for ungaged streams. Hypothetical withdrawals of increasing magnitude, and associated passby flow requirements pursuant to the Commission's LFPP, were superimposed on daily streamflow records for 63 selected reference gages to generate post-water use daily flow records. Flow statistics and related indices were computed from both the pre- (baseline) and post-water use daily flow time series data using TNC's Indicators of Hydrologic Alteration (IHA) software, version 7.1 (TNC, 2009). The resultant hydrologic indices were then compared and checked against the environmental flow standards depicted above in Table 10. The maximum hypothetical water use rendering post-water use hydrologic indices that still met the environmental flow standards was designated as the ELOHA-based water capacity for each reference gage. It was observed that the seasonal flow standards were the limiting factors in determining the ELOHA metric since (1) simulated passby flow requirements ensured compliance with the low flow standards, and (2) water capacity based on the high flow standards would be greater than for the seasonal flow standards. It was also noted that the environmental flow standards for September were limiting factors as they typically generate lower water capacities than other months as September is typically the lowest flow month for the Basin.

Following regional regression analysis procedures outlined in Section 3.2, relationships between watershed characteristics and derived ELOHA-based water capacities for the 63 reference gages were employed to generate a regression equation for estimating the ELOHA metric for ungaged reaches. The developed regression equation, which is listed in Appendix G, had an adjusted R-square value of 0.96 and a standard error of 27 percent. The ELOHA metric was also calculated for the 102 stream gages assigned to specific gaged reaches using the iterative withdrawal simulation procedure described above.

4.3 Candidate Water Capacity Metrics

The various water capacity metrics presented above were compared against the criteria outlined previously to identify a set of practicable metrics for analysis as part of the study. Regarding baseflow recurrence interval metrics, average, 2-year, and 5-year baseflow statistics were dropped from consideration in favor of higher recurrence intervals more suitable for evaluating sustainable water capacity under low flow conditions. The 50-year baseflow was eliminated from further contemplation as it was deemed to represent too severely stressed hydrologic conditions for determining water capacity. Given the designation of the 10-year baseflow as the sustainable limit of water resource development in the Commission's Groundwater Management Plan (SRBC, 2005), it was qualified as a water capacity metric for detailed evaluation in the study. The previous 7Q10 threshold and low flow margin water capacity metrics containing 7Q10 were eliminated from consideration because they did not meet the criterion of conformance with existing policies and plans. Per the Commission's CU Mitigation Plan (SRBC, 2008), TNC's Ecosystem Flow Recommendations (DePhilip and Moberg, 2010), and the Commission's LFPP (SRBC, 2012), 7Q10 was deemed unsuitable for use as an environmental flow management threshold. Given their conformance with thresholds implemented via the Commission's Groundwater Management Plan (SRBC, 2005) and LFPP (SRBC, 2012), the 10-year baseflow minus September P75/P95 and September P50 minus September P75/P95 low flow margin metrics were shortlisted for assessing water capacity. Influenced by contemporary environmental flow science, including TNC's Ecosystem Flow Recommendations (DePhilip and Moberg, 2010), the ELOHA metric was also nominated for evaluation of water capacity for Basin watersheds.

In summary, the candidate water capacity metrics identified for detailed evaluation as part of the study included: (1) 10-year baseflow; (2) 10-year baseflow minus September P75/P95 flow; (3) September P50 flow minus September P75/P95 flow; and (4) ELOHA. These four metrics were determined to be best aligned with the set of overarching criteria established based on the objectives of the study. These criteria, repeated from Section 4.2, included (1) consistent Basinwide applicability; (2) derivation via desktop methods; (3) reasonable estimation accuracy; (4) ability to regionalize; (5) conformance with existing policies and plans; (6) consideration of human and ecosystem needs; (7) differentiation against total approved CU; and (8) ease of communication. Table 11 provides a comparison of the candidate water capacity metrics relative to these criteria. To assess the performance of the candidate metrics in quantifying water capacity for watersheds throughout the Basin, a series of maps and associated summary tables were also generated and are included in Appendix H and I.

Table 11. Candidate Water Capacity Metrics and Evaluation Criteria

Metric	10-Year Baseflow	10-Year Baseflow - September P75/P95	September P50 - September P75/P95	ELOHA
Method	Baseflow Recurrence Interval	Low Flow Margin	Low Flow Margin	Ecological Limits of Hydrologic Alteration
Estimation Accuracy	High	Medium	Low	Medium
Ease of Regionalization	Easy	Medium	Medium	Medium
Aligned With Existing Plans/Policies	✓	✓		
Balances Resource Limits & Ecosystem Needs		✓	✓	
Ecosystem Flow-Based		✓	✓	✓
Differentiation Against Total Approved CU	[0 - 54%]	[0 - 100%]	[0.2 - 5,743.8%]	[0.5 - 368%]
Ease of Communication	Medium	Hard	Hard	Hard

The 10-year baseflow metric, while having high estimation accuracy, ease of transferability, and conformance with the Commission's Groundwater Management Plan (SRBC, 2005), does not make direct provision for ecosystem flow needs. While it has served the Commission well in ensuring sustainable groundwater development, which entails consideration of storage and response lag components, it was never intended for direct application as a CU threshold. With total approved CU factored in, this metric included only one HUC-10 watershed with less than 10 mgd of water availability. The 10-year baseflow minus September P75/P95 metric addressed some of these shortcomings by incorporating a lower margin boundary to account for ecosystem flow needs, without sacrificing accuracy and regionalization. By incorporating the lower margin and accounting for total approved CU, eight HUC-10 watersheds had less than 10 mgd of water availability, with two having less than 0 mgd.

The September P50 – September P75/P95 metric was found to have technical deficiencies associated with estimation accuracy compounded over three monthly percent exceedance flow statistics. The ability to accurately differentiate between September P50, P75, and P95, particularly for small, ungaged watersheds using regression equations, posed significant challenges to performing water capacity analyses. Also, integrating water use resulted in 81 watersheds with 10 mgd or less of water availability, and 25 with negative balances, further confirming this metric to be too stringent for management purposes. Derivation of the ELOHA metric represented a novel approach to assessing water capacity based on TNC's Ecosystem Flow Recommendations (DePhilip and Moberg, 2010). Environmental flow standards covering the entire natural flow regime were leveraged in an attempt to develop a practicable CU management threshold. While rooted in ecosystem-based bounds on flow alteration, the metric does not directly consider human water demands and associated resource limits to ensure sustainable water development. This was observed when total approved CU was applied, causing 113 HUC-10 watersheds to have 10 mgd or less of water availability, 10 of which had no remaining water capacity.

4.4 Selected Water Capacity Threshold

In order for the Commission to fulfill the desired result, goals, and actions needed for the Sustainable Water Development PMA in the Comprehensive Plan, and satisfy the CWUAS purpose and scope, it was essential to establish a sustainable limit for water resources development. Accordingly, an effort was made to identify a selected water capacity threshold based on a thorough evaluation of the study objectives, criteria outlined above, performance of the candidate metrics for Basin watersheds, and existing policy and planning principles.

The low flow margin method was determined to be the water capacity determination approach that best addresses the Commission's Sustainable Water Development PMA goals and conforms with existing plan and policy thresholds. The method integrates objectives with respect to defining a sustainable limit of water resource development while also allowing for a prescribed flow to support ecosystem needs. The upper margin boundary defines the sustainable limit of water development based on acceptable risk associated with a target low flow management condition. The lower margin boundary represents a minimum flow set aside to support ecosystem needs during that same condition. The lower boundary can be conceptualized as a water allocation for ecological demands. Under a specified low flow management condition, the margin signifies potential water capacity for development to meet human demands, while the lower margin boundary denotes designated water capacity to satisfy ecological demands.

To integrate the Commission's sustainable limit of water resource development cited in the Groundwater Management Plan (SRBC, 2005) and low flow protection thresholds specified in the LFPP (SRBC, 2012), the 10-year baseflow minus September P75/P95 low flow margin metric was selected for quantifying water capacity in Basin watersheds. The metric also scored most favorably, in comparison to the other candidates, with respect to the evaluation criteria outlined above. The underlying management strategy associated with the selected metric was based on ensuring sustainable water supply for meeting human and ecological needs during a 10-

year recurrence interval baseflow condition. The 10-year baseflow was used to define the upper margin boundary that represents the potential limit of water development based on that target baseflow management condition. The September P75 or September P95 flow was employed to establish the lower margin boundary which demarcates the minimum flow set aside to support ecosystem flow needs during the same baseflow management condition. September monthly low flow thresholds were specified since the majority of 10-year baseflow events in the Basin were found to occur during that critical low flow month. The low flow margin concept and selected water capacity metric are depicted graphically in Figure 11.

Directly applying the selected low flow margin metric as a CU management threshold could lead to conditions where watershed yields are frequently reduced to September P75 or P95 flows or lower. Related water capacity analysis work by the NJ Highlands Council, USGS, and NJDEP defined the low flow margin method based on the September P50 minus 7Q10 flow. NJDEP (2013) noted that the method assumes only a portion of the margin can be continuously removed from the system without creating unacceptable ecologic impacts. NJ Highlands Council (2008) stated that it is necessary to determine how much of the low flow margin can be provided for human use without harm to other water users or aquatic resources. A safety factor is a specified percentage that can be applied to generate an adjusted water capacity threshold that accounts for reserved capacity. Reserved water capacity is often purposefully assigned to allow for emergency situations, unaccounted for water use, impact avoidance, and uncertainty. The Commission's Groundwater Management Plan cites known withdrawals in developing areas that exceed 50 percent of the recharge during a 1-in-10-year drought as one of the criteria evaluated to identify Potentially Stressed Areas (PSAs) (SRBC, 2005). This criterion acts as a safety factor to ensure sustainable groundwater development. Based on each of the factors described above, the Commission's selected water capacity threshold for this study was specified as 50 percent of the 10-year baseflow minus the September P75/P95 flow (Figure 11).

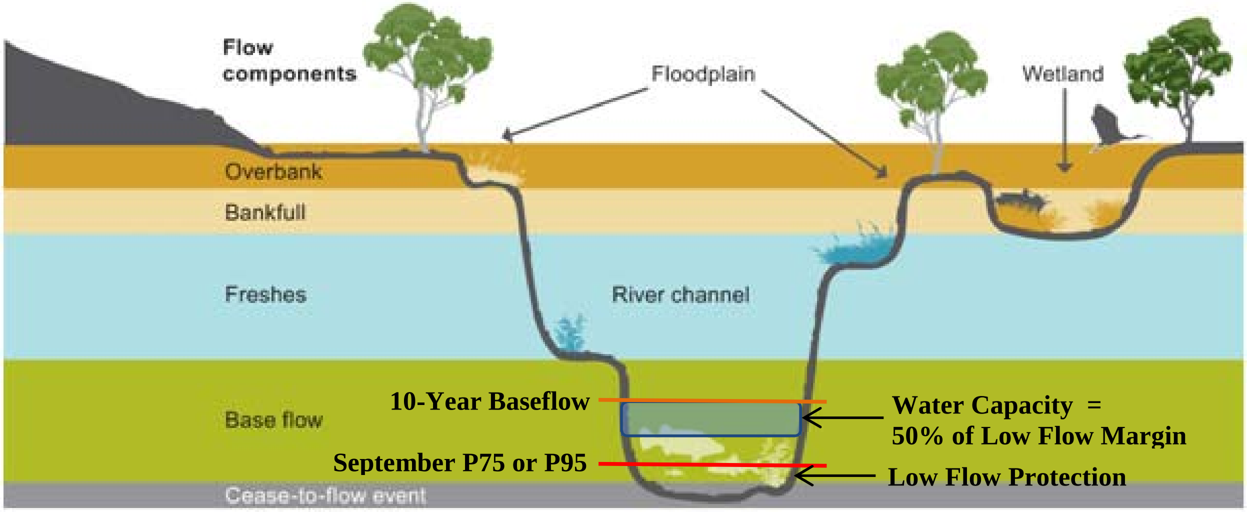


Figure 11. Schematic Illustrating Selected Water Capacity Threshold (Modified from Murray-Darling Basin Authority, 2011)

4.5 Water Capacity Results

Figure 12 depicts water capacity for HUC-10 watersheds in the Basin based on the selected threshold. Tabular data are also summarized in Appendix D. Results were representative of calculations performed at HUC-10 pour point locations and should not be construed as representative of uniform conditions throughout each respective watershed. As expected, capacity was greatest for watersheds traversed by mainstem rivers and major tributaries. Cumulative water capacity by subbasin pour point is summarized in Table 12. Water capacity for the Basin was estimated at 4,371.2 mgd, and was highest for the Middle Susquehanna (1,820.7 mgd) followed by the West Branch Susquehanna (1,289.7 mgd) and Upper Susquehanna (975.9 mgd) subbasins. Capacity per unit area was greatest for the Upper Susquehanna (0.20 mgd/mi^2) and West Branch Susquehanna (0.18 mgd/mi^2) subbasins. Water capacity and capacity per unit area were lowest for the Chemung subbasin (247.5 mgd, 0.010 mgd/mi^2). The lower capacity for the Chemung subbasin was influenced by its relatively small drainage area and low mean annual precipitation compared to other subbasins. Drainage area, precipitation, and baseflow index were found to be the biggest drivers influencing water capacity at the subbasin scale.

Table 12. Water Capacity for Subbasin Pour Points

Map ID	Subbasin Name	DA (mi^2)	Water Capacity (mgd)
A	Upper Susquehanna	4,945.0	975.9
B	Chemung	2,595.5	247.5
C	Middle Susquehanna	11,310.5	1,820.7
D	West Branch Susquehanna	6,978.7	1,289.7
E	Juniata	3,403.5	431.0
F	Lower Susquehanna	27,501.7	4,371.2

Water capacity was greater than 10 mgd for 150 of 170 (88 percent) HUC-10 watersheds and greater than 25 mgd for 96 of 170 (56 percent) watersheds. Tributary watersheds with the highest capacities included Sinnemahoning Creek (225.5 mgd), Lower Pine Creek (199.8 mgd), Tioughnioga River (169.0 mgd), Unadilla River (134.7 mgd), and Tioga River (128.6 mgd). Higher water capacities for these watersheds were influenced by larger drainage area size, mean annual precipitation, and baseflow index values. The results suggested that these mainstem river and large tributary watersheds have yields more suited to support greater cumulative CU in comparison to smaller HUC-10 watersheds.

Water capacity was less than 10 mgd for 20 of 170 (12 percent) HUC-10 watersheds and less than 5 mgd for 5 of 170 (3 percent) watersheds. Table 13 lists tributary HUC-10 watershed pour points with the lowest water capacity. The lowest capacities were typically associated with smaller, headwater watersheds generally less than 100 square miles. The majority of watersheds with capacities less than 5 mgd were located in the Lower Susquehanna (10 of 20, 50 percent) and Juniata (6 of 20, 30 percent) subbasins. These results were noteworthy considering existing and projected CU quantities were observed to be greatest for watersheds in the Lower Susquehanna subbasin. Water capacity was estimated to be 0.0 mgd for Little Conestoga Creek

Watershed. It should be noted that this does not imply that these watersheds yield no streamflow under low flow conditions. Rather, it signifies that no additional water capacity is sustainably available based on the selected threshold. Capacity ranged from approximately 0.01 to 0.10 mgd/square mile for the other watersheds listed. A few watersheds with drainage areas approaching or greater than 100 square miles were also listed, including Muddy Creek, East Branch Octoraro Creek, and Spruce Creek. Portions of these watersheds were underlain by carbonate bedrock and, as such, tend to yield higher baseflows. Flow duration curves associated with high baseflow streams are typically not as steep as those of flashier, freestone systems. Accordingly, the low flow margin for these streams tended to be truncated, resulting in lower estimates of water capacity based on the selected water capacity threshold.

Table 13. Tributary HUC-10 Watershed Pour Points with the Lowest Water Capacity

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	Water Capacity (mgd)
1	Little Conestoga Creek	0205030610	65.5	0.0
2	Muddy Creek	0205030613	138.4	1.3
3	Quittapahilla Creek	0205030508	77.3	3.8
4	Canacadea Creek	0205010401	58.3	4.6
5	East Branch Octoraro Creek	0205030614	90.7	4.7
6	Blacklog Creek	0205030403	72.6	5.2
7	Spruce Creek	0205030204	109.1	5.6
8	Cocolamus Creek	0205030410	64.2	6.1
9	Little Conewago Creek	0205030604	65.4	6.6
10	South Branch Conewago Creek	0205030601	73.5	7.2

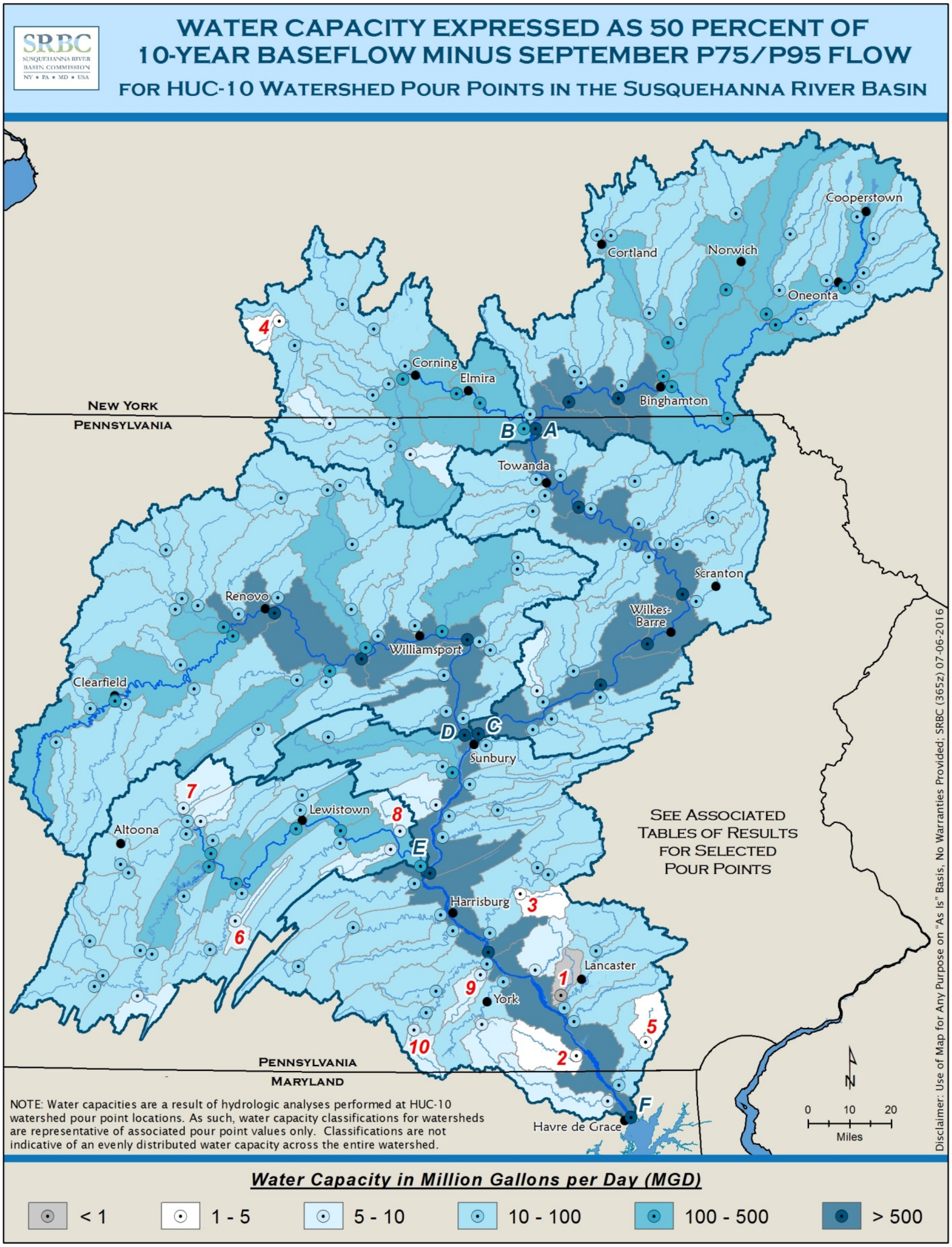


Figure 12. Water Capacity for HUC-10 Watershed Pour Points

5.0 WATER AVAILABILITY

Water availability is defined as the hydrologic capacity of a water source or watershed to sustain additional water demands after considering other current water uses and water conditions (Global Environmental Management Initiative (GEMI), 2012). These include applicable water quality standards and ecosystem flow needs. For this study, water availability for HUC-10 watershed pour points was calculated by subtracting cumulative CU from the selected water capacity threshold presented in the previous section. The difference represents additional water capacity available for sustainable water resources development. Water availability deficits signify watersheds in which additional water planning and/or management efforts may be needed.

5.1 Previously Identified Stressed or Critical Watersheds

Initiation of the assessment of water availability for Basin watersheds included a review of watersheds previously identified as critical or stressed in related water planning efforts. The Commission's Groundwater Management Plan (SRBC, 2005) identified several PSAs in the Basin where the utilization of groundwater resources was approaching or exceeding the sustainable limit of the resource, defined as the average annual baseflow available in the watershed during a 1-in-10-year drought. The identified PSAs encompassed seven areas in Pennsylvania including the Manheim/Lititz/Ephrata Valley, Fruit Belt (York/Adams Counties), Hanover area, Hershey area (Spring Creek basin), Fredericksburg area, Roaring Spring area, and State College area, and the Corning area in New York. The plan also identified two Water Challenged Areas (WCAs), including the Bonneauville Shale Belt and Diabase area, which contain low-yielding bedrock units in the southern Pennsylvania portion of the Basin that produce limited amounts of groundwater to support water resources development. These areas are noted in Figure 13 and summarized by HUC-10 watershed in Table 14.

Pennsylvania developed an updated State Water Plan (SWP) in 2009 (PADEP, 2009). That effort included the completion of a statewide watershed screening and data verification process to help identify potential Critical Water Planning Areas (CWPA). A water-analysis screening tool was developed to compare water use information to initial screening criteria based on estimated 7Q10 flow statistics for watershed pour points (USGS, 2008). The initial screening criteria were 50 percent of 7Q10 for all streams except those designated as Class A wild trout streams in areas underlain by carbonate bedrock, for which 30 percent of 7Q10 was used. Basin watersheds identified as priorities during the screening process, and evaluated further as candidate CWPAs, included Toby Creek, Spring Creek, Nittany Creek, Anderson Creek, Sugar Creek, Little Catawissa Creek, Conestoga River, Chiques Creek, Swatara Creek, Beaverdam Branch, Conewago Creek, Codorus Creek, and Deer Creek. Of these, Spring Creek, Sugar Creek, Toby Creek, and tributaries to Conewago Creek, Conestoga River, and Swatara Creek were recommended for designation as CWPAs by SWP regional committees. These areas are also depicted in Figure 13 and presented by HUC-10 watershed in Table 14.

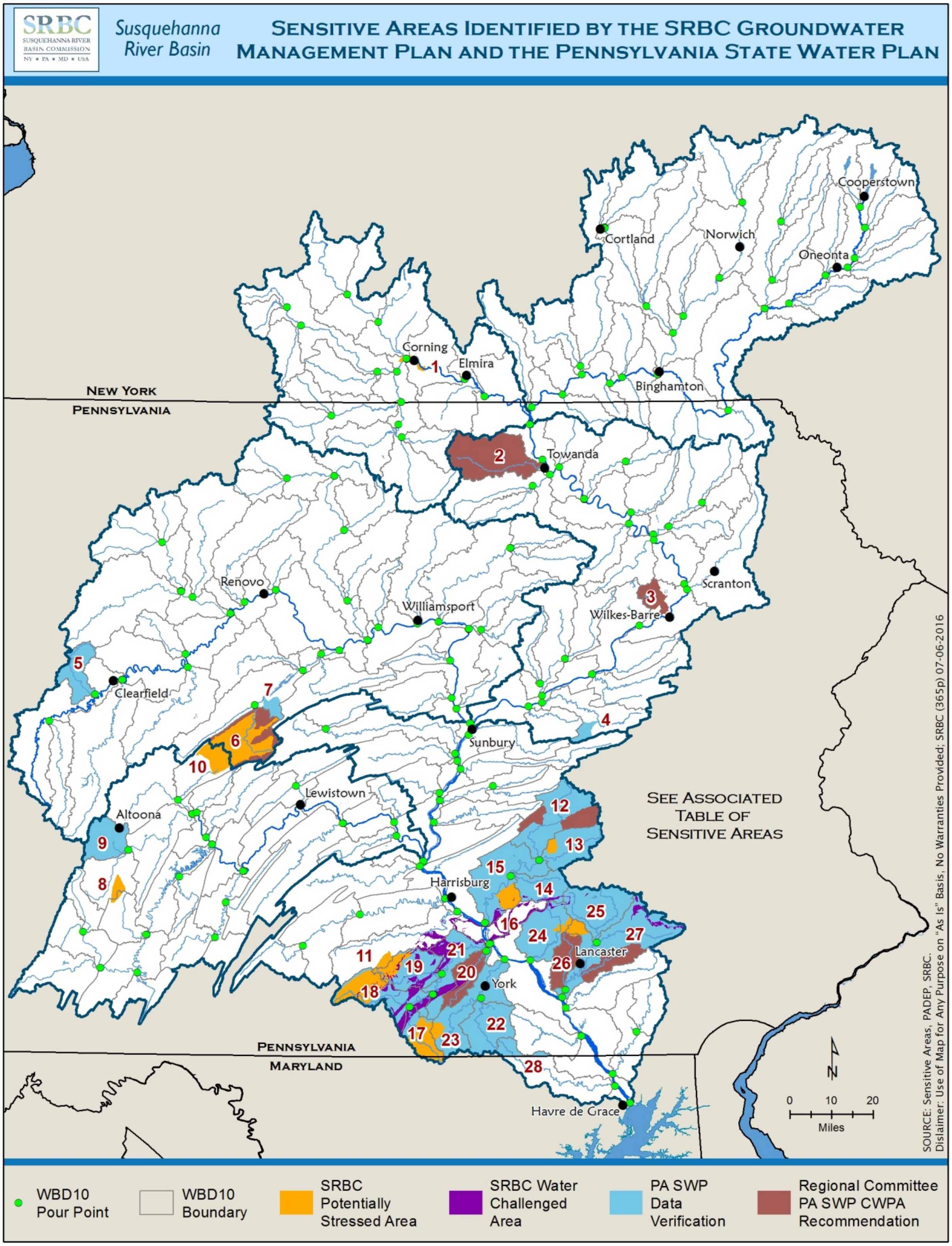


Figure 13. Sensitive Areas Identified by the Commission's Groundwater Management Plan and the Pennsylvania State Water Plan

Table 14. HUC-10 Watersheds Containing Sensitive Areas Identified by the Commission's Groundwater Management Plan and the Pennsylvania State Water Plan

Map ID	HUC-10 Watershed	SRBC Potentially Stressed Area	SRBC Water Challenged Area	PA SWP Data Verification Watershed	Regional Committee PA SWP CWPA Recommendation
1	Upper Chemung River	Corning			
2	Sugar Creek			Sugar Creek	Sugar Creek
3	Upper Susquehanna River			Toby Creek	Toby Creek
4	Catawissa Creek			Little Catawissa Creek	
5	Anderson Creek			Anderson Creek	
6	Spring Creek	State College		Spring Creek	Spring Creek
7	Bald Eagle Creek			Nittany Creek	
8	Upper Frankstown Branch Juniata River	Roaring Spring			
9	Beaverdam Branch			Beaverdam Branch	
10	Spruce Creek	State College			
11	Yellow Breeches Creek	PA Fruit Belt	Diabase		
12	Upper Swatara Creek			Swatara Creek	Lower Little Swatara Creek, Mill Creek
13	Little Swatara Creek	Fredericksburg		Swatara Creek	
14	Quittapahilla Creek		Diabase	Swatara Creek	
15	Lower Swatara Creek	Hershey	Diabase	Swatara Creek	Spring Creek
16	Susquehanna River		Diabase		
17	South Branch Conewago Creek	Hanover	Bonneauville Shale Belt	Conewago Creek	
18	Upper Conewago Creek	PA Fruit Belt	Bonneauville Shale Belt, Diabase	Conewago Creek	
19	Bermudian Creek	PA Fruit Belt	Diabase	Conewago Creek	
20	Little Conewago Creek		Bonneauville Shale Belt	Conewago Creek	Little Conewago Creek
21	Lower Conewago Creek		Bonneauville Shale Belt, Diabase	Conewago Creek	
22	South Branch Codorus Creek			Codorus Creek	
23	Codorus Creek	Hanover		Codorus Creek	
24	Chiques Creek	Manheim, Lititz	Diabase	Chiques Creek	
25	Cocalico Creek		Diabase	Conestoga River	
26	Little Conestoga Creek			Conestoga River	Little Conestoga Creek
27	Conestoga River	Manheim, Lititz	Diabase	Conestoga River	Mill Creek
28	Deer Creek			Deer Creek	

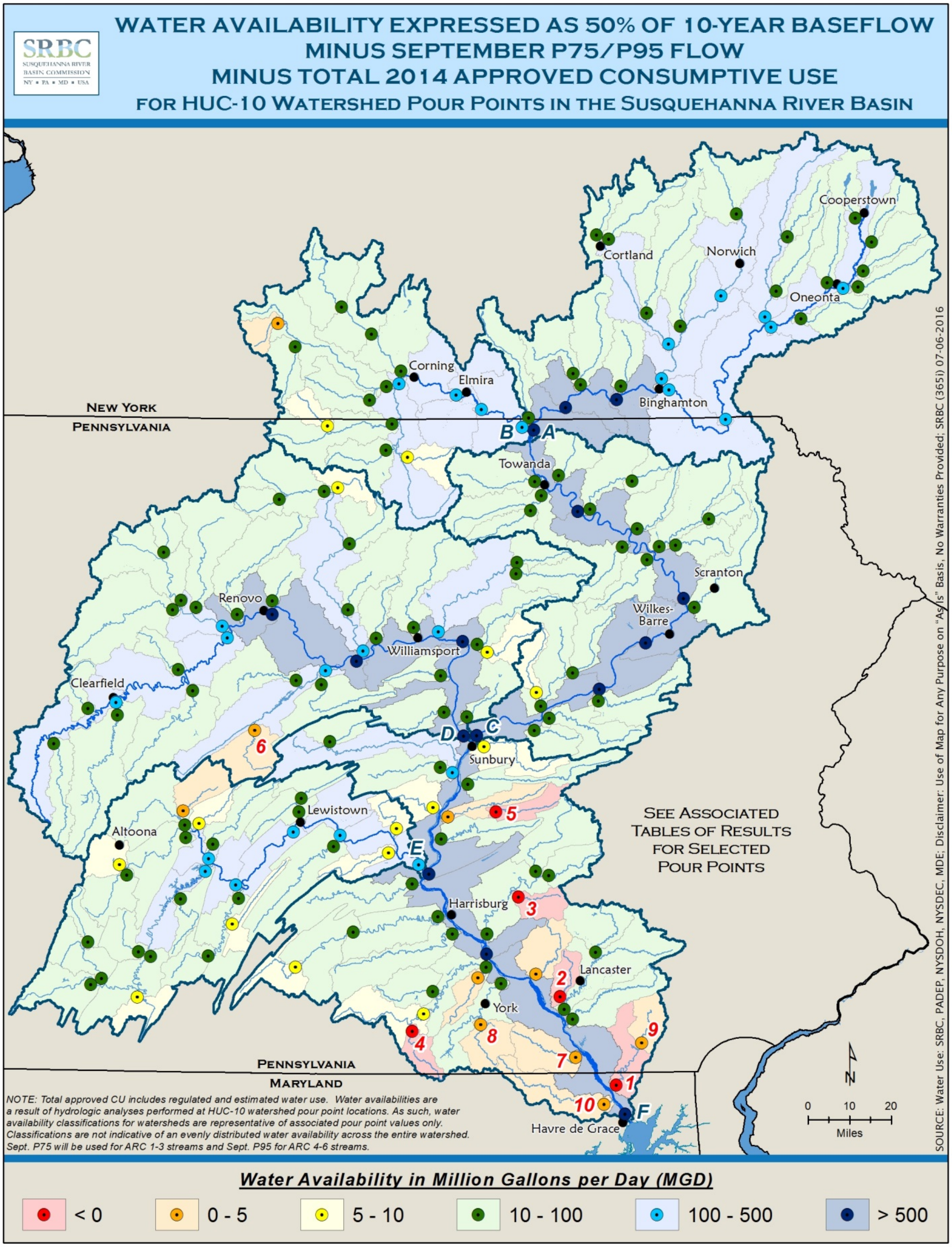
The sensitive areas mapped and tabulated above were leveraged during the study process to validate water availability results associated with application of the selected water capacity threshold. Although the sensitive areas were originally identified at varying spatial scales, the encompassing tributary HUC-10 watersheds were used to substantiate the performance of the selected threshold compared to other candidate water capacity metrics included in Appendix H and I. A list of 19 out of 28 sensitive watersheds were identified within tributary HUC-10 watersheds, which could be used for comparison. An assessment was performed ranking watersheds based on lowest estimated water availability according to the selected water capacity threshold and the other candidate metrics. The watersheds with the 19 lowest ranked water availability estimates were examined to assess overlap with the 19 sensitive watersheds. The results are summarized in Table 15. It can be seen that the selected water capacity metric of 10-year baseflow minus September P75/P95 flow identified more HUC-10 watersheds containing sensitive areas than the other candidate metrics. These results further emphasize the suitability of the selected water capacity threshold for assessing water availability for Basin watersheds.

Table 15. Performance of Water Capacity Metrics in Identifying Lowest Water Availability for HUC-10 Watersheds Containing Sensitive Areas

HUC-10 Watershed	BF10	BF10 - Sep. P75/95	Sep. P50 - Sep P75/95	ELOHA
Sugar Creek				✓
Catawissa Creek				
Anderson Creek			✓	
Spring Creek		✓	✓	
Upper Frankstown Branch Juniata River				
Beaverdam Branch			✓	
Spruce Creek		✓	✓	
Yellow Breeches Creek				
Upper Swatara Creek				
Little Swatara Creek				
Quittapahilla Creek		✓		✓
South Branch Conewago Creek	✓	✓	✓	✓
Bermudian Creek				
Little Conewago Creek	✓	✓		✓
South Branch Codorus Creek	✓	✓	✓	✓
Chiques Creek		✓		
Cocalico Creek				
Little Conestoga Creek	✓	✓	✓	
Deer Creek		✓		

5.2 Baseline 2014 Water Availability for HUC-10 Watersheds

Figure 14 illustrates water availability for HUC-10 watersheds in the Basin based on total 2014 approved CU. As such, results reflected a worst case scenario in which all CU projects were operating simultaneously at their peak limits, without consideration of water supply storage or mitigation measures. Tabular data are also summarized in Appendix D. Results were also representative of calculations performed at HUC-10 pour point locations and should not be construed as representative of uniform conditions throughout each respective watershed.



NOTE: Total approved CU includes regulated and estimated water use. Water availabilities are a result of hydrologic analyses performed at HUC-10 watershed pour point locations. As such, water availability classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of an evenly distributed water availability across the entire watershed. Sept. P75 will be used for ARC 1-3 streams and Sept. P95 for ARC 4-6 streams.

SOURCE: Water Use: SRBC, PADEP, NYSDOH, NYSDEC, MDE; Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (3651) 07-06-2016

Figure 14. Water Availability Expressed as Water Capacity Minus Total 2014 Approved CU for HUC-10 Watershed Pour Points

As anticipated, availability was highest for watersheds drained by mainstem rivers and major tributaries, which also exhibited the greatest water capacity. Water availability by subbasin pour point is outlined in Table 16. Water availability for the Basin was assessed at 3,336.4 mgd, and was most significant in the Middle Susquehanna (1,558.1 mgd) trailed by the West Branch Susquehanna (1,164.4 mgd) and Upper Susquehanna (922.9 mgd) subbasins. The Middle Susquehanna and West Branch Susquehanna subbasins were also noted as having the highest water capacity. Availability per unit area was greatest for the Upper Susquehanna (0.19 mgd/mi^2) and West Branch Susquehanna (0.17 mgd/mi^2) subbasins.

Table 16. Water Availability for Subbasin Pour Points Based on Water Capacity Minus Total 2014 Approved CU

Map ID	Subbasin Name	DA (mi^2)	Water Availability (mgd)
A	Upper Susquehanna	4,945.0	922.9
B	Chemung	2,595.5	210.1
C	Middle Susquehanna	11,310.5	1,558.1
D	West Branch Susquehanna	6,978.7	1,164.4
E	Juniata	3,403.5	407.5
F	Lower Susquehanna	27,501.7	3,336.4

Water availability was lowest for the Chemung subbasin (210.1 mgd), which was influenced by low water capacity relative to other subbasins, despite also having low total approved and reported CU (37.4 mgd and 12.4 mgd, respectively). Although this study has provided fully cumulative pour point based results, an examination of the Lower Susquehanna subbasin without upstream influences was desired for comparison with other subbasins due to the large population and dense clustering of existing water withdrawals. Total approved CU, water capacity, and resultant water availability for this area was 623.4 mgd, 829.8 mgd, and 206.4 mgd, respectively. Since more than 60 percent of the total approved CU occurred in this subbasin, coupled with a relatively low water capacity, it was not surprising that such a low water availability per unit area (0.04 mgd/mi^2) existed for the Lower Susquehanna subbasin. This scenario result was calculated quickly by simply removing upstream CU and capacity and should be treated as such. It should be noted that water capacity is a direct result of upstream drainage area influences and, accordingly, most large water users in this region, totaling 411.8 mgd (66 percent), were located along the mainstem Susquehanna River.

Water availability was more than 10 mgd for 140 of 170 (82 percent) HUC-10 watersheds and more than 25 mgd for 91 of 170 (54 percent) watersheds, considering total approved CU. Tributary watersheds with the highest availabilities included Lower Chenango River (341.5 mgd), Sinnemahoning Creek (221.5 mgd), Lower Pine Creek (188.1 mgd), Tioughnioga River (162.0 mgd), and Unadilla River (133.4 mgd), Lower Loyalsock Creek (117.9 mgd), Penns Creek (103.6 mgd), and Bald Eagle Creek (102.1 mgd). Greater water availabilities for these watersheds were influenced by larger drainage areas, higher water capacity, and relatively minor or moderate amounts of total approved and reported CU. The results suggested that these relatively larger, less developed tributary watersheds had water availabilities more suitable for accommodating additional, sustainable water resources development in contrast to smaller HUC-10 watersheds in the Basin.

Water availability was less than 10 mgd for 30 of 170 (18 percent) HUC-10 watersheds and less than 5 mgd for 15 of 170 (9 percent) watersheds. Table 17 includes tributary HUC-10 watershed pour points with the lowest water availability. The lowest availabilities were generally linked with smaller, headwater watersheds typically less than 150 square miles. The bulk of the watersheds with availability less than 5 mgd are located in the Lower Susquehanna subbasin (12 of 15, 80 percent). These results were notable since existing and projected CU quantities were found to be greatest for watersheds in the Lower Susquehanna subbasin. Water availability was estimated to be less than or equal to 0 mgd for the Octoraro Creek (-6.7 mgd), Little Conestoga Creek (-5.2 mgd), Quittapahilla Creek (-4.5 mgd), South Branch Conewago Creek (-4.1 mgd), and Deep Creek (-3.0 mgd) Watersheds. Water availability in Octoraro Creek was heavily influenced by a 30 mgd PWS out-of-basin diversion which was considered fully consumptive. Limited water availability in the Little Conestoga Creek Watershed was driven by low water capacity (0.0 mgd) and numerous smaller CU projects. For the Quittapahilla Creek Watershed, limited availability was a function of low water capacity, a diversion for PPL Ironwood, and numerous smaller CU projects. In South Branch Conewago Creek, low availability was influenced by the Borough of Hanover's diversion of water out of the local watershed. Low water availability in Deep Creek Watershed resulted from CU associated with the Sterman Masser and Huntsinger Farms regional irrigation system operations.

Table 17. Tributary HUC-10 Watershed Pour Points with Lowest Water Availability Based on Water Capacity Minus Total 2014 Approved CU

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	Water Availability (mgd)
1	Octoraro Creek	0205030615	210.3	-6.7
2	Little Conestoga Creek	0205030610	65.5	-5.2
3	Quittapahilla Creek	0205030508	77.3	-4.5
4	South Branch Conewago Creek	0205030601	73.5	-4.1
5	Deep Creek	0205030107	77.0	-3.0
6	Spring Creek	0205020401	146.0	0.4
7	Muddy Creek	0205030613	138.4	0.7
8	South Branch Codorus Creek	0205030606	116.8	1.3
9	East Branch Octoraro Creek	0205030614	90.7	3.0
10	Deer Creek	0205030616	171.0	3.1

Water availability ranged from approximately 0.003 to 0.033 mgd/square mile for the other watersheds listed in Table 17. Several watersheds with drainage areas greater than 100 square miles were listed, including Spring Creek, Muddy Creek, South Branch Codorus Creek, and Deer Creek. Sections of these watersheds contained carbonate bedrock, which often yields higher baseflows and more gently sloping flow duration curves. As such, the low flow margin for these systems was often abridged, resulting in lower estimates of water capacity based on the selected threshold, which can be inadequate for satisfying moderate CU. Low water availability in the Spring Creek Watershed was also influenced by the State College, Borough of Bellefonte, and Pennsylvania State University water supply systems. In Muddy Creek Watershed, limited availability resulted from a combination of low water capacity and estimated agricultural and self-supplied residential CU. Low water availability in South Branch Codorus Creek Watershed was influenced by York Water Company's public water supply system. For Deer Creek Watershed, limited availability was driven by the City of Aberdeen's public water supply system.

5.3 Baseline 2014 Water Availability for Focus Watersheds

The water availability results presented in the previous section reflected analyses performed at the HUC-10 watershed scale. As mentioned previously, the results were representative of calculations performed at HUC-10 pour point locations and should not be construed as representative of uniform conditions throughout each respective watershed. This spatial scale constraint could mask conditions in which water availability was significantly limited for a specific area within a HUC-10 watershed, while the overall results suggested surplus water availability. On the other hand, the results for a HUC-10 watershed could indicate water availability as severely limited, while concentrated water use in an isolated subwatershed was driving the results and water availability was substantial in all other subwatersheds. The potential for these situations prompted an in-depth, finer scale evaluation for a select set of focus watersheds.

The focus watersheds (South Branch Conewago Creek, Halter Creek, and Meshoppen Creek Watersheds) were chosen in an attempt to compare water availability results to previous studies and/or areas of concern. Water use, capacity, and availability were examined at five pour points in each focus watershed based on total approved and reported CU. More detailed information regarding the focus watersheds analysis, including an evaluation of the performance of the other candidate water capacity metrics, is included in Appendix J.

5.3.1 South Branch Conewago Creek Watershed

The South Branch Conewago Creek Watershed (HUC-10 ID 0205030601), located in Adams and York Counties, Pennsylvania, and Carroll County, Maryland, was selected as a focus watershed since it is almost entirely covered by both the Hanover Area PSA and the Bonneauville Shale Belt WCA as defined in the Commission’s Groundwater Management Plan (SRBC, 2005). The watershed was also examined in 2010 by PADEP as part of the Pennsylvania State Water Plan update, when it was selected for data verification. Although the results of that effort suggested that the watershed be prioritized for consideration as a CWPA, it has not been given that official designation to date.

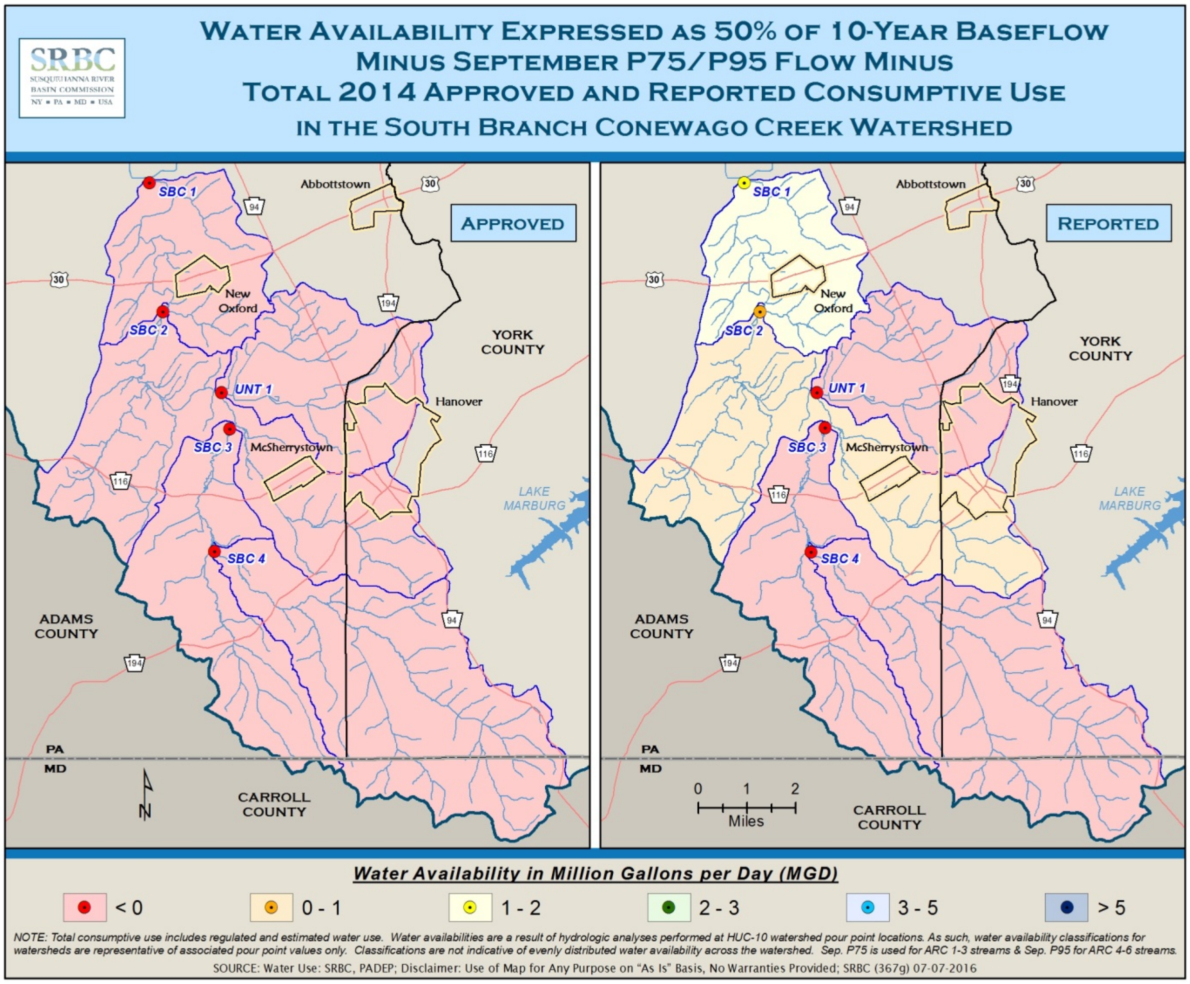
Approved CU in the South Branch Conewago Creek Watershed totaled 11.0 mgd, with reported CU accounting for less than half at 5.6 mgd. Estimated agriculture and self-supplied residential CU accounted for an additional 0.3 mgd. Public water suppliers were responsible for 94 percent of the CU, with food processing and golf course irrigation making up the remaining 6 percent. The CU total was elevated due to the Borough of Hanover surface water withdrawals that entailed diversions out of the watershed and were thus considered 100 percent consumptive.

Water capacity for the South Branch Conewago Creek subwatersheds was estimated using the regression equations developed as part of this study. The watershed was in the non-glaciated region of the Basin and contained streams with ARC segments ranging from 1 to 3, thus incorporating September P75 as the lower margin boundary for the selected water capacity threshold. The geology of the watershed consisted of folded sandstones and shales in the north, carbonate rocks through the central portion, and metamorphic rocks in the south. Two physiographic sections split the watershed, with the piedmont lowlands in the north and the piedmont uplands in the south. Compared to overall Basin watershed characteristic ranges, soils had a higher clay content, average thickness and erodibility factor, and low permeability. Urban development was high at more than 10 percent of the land use, with higher concentrations surrounding Hanover in the east and New Oxford in the north.

Water availability in the South Branch Conewago Creek Watershed was heavily influenced by the Borough of Hanover withdrawals that existed in subwatersheds SBC 4 and UNT 1, and by the Bonneauville Shale Belt WCA, which limited recharge in the watershed. Water availability results based on total approved CU showed a negative balance for each of the five subwatersheds evaluated (Table 18). The availability results were similar when considering total reported CU (Figure 15). Although subwatersheds SBC1 and SBC2 showed gaining water availability, it was only a very slight change. The analysis produced results, similar to PADEP's findings and the Commission's PSA and WCA determinations within the watershed, further validates the appropriateness of the selected water capacity threshold for identifying stressed or critical watersheds.

Table 18. Total 2014 Approved and Reported CU, Water Capacity and Water Availability for South Branch Conewago Creek Watershed

Map ID	Approved CU (mgd)	Reported CU (mgd)	Water Capacity (mgd)	Water Availability With Approved CU (mgd)	Water Availability With Reported CU (mgd)
SBC1	11.3	5.9	7.2	-4.1	1.3
SBC2	10.7	5.7	6.4	-4.3	0.7
SBC3	10.5	5.5	4.0	-6.5	-1.5
SBC4	10.4	5.5	2.9	-7.5	-2.6
UNT1	4.8	1.4	0.7	-4.1	-0.7



NOTE: Total consumptive use includes regulated and estimated water use. Water availabilities are a result of hydrologic analyses performed at HUC-10 watershed pour point locations. As such, water availability classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of evenly distributed water availability across the watershed. Sep. P75 is used for ARC 1-3 streams & Sep. P95 for ARC 4-6 streams.

SOURCE: Water Use: SRBC, PADEP; Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (367g) 07-07-2016

Figure 15. Water Availability Expressed as Water Capacity Minus Total 2014 Approved and Reported CU in the South Branch Conewago Creek Watershed

5.3.2 Halter Creek Watershed

Halter Creek Watershed (HUC-10 ID 0205030201), located in Bedford and Blair Counties, Pennsylvania, was selected as a focus watershed due to the presence of the Roaring Spring Area PSA identified in the Commission's Groundwater Management Plan (SRBC, 2005). Additionally, the findings of the Commission's Morrison Cove Water Resources Availability Study (SRBC, 2011) indicated that water use in the Halter Creek Watershed exceeded water availability on a sustainable basis.

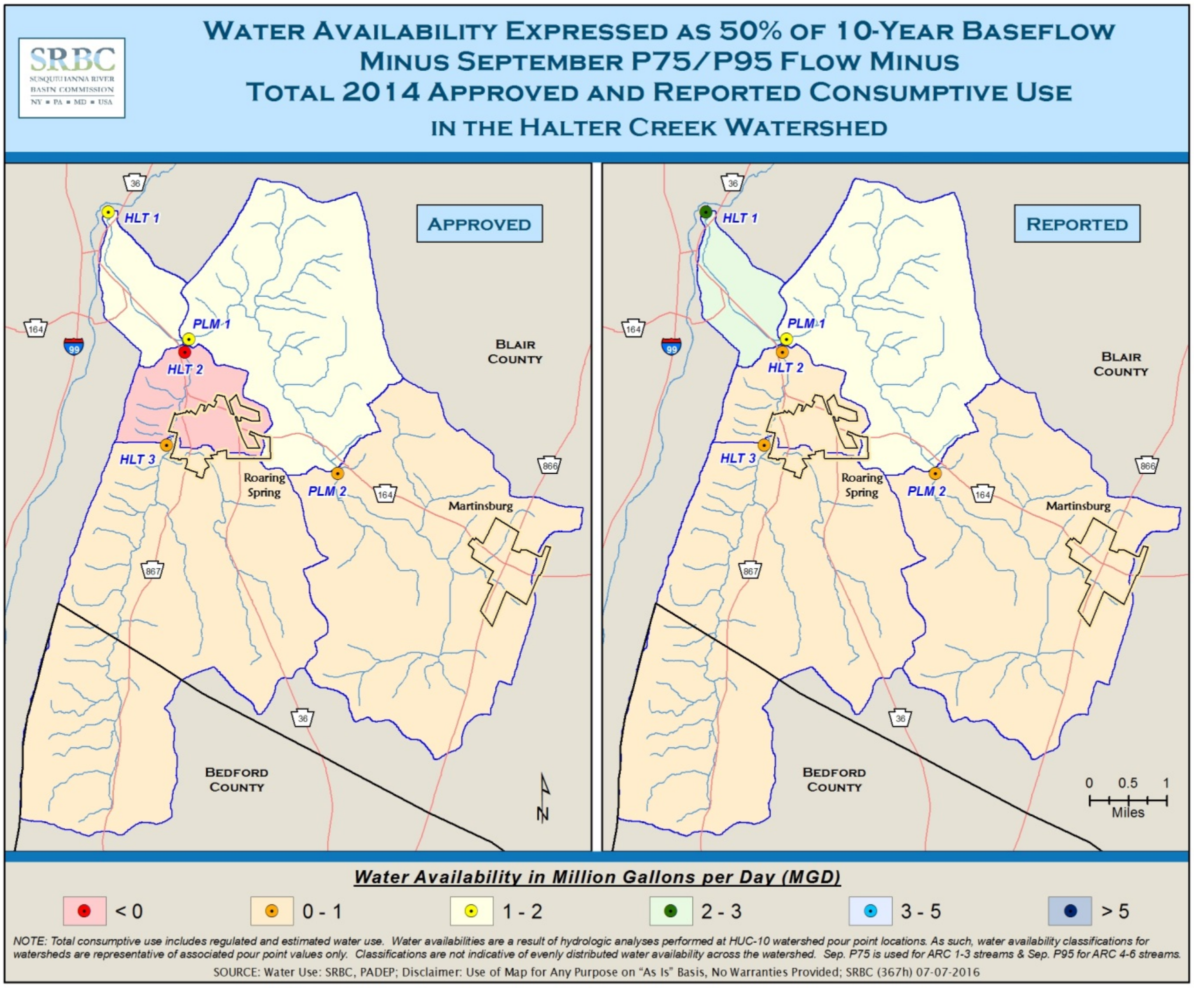
Approved CU in the Halter Creek Watershed totaled 1.2 mgd, with total reported CU accounting for less than 20 percent at 0.3 mgd. Estimated agricultural and self-supplied residential CU accounted for an additional 0.2 mgd. The breakdown of CU by sector included manufacturing at 50 percent, golf courses at 22 percent, mining at 17 percent, and public water supplies at 11 percent. Although the amount of CU varied by sector, the withdrawal locations in the watershed were concentrated with over half of the water use being withdrawn from the Roaring Spring. The three other primary withdrawal locations included a quarry near the confluence of Plum Creek and Halter Creek, a series of springs in the Plum Creek headwaters, and a golf course in the Halter Creek headwaters.

Water capacity in the Halter Creek Watershed was estimated using the regression equations developed during the study. This watershed was also non-glaciated and contained streams with ARC segments 1 to 3, therefore integrating September P75 as the lower margin boundary for the selected water capacity threshold. The geology consisted of folded sandstones and shales in the higher elevations along the watershed boundary and carbonate rocks in the valley. The entire watershed was located within the Valley and Ridge physiographic province, Middle section. Compared to overall Basin soil ranges, soils within the watershed had a high thickness and clay content with an average permeability and a low erodibility factor. Urban development was above average, accounting for 8 percent of the land use with higher concentrations surrounding Roaring Spring in the west and Martinsburg in the east.

Water availability in the Halter Creek Watershed was predominantly influenced by concentrated withdrawal locations. Availability in the watershed was limited considering total approved CU (Table 19). Figure 16 depicts little water availability for the watershed, though slight gains can be observed moving downstream in the system. These results supported the Commission's Roaring Spring Area PSA determination and the Morrison Cove Study findings of unsustainable water availability, specifically in the Halter Creek Watershed. This outcome further validated the appropriateness of the selected water capacity threshold for detecting sensitive water availability areas.

Table 19. Total 2014 Approved and Reported CU, Water Capacity and Water Availability for Halter Creek Watershed

MAP ID	Approved CU (mgd)	Reported CU (mgd)	Water Capacity (mgd)	Water Availability With Approved CU (mgd)	Water Availability With Reported CU (mgd)
HLT1	1.4	0.4	3.0	1.6	2.6
HLT2	1.2	0.3	0.5	-0.7	0.2
HLT3	0.3	0.1	0.9	0.6	0.7
PLM1	0.4	0.2	2.0	1.6	1.8
PLM2	0.1	0.1	1.0	0.9	0.9



NOTE: Total consumptive use includes regulated and estimated water use. Water availabilities are a result of hydrologic analyses performed at HUC-10 watershed pour point locations. As such, water availability classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of evenly distributed water availability across the watershed. Sep. P75 is used for ARC 1-3 streams & Sep. P95 for ARC 4-6 streams.

SOURCE: Water Use: SRBC, PADEP; Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (367h) 07-07-2016

Figure 16. Water Availability Expressed as Water Capacity Minus Total 2014 Approved and Reported CU in the Halter Creek Watershed

5.3.3 Meshoppen Creek Watershed

Meshoppen Creek Watershed (HUC-10 ID 0205010608), located in Susquehanna and Wyoming Counties, Pennsylvania, was chosen as the third focus watershed due to its proximity to natural gas development activity in the Basin. Although not studied in-depth to date with regard to water use and availability, there are water resources development concerns among the general public in watersheds supporting natural gas related withdrawals. As of 2015, there were five surface water withdrawals and one groundwater withdrawal within the watershed approved for use by the natural gas industry.

Approved CU in the Meshoppen Creek Watershed totaled 4.0 mgd, with reported CU accounting for less than half at 1.9 mgd. Estimated agricultural and self-supplied residential CU accounted for an additional 0.2 mgd. Withdrawals by the natural gas industry accounted for 99 percent of the CU in the watershed, with public water supplies representing the only other sector present at less than 1 percent. The natural gas industry surface water withdrawals were located solely along Meshoppen Creek and the groundwater withdrawal was located in the Little

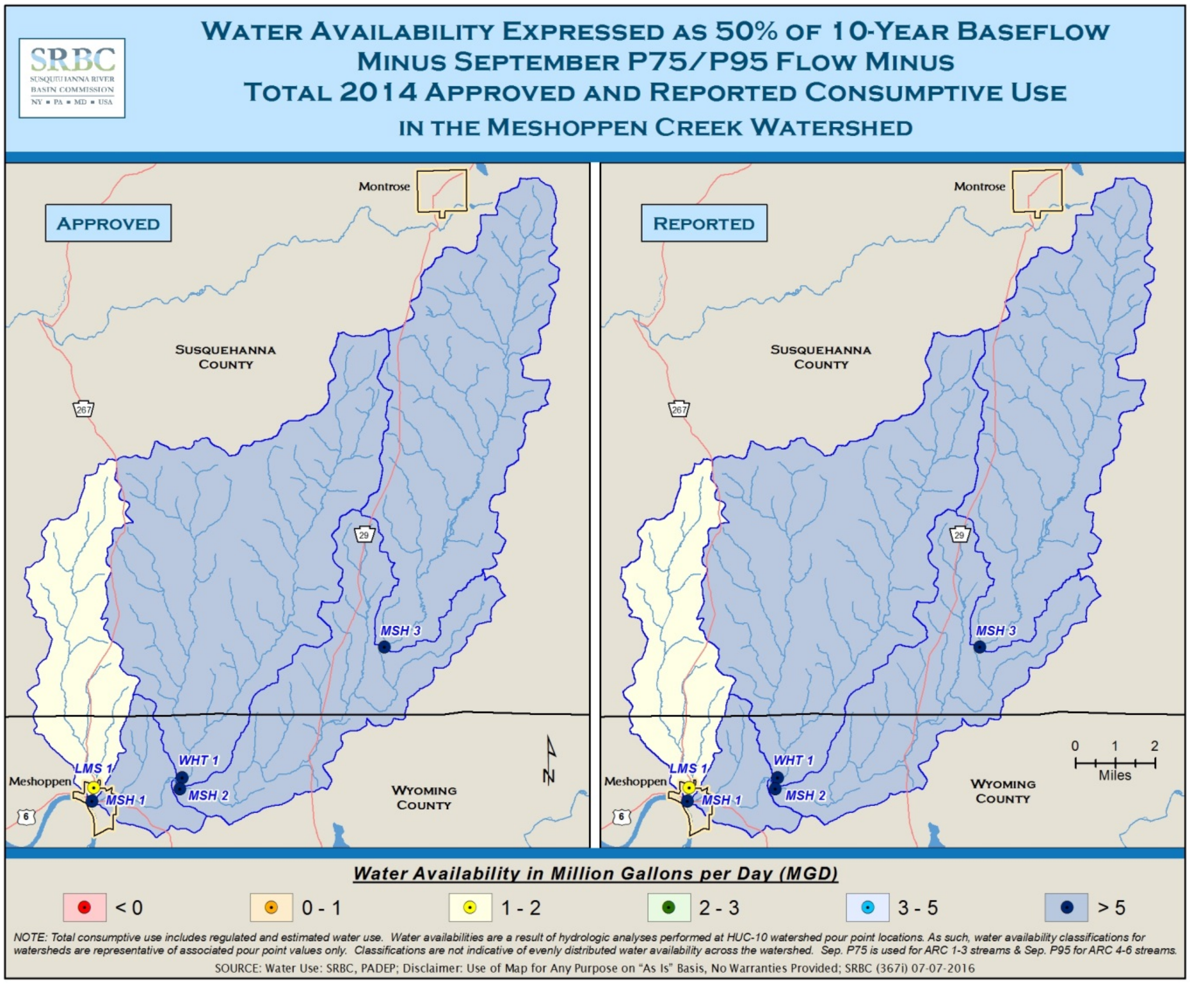
Meshoppen Creek subwatershed. Withdrawals associated with natural gas extraction operations were considered 100 percent consumptively used.

Water capacity in the Meshoppen Creek Watershed was determined based on the regression equations developed as part of the study. This watershed was located in the glaciated region of the Basin and contained streams with ARC segments ranging from 1 to 3, hence incorporating September P75 as the lower margin boundary for the selected water capacity threshold. The watershed was entirely comprised of flat sandstone geology and fully in the Appalachian Plateaus physiographic province, Southern New York section. Compared to overall Basin soil ranges, watershed soils had an average thickness, clay content, and erodibility factor, with very low permeability. Urban development was very low at less than one percent of the land use influenced by the Borough of Meshoppen, which is located at the mouth of the watershed.

Water availability in the Meshoppen Creek Watershed was analyzed due to the presence of approved water withdrawals by the natural gas industry. The watershed was predominantly undeveloped and generally had higher water capacities than the focus watersheds described earlier (Table 20). Results based on total approved and reported CU showed ample water availability for Meshoppen Creek subwatersheds (Table 20). Figure 17 shows vastly different water availability results compared to the other focus watersheds evaluated. Availability appeared to be sustainable throughout the Meshoppen Creek Watershed. Furthermore, during P95 passby flow conditions, all five natural gas industry surface water withdrawals were required to cease operations, which effectively reduced water use by 3.8 mgd. These existing passby flow requirements associated with approved withdrawals further ensures sustainable water availability during critical low flow periods.

Table 20. Total 2014 Approved and Reported CU, Water Capacity and Water Availability for Meshoppen Creek Watershed

MAP ID	Approved CU (mgd)	Reported CU (mgd)	Water Capacity (mgd)	Water Availability With Approved CU (mgd)	Water Availability With Reported CU (mgd)
MSH1	4.2	2.1	18.9	14.7	16.9
MSH2	3.7	1.7	9.2	5.5	7.5
MSH3	1.0	0.6	6.1	5.1	5.5
LMS1	0.2	0.2	1.9	1.7	1.7
WHT1	0.1	0.1	6.6	6.5	6.5



NOTE: Total consumptive use includes regulated and estimated water use. Water availabilities are a result of hydrologic analyses performed at HUC-10 watershed pour point locations. As such, water availability classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of evenly distributed water availability across the watershed. Sep. P75 is used for ARC 1-3 streams & Sep. P95 for ARC 4-6 streams.

SOURCE: Water Use: SRBC, PADEP; Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (367i) 07-07-2016

Figure 17. Water Availability Expressed as Water Capacity Minus Total 2014 Approved and Reported CU in the Meshoppen Creek Watershed

5.4 Projected 2030 Water Availability for HUC-10 Watersheds

Projections of future water use in the Basin were developed to provide insight into prospective water availability conditions and potential management actions that could be taken to avoid imminent water supply and demand conflicts. Water availability based on total projected 2030 approved CU for the Basin was 3,167.9 mgd, down from 3,336.4 mgd in 2014. Figure 18 depicts water availability for HUC-10 watersheds in the Basin based on total 2030 approved CU. The most considerable decreases in water availability for the Basin were attributed primarily to projected increases in PWS and the cumulative effects of projected natural gas-related withdrawals. As noted in Section 2.5.2, approved CU for these sectors were projected to grow by 20 percent and 47 percent, respectively, by 2030. Projected water availability was less than 2014 results for all subbasin pour points, due to increases in total approved CU. However, none of the subbasins experienced a reduction greater than 5 percent (Table 21). At the HUC-10 watershed scale, projected water availability results were not significantly different than water availability in 2014. The ten HUC-10 watersheds that illustrated the lowest projected water availability (Table 22) were the same watersheds provided in Table 17 in Section 5.2.1. Of these watersheds, Octoraro Creek (-14.9 mgd), South Branch Conewago Creek (-6.7 mgd), Little

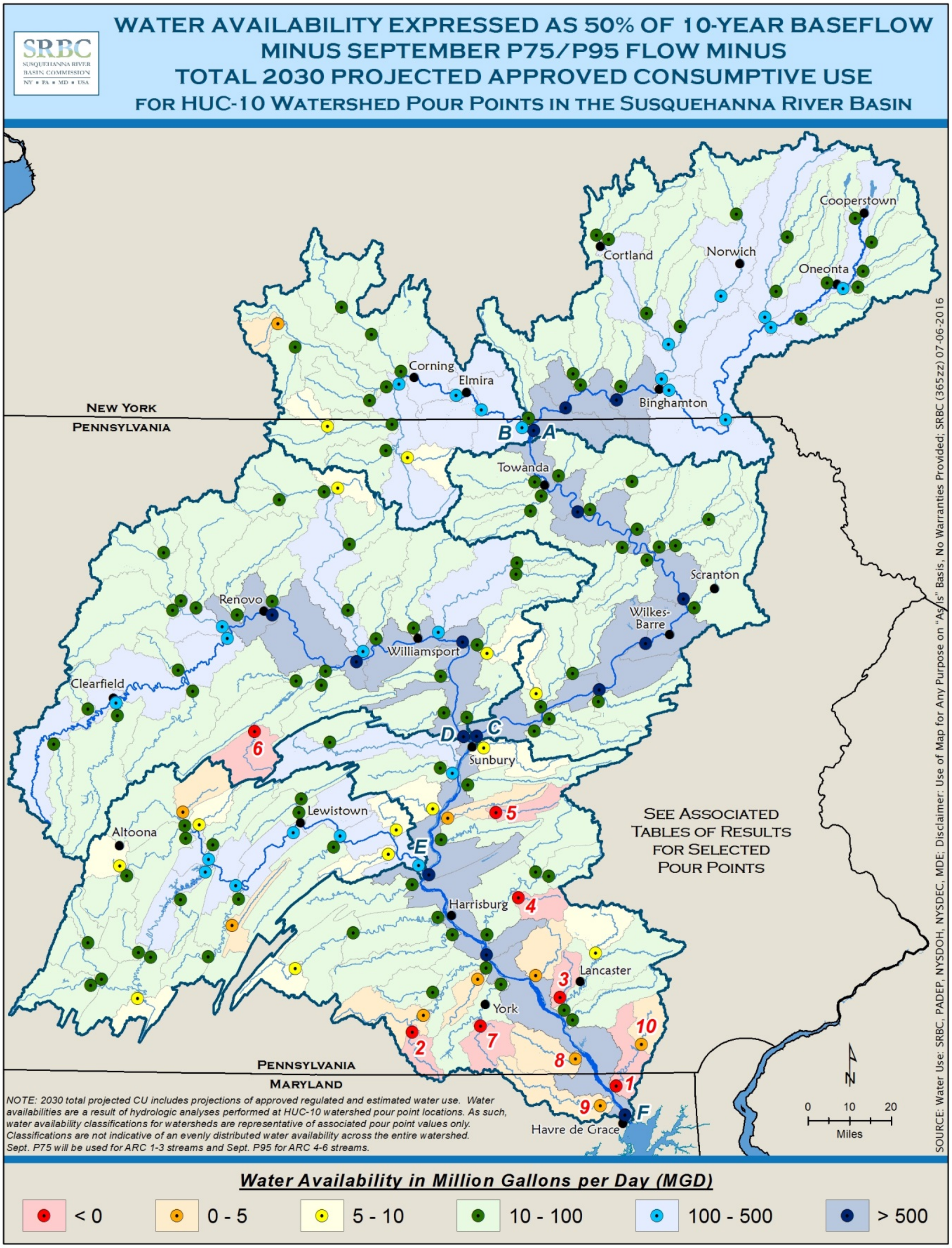
Conestoga Creek (-6.1 mgd), Quittapahilla Creek (-5.1 mgd), Deep Creek (-2.7 mgd), Spring Creek (-1.9 mgd), and South Branch Codorus Creek (-0.2 mgd) were projected to have negative water availability in 2030. The Octoraro Creek saw the largest reduction from present day water availability at -8.2 mgd followed by South Branch Conewago Creek at -2.6 mgd. These decreases in water availability were attributed to higher population ratios, and thus, larger PWS demands from Chester and Hanover, respectively. Deep Creek was the only watershed in Table 22 to experience a gain in water availability from 2014 to 2030, although still exhibiting a negative balance. This increase was based largely on a declining population ratio in Schuylkill County, Pennsylvania. Overall, a total of 142 of 170 HUC-10 watersheds (84 percent) saw a decrease in water availability from 2014 to 2030. Although, only 18 of 170 saw a reduction greater than 5 mgd.

Table 21. Water Availability for Subbasin Pour Points Based on Water Capacity Minus Total 2030 Projected Approved CU

Map ID	Subbasin Name	DA (mi^2)	2030 Water Availability (mgd)
A	Upper Susquehanna	4,945.0	922.6
B	Chemung	2,595.5	207.3
C	Middle Susquehanna	11,310.5	1,543.4
D	West Branch Susquehanna	6,978.7	1,139.2
E	Juniata	3,403.5	394.1
F	Lower Susquehanna	27,501.7	3,167.9

Table 22. Tributary HUC-10 Watershed Pour Points with Lowest Water Availability Based on Water Capacity Minus Total 2030 Projected Approved CU

Map ID	Subbasin Name	HUC-10 ID	DA (mi^2)	2030 Water Availability (mgd)
1	Octoraro Creek	0205030615	210.3	-14.9
2	South Branch Conewago Creek	0205030601	73.5	-6.7
3	Little Conestoga Creek	0205030610	65.5	-6.1
4	Quittapahilla Creek	0205030508	77.3	-5.1
5	Deep Creek	0205030107	77.0	-2.7
6	Spring Creek	0205020401	146.0	-1.9
7	South Branch Codorus Creek	0205030606	116.8	-0.2
8	Muddy Creek	0205030613	138.4	0.6
9	Deer Creek	0205030616	171.0	1.6
10	East Branch Octoraro Creek	0205030614	90.7	2.7



NOTE: 2030 total projected CU includes projections of approved regulated and estimated water use. Water availabilities are a result of hydrologic analyses performed at HUC-10 watershed pour point locations. As such, water availability classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of an evenly distributed water availability across the entire watershed. Sept. P75 will be used for ARC 1-3 streams and Sept. P95 for ARC 4-6 streams.

SOURCE: Water Use: SRBC, PADEP, NYSDOH, NYSDEC, MDE; Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (365zz) 07-06-2016

Figure 18. Water Availability Expressed as Water Capacity Minus Total 2030 Projected Approved CU for HUC-10 Watershed Pour Points

6.0 PROTECTION, MITIGATION AND ENHANCEMENT MEASURES

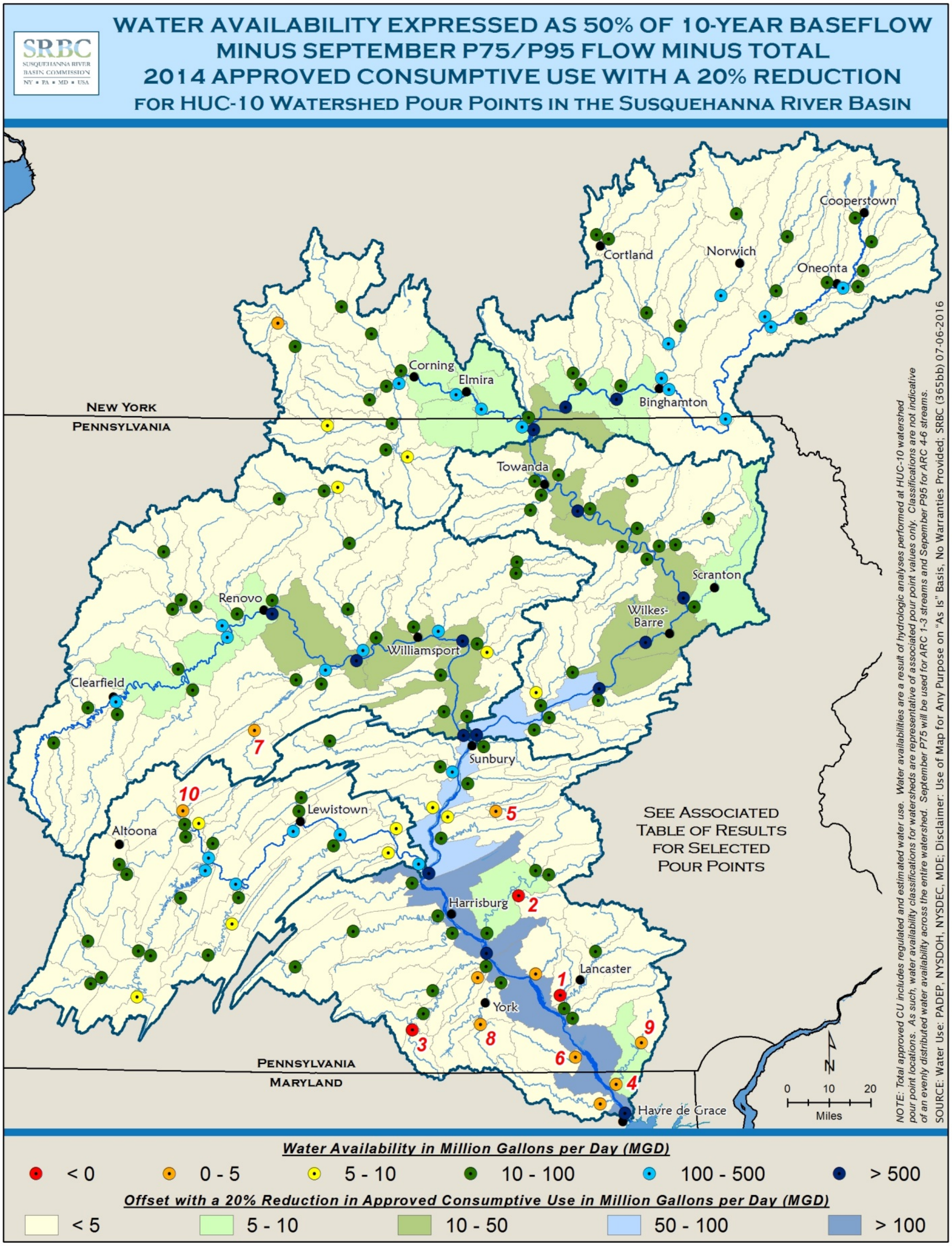
Per the standards for consumptive uses of water and water withdrawals in regulation, the Commission may deny, limit, or condition withdrawals, and require mitigation for CU to avoid significant adverse impacts to the water resources of the Basin (18 CFR §§ 806.22 and 806.23). In doing so, the Commission may consider impacts including lowering of groundwater or streamflow levels, rendering competing supplies unreliable, affecting other water uses, causing water quality degradation, affecting living resources or their habitat, causing permanent loss of aquifer storage, or affecting low flow of streams (18 C.F.R. § 806.23). The Commission may impose conditions to mitigate impacts by requiring limits on the quantity, timing or rate of withdrawal or drawdown, provision of alternate water supply or mitigating measures, special monitoring measures, stream flow protection measures, or implementation of acceptable operations plans (18 C.F.R. § 806.23(b)(3)).

As part of the study, a suite of PM&E measures was evaluated with respect to their effect on cumulative water use and availability within Basin watersheds. The ability to assess the impact of these measures was particularly important for PSAs and other regions with possible water supply and demand conflicts. The PM&E measures were developed based on objectives to avoid, minimize, or mitigate potential CU impacts to instream flow needs, water quality, and competing users. Example strategies included water use reductions, passby flows, conservation releases, CU mitigation releases, water use caps, and others.

6.1 Water Use Reductions

A water use reduction is a designated amount by which water use is lessened or diminished. This can be achieved via conservation and/or regulatory actions. As part of the review and approval of projects, the Commission may reduce withdrawal or consumptive use rates to the amount needed to meet the project's reasonable, foreseeable needs or to avoid significant adverse impacts to the water resources of the Basin. The water use reduction PM&E measure was designed to evaluate the effect of potential future water use reductions on cumulative water use and availability within Basin watersheds. Reductions can be particularly useful in evaluating alternatives for addressing water supply/demand conflicts in critical or stressed areas. The reduction may be expressed as a rate or a percentage and was applied to the total approved CU quantity computed for a specific watershed being evaluated.

Water use reductions effectively decreased the amount of CU that was input into the water availability calculations. This resulted in modified water availability for the affected watersheds, which reflected the influence of the PM&E measure. Figure 19 depicts water availability based on total 2014 approved CU with a 20 percent mandatory water use reduction that could be imposed under a drought emergency declaration in the Basin. Under this scenario, CU was reduced by 207.0 mgd Basinwide. Table 23 shows the tributary HUC-10 watersheds with the lowest availability based on approved CU with a 20 percent water use reduction. Water availability increased universally for each of the HUC-10 watersheds listed in response to the water use reductions. More significant changes in availability were noted for the Octoraro Creek and Deep Creek Watersheds, which increased by 7.1 mgd and 3.5 mgd, respectively, and no longer showed negative water availability balances.



NOTE: Total approved CU includes regulated and estimated water use. Water availabilities are a result of hydrologic analyses performed at HUC-10 watershed pour point locations. As such, water availability classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of an evenly distributed water availability across the entire watershed. September P75 will be used for ARC 1-3 streams and Sepember P95 for ARC 4-6 streams.

SOURCE: Water Use: PADEP, NYSDOH, NYSDEC, MDE; Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (365bb) 07-06-2016

Figure 19. Water Availability Expressed as Water Capacity Minus Total 2014 Approved CU with a 20 Percent Reduction for HUC-10 Watershed Pour Points

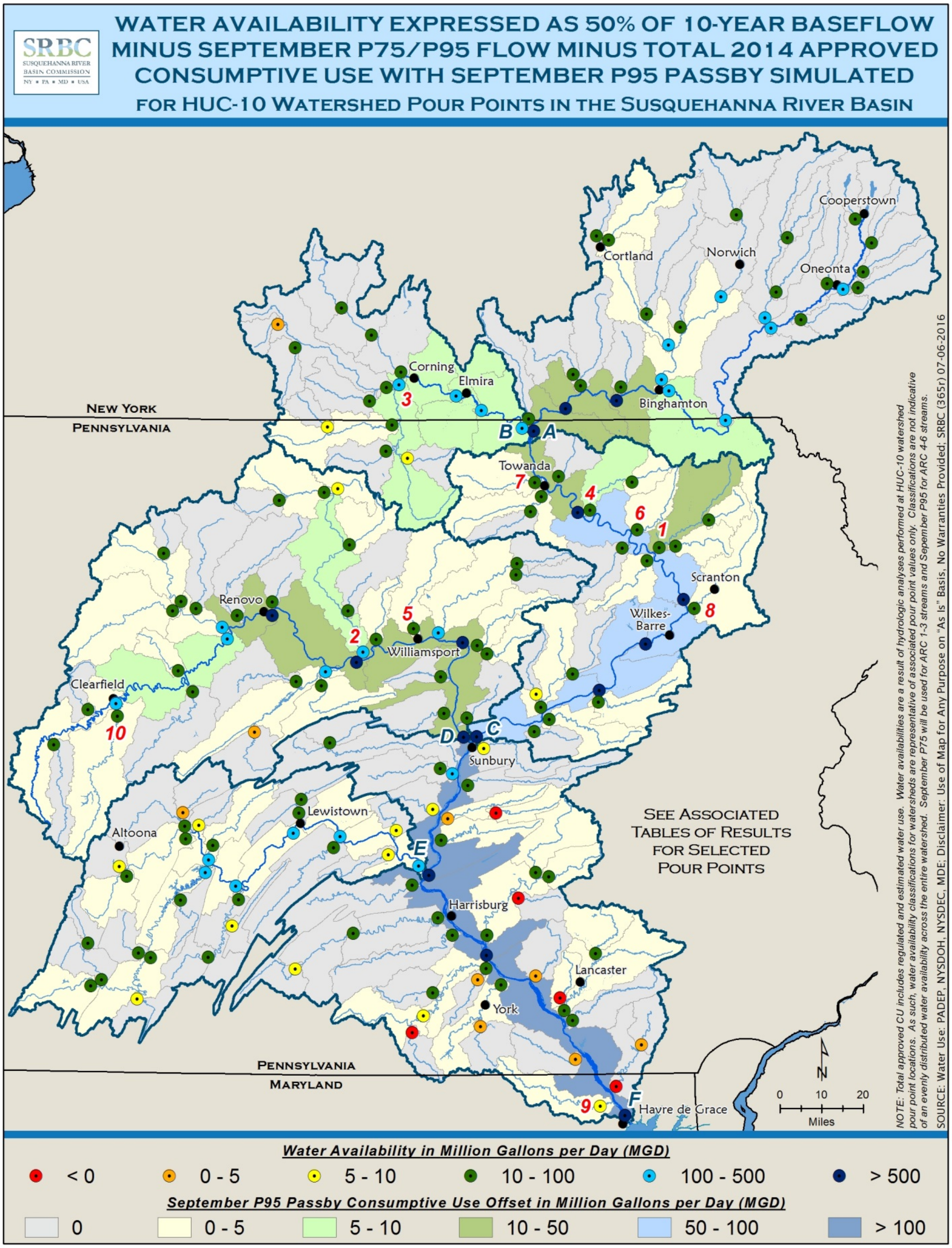
Table 23. Tributary HUC-10 Watershed Pour Points with Lowest Water Availability Based on Water Capacity Minus Total 2014 Approved CU with a 20 Percent Reduction

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	Water Availability (mgd)	Total Approved CU Offset (mgd)
1	Little Conestoga Creek	0205030610	65.5	-4.2	1.0
2	Quittapahilla Creek	0205030508	77.3	-2.9	1.7
3	South Branch Conewago Creek	0205030601	73.5	-1.8	2.3
4	Octoraro Creek	0205030615	210.3	0.4	7.1
5	Deep Creek	0205030107	77.0	0.5	3.5
6	Muddy Creek	0205030613	138.4	0.8	0.1
7	Spring Creek	0205020401	146.0	2.5	2.1
8	South Branch Codorus Creek	0205030606	116.8	2.7	1.5
9	East Branch Octoraro Creek	0205030614	90.7	3.4	0.3
10	Spruce Creek	0205030204	109.1	3.7	0.5

6.2 Passby Flows

The Commission's LFPP provides guidance for determining passby flows and conservation releases associated with water withdrawal projects. A passby flow is a prescribed streamflow at which a withdrawal must cease. The Commission uses passby flows for defining an operational limit in its approvals of water withdrawals, essentially making the withdrawal interruptible at a particular flow threshold(s) during periods of low monthly streamflow. As such, passby flows can be effective at providing instream flow protection by reducing water use during low flow conditions. The comprehensive water use database included information regarding passby flow requirements associated with Commission-approved projects. The passby flow PM&E measure was intended to assess the influence of passby flow requirements in curtailing water use during critical low flow periods, and the resultant effect on cumulative water use and availability within Basin watersheds. Based on a selected passby flow threshold, water use records with passby flow requirements of greater or equal magnitude were masked from the calculation of cumulative CU for a given watershed being evaluated.

Passby flows, based on a designated hydrologic condition, effectively eliminated a portion of the CU that was input into the water availability calculations. This rendered adjusted water availability for watersheds affected by the PM&E measure. Figure 20 shows water availability based on total 2014 approved CU with September P95 passby flows simulated. Table 24 outlines total approved CU reductions by subbasin pour point for September P95 passby flow conditions. Under this scenario, CU was reduced by 218.1 mgd Basinwide, which included 108 mgd associated with the Baltimore diversion in the Lower Susquehanna subbasin. It was also notable that total approved CU was reduced by 63.6 mgd and 36.6 mgd for the Middle Susquehanna and West Branch Susquehanna subbasins, respectively. Table 25 lists tributary HUC-10 watersheds with the highest approved CU reductions based on September P95 passby flows simulated. The majority of watersheds with the largest reductions were located in northern Pennsylvania and were driven by passby flow requirements associated with approved natural gas withdrawals. In contrast, no significant CU reductions occurred in previously identified tributary watersheds with the lowest water availability as they were comprised of projects with fewer passby flow restrictions.



NOTE: Total approved CU includes regulated and estimated water use. Water availabilities are a result of hydrologic analyses performed at HUC-10 watershed pour point locations. As such, water availability classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of an evenly distributed water availability across the entire watershed. September P75 will be used for ARC 1-3 streams and Sepember P95 for ARC 4-6 streams.

SOURCE: Water Use: PADEP, NYSDOH, NYSDEC, MDE; Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (365r) 07-06-2016

Figure 20. Water Availability Expressed as Water Capacity Minus Total 2014 Approved CU with September P95 Passby Simulated for HUC-10 Watershed Pour Points

Table 24. Total 2014 Approved CU Offsets with September P95 Passby Flows Simulated by Subbasin Pour Point

Map ID	Subbasin Name	DA (mi^2)	Total Approved CU Offset (mgd)
A	Upper Susquehanna	4,945.0	13.2
B	Chemung	2,595.5	9.2
C	Middle Susquehanna	11,310.5	63.6
D	West Branch Susquehanna	6,978.7	36.6
E	Juniata	3,403.5	1.4
F	Lower Susquehanna	27,501.7	218.1

Table 25. Tributary HUC-10 Watershed Pour Points with Highest Total 2014 Approved CU Offsets with September P95 Passby Flows Simulated

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	Total Approved CU Offset (mgd)
1	Tunkhannock Creek	0205010612	413.7	10.6
2	Lower Pine Creek	0205020506	980.7	7.7
3	Tioga River	0205010409	1,383.1	7.4
4	Wyalusing Creek	0205010607	220.1	5.6
5	Lycoming Creek	0205020602	271.9	5.0
6	Meshoppen Creek	0205010608	114.0	3.8
7	Sugar Creek	0205010601	188.1	3.4
8	Lackawanna River	0205010701	347.7	3.3
9	Deer Creek	0205030616	171.0	3.0
10	Clearfield Creek	0205020103	393.1	2.3

6.3 Conservation Releases

A conservation release is defined as a prescribed quantity of flow from an impoundment that must be continuously maintained downstream of the impoundment for low flow protection. Conservation releases are intended to prevent water quality degradation and adverse lowering of streamflow levels downstream of the impoundment, thereby protecting aquatic resources and other water uses. Conservation releases maintain specified flow requirements, not only during periods of low flow, but throughout the life of the reservoir, including periods when the reservoir is replenishing its storage during refilling. The conservation release PM&E measure was envisioned to evaluate the effect of conservation release requirements in offsetting water use during low flow periods, and the subsequent influence on cumulative water use and availability within Basin watersheds. Because conservation releases are intended to be maintained year-round, they often constitute augmentation to natural low flows. As such, they can be considered to offset water use that would be otherwise satisfied by natural low flows. Conservation releases are typically reflected as a release rate that is simulated to decrease the amount of CU factored into the water availability calculations. This results in refined water availability for the affected watershed which reflects the benefit of the PM&E measure.

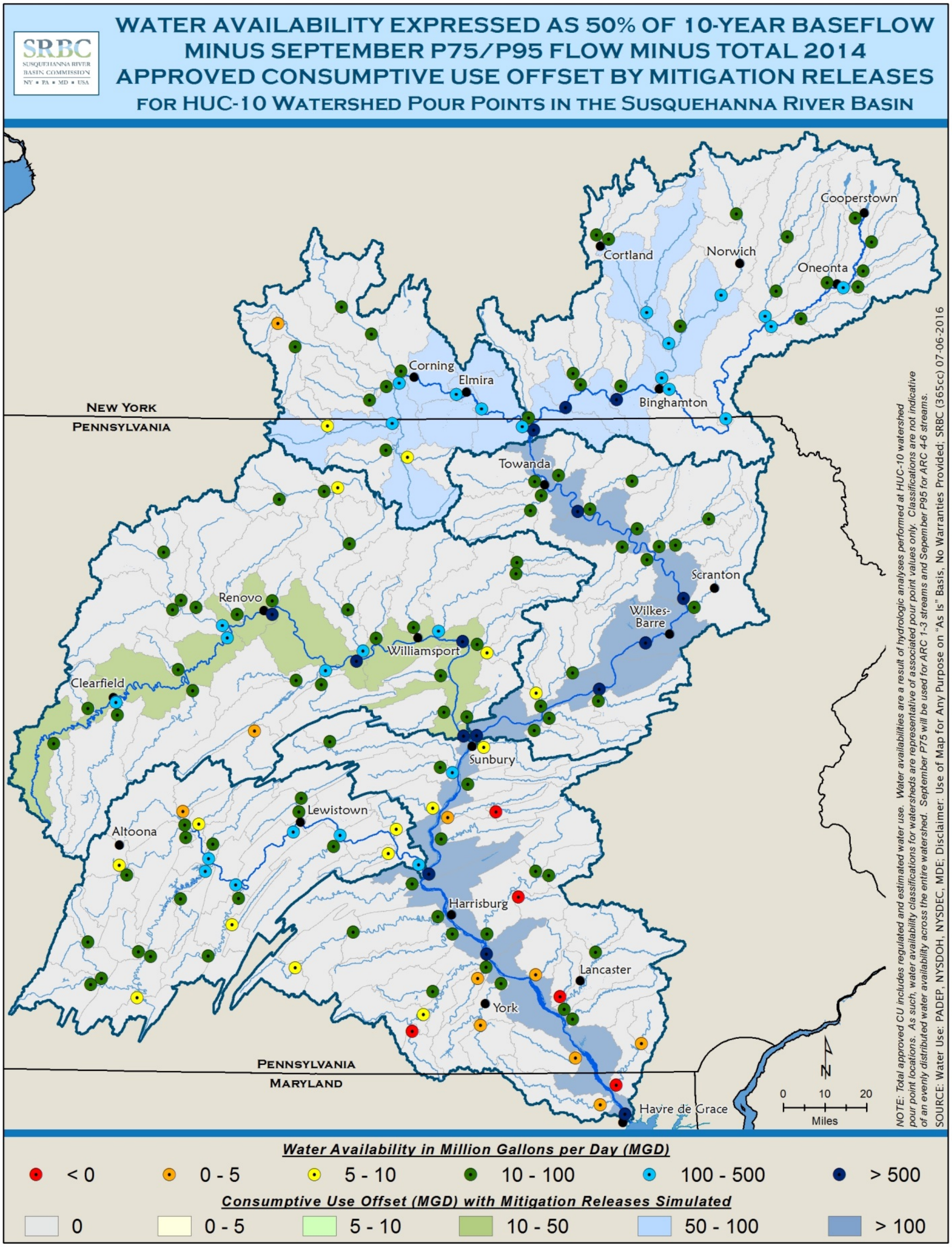
6.4 Consumptive Use Mitigation Releases

The Commission requires approved CU projects to provide mitigation for their CU during low flow periods. Mitigation may be provided by a number of methods including the release of water from storage for low flow augmentation. These releases are intended to eliminate human-influenced impacts caused by CU during low flow periods in an attempt to preserve natural low flow conditions. This insures that water is available for downstream uses, including instream uses. CU mitigation releases are not intended to maintain specific streamflow targets during low flow periods. Rather, they are intended to offset CU during those periods so as to not further aggravate low flow conditions and associated stresses. The CU mitigation release PM&E measure was designed to assess the impact of mitigation projects in offsetting CU during low flow periods, and the resultant effect on water use in the Basin. Since mitigation releases are required during low flow periods, they result in augmentation to natural flows for the purpose of offsetting CU. CU mitigation releases are expressed as a rate that effectively acts to mask an equivalent amount of CU input into the water availability calculation for an applicable watershed. Simulation of mitigation releases can be useful in evaluating the degree to which CU makeup is achieved within each of the major subbasins as well as the Basin as a whole.

The Commission has partnered on a number of CU mitigation or low flow augmentation release projects in the Basin. These include water supply storage at USACE’s Cowanesque and Curwensville Lakes, environmental releases at Whitney Point Lake, and low flow augmentation releases of treated mine pool storage at Lancashire 15 Abandoned Mine Drainage (AMD) Treatment Plant. Figure 21 shows water availability based on total 2014 approved CU with the above mentioned CU mitigation/low flow augmentation releases simulated. Under this scenario, CU was reduced by 162.8 mgd Basinwide. It was also notable that total approved CU was reduced by 64.6, 70.4, 135, and 27.8 mgd for the Upper Susquehanna, Chemung, Middle Susquehanna, and West Branch Susquehanna subbasins, respectively.

6.5 Water Use Caps

A water use cap is a designated limit on the amount of water use permissible in a given area or watershed. These caps can be employed via a temporary or permanent regulatory action. The Compact provides two potential mechanisms for implementing water use caps, including (1) determination of protected areas, and (2) declaration of a drought emergency. Regarding the former, the Commission may delineate specific areas in the Basin, where water demands have developed to the point of creating a water shortage or conflicts with the Comprehensive Plan, for designation as protected areas. For determining protected areas, the Compact states that no person shall divert or withdraw water for domestic, municipal, agricultural, or industrial uses in excess of quantities prescribed by the Commission via general regulations. During a drought, which may cause a shortage of available water supply, the Commission, in coordination with its member jurisdictions, may delineate the area of the shortage and declare a drought emergency therein. The Compact states that for the duration of the drought emergency, the Commission may direct increases or decreases in any allocations, diversions, or releases previously granted or required, for a limited time to meet the emergency condition. The Compact also states that permits shall be granted, modified, or denied, to avoid depletion of natural streamflow and groundwater in the protected area or emergency area that will impact the Comprehensive Plan or equitable water rights during a water shortage.



NOTE: Total approved CU includes regulated and estimated water use. Water availabilities are a result of hydrologic analyses performed at HUC-10 watershed pour point locations. As such, water availability classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of an evenly distributed water availability across the entire watershed. September P75 will be used for ARC 1-3 streams and Sepember P95 for ARC 4-6 streams.

SOURCE: Water Use: PADEP, NYSDOH, NYSDEC, MDE; Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (365cc) 07-06-2016

Figure 21. Water Availability Expressed as Water Capacity Minus Total 2014 Approved CU Offset by Mitigation Releases for HUC-10 Watershed Pour Points

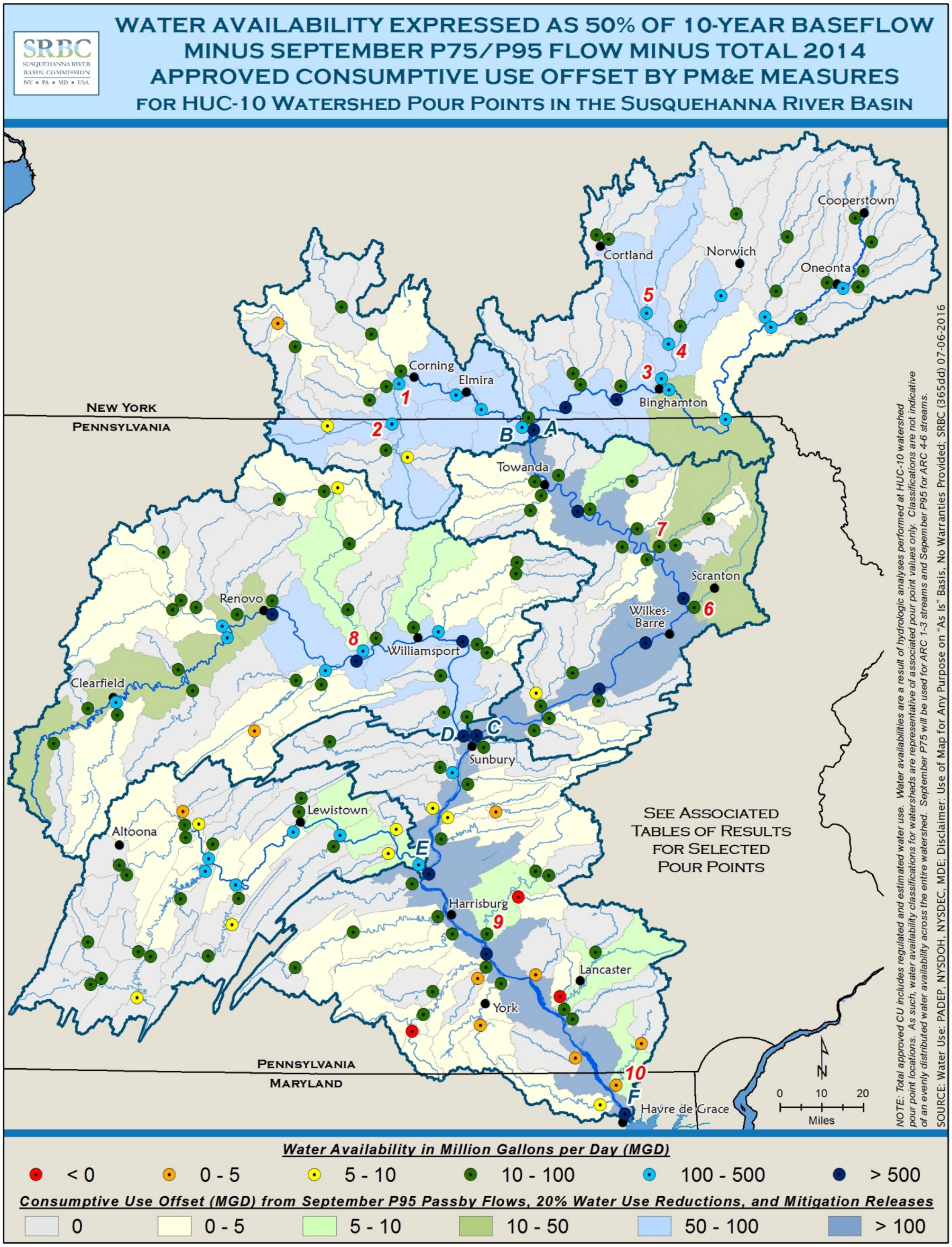
The water use cap PM&E measure was formulated to assess the effect of potential future limits on the amount of water use for a designated watershed on cumulative water use and availability for Basin watersheds. The cap may be expressed as a rate that is either greater than or less than the total approved CU quantity computed for a specific watershed being evaluated. As such, water use caps effectively increase or decrease the amount of hypothetical CU that is input into the water availability calculations. This results in adjusted water availability for the watershed that reflects the effects of the PM&E measure. Like water use reductions, water use caps can be especially useful in evaluating alternatives for addressing water supply and demand conflicts in existing stressed or critical watersheds as well as future designated protected or emergency areas.

6.6 Aggregate Effects and Future Measures

After evaluating each of the singular PM&E measures described above, the Commission sought to assess the aggregate effects of these practices on cumulative water use and availability for Basin watersheds. The combined impact of 20 percent water use reductions, September P95 passby flows, and CU mitigation releases was simulated. These results are depicted in Figure 22. The map indicates that there were CU reductions and/or offsets occurring throughout the Basin, with over 100 mgd of CU offsets in mainstem Susquehanna River HUC-10 watersheds from the New York state line to the mouth of the Basin. Table 26 summarizes results by subbasin pour point. Substantial CU offsets were noted for the Basin (544.2 mgd) and the Middle Susquehanna subbasin (238.4 mgd), whereas only marginal CU offsets (5.8 mgd) were observed in the Juniata subbasin. Table 27 lists the tributary HUC-10 watershed pour points with the highest total CU offsets resulting from simulation of the combination of PM&E measures. Over 60 mgd of CU offsets were identified for the Tioga River, Cowanesque River, Lower Chenango, Tioughnioga River, and Otselic River Watersheds. However, out of the 10 previously identified tributary watersheds with the lowest water availability, only Octoraro Creek had significant CU offsets, mainly due to a 20 percent water use reduction. Again, this was primarily a function of the other watersheds containing approved water use projects with fewer PM&E requirements.

Table 26. Total 2014 Approved CU Offsets with September P95 Passby Flows, 20 Percent Water Use Reductions, and Mitigation Releases Simulated by Subbasin Pour Point

Map ID	Subbasin Name	DA (mi^2)	Total CU Offsets (mgd)
A	Upper Susquehanna	4,945.0	85.8
B	Chemung	2,595.5	85.2
C	Middle Susquehanna	11,310.5	238.4
D	West Branch Susquehanna	6,978.7	82.1
E	Juniata	3,403.5	5.8
F	Lower Susquehanna	27,501.7	544.2



WATER AVAILABILITY EXPRESSED AS 50% OF 10-YEAR BASEFLOW MINUS SEPTEMBER P75/P95 FLOW MINUS TOTAL 2014 APPROVED CONSUMPTIVE USE OFFSET BY PM&E MEASURES FOR HUC-10 WATERSHED POUR POINTS IN THE SUSQUEHANNA RIVER BASIN

SEE ASSOCIATED TABLES OF RESULTS FOR SELECTED POUR POINTS

NOTE: Total approved CU includes regulated and estimated water use. Water availabilities are a result of hydrologic analyses performed at HUC-10 watershed pour point locations. As such, water availability classifications for watersheds are representative of associated pour point values only. Classifications are not indicative of an evenly distributed water availability across the entire watershed. September P75 will be used for ARC 1-3 streams and Sepember P95 for ARC 4-6 streams.

SOURCE: Water Use: PADEP, NYSDOH, NYSDEC, MDE; Disclaimer: Use of Map for Any Purpose on "As Is" Basis, No Warranties Provided; SRBC (365dd) 07-06-2016

Figure 22. Water Availability Expressed as Water Capacity Minus Total 2014 Approved CU with September P95 Passby Flows, 20 Percent Water Use Reductions, and Mitigation Releases Simulated for HUC-10 Watershed Pour Points

Table 27. Tributary HUC-10 Watershed Pour Points with Highest Total 2014 Approved CU Offsets with September P95 Passby Flows, 20 Percent Water Use Reductions, and Mitigation Releases Simulated

Map ID	Subbasin Name	HUC-10 ID	DA (mi^2)	Total CU Offsets (mgd)
1	Tioga River	0205010409	1,383.1	81.0
2	Cowanesque River	0205010408	300.6	71.8
3	Lower Chenango River	0205010208	1,610.8	69.0
4	Tioughnioga River	0205010204	764.5	67.4
5	Otselic River	0205010203	258.3	64.7
6	Lackawanna River	0205010701	347.7	11.5
7	Tunkhannock Creek	0205010612	413.7	11.0
8	Lower Pine Creek	0205020506	980.7	8.5
9	Lower Swatara Creek	0205030509	571.2	7.4
10	Octoraro Creek	0205030615	210.3	7.1

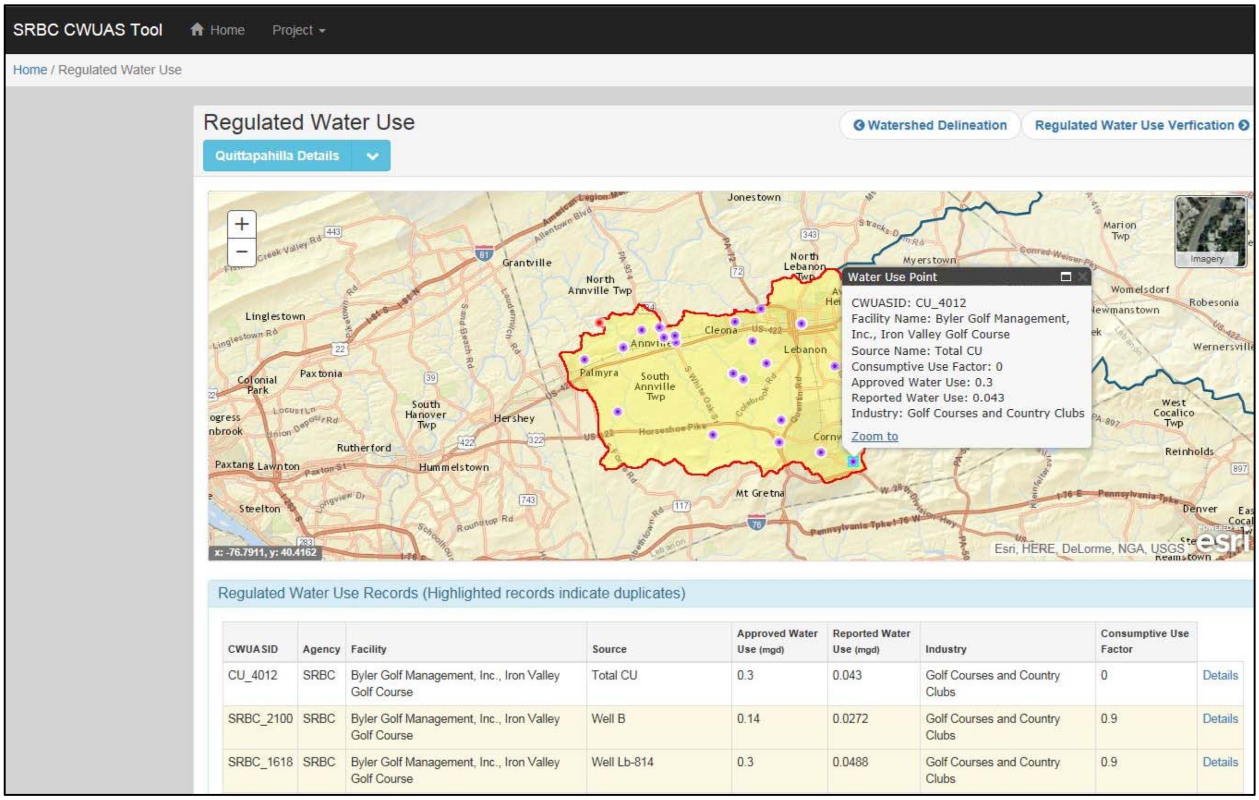
The above PM&E measures evaluated during the study were by no means the only alternatives available for addressing cumulative water use and availability concerns for Basin watersheds. It is anticipated that future work in this area will entail integration of a more comprehensive list of potential water quantity PM&E measures. These could be applied at a Basinwide or priority subwatershed scale. Additional options could include surface water storage, subsurface mine pools, aquifer storage and recovery, wetland creation, water reuse, infiltration basins/trenches, rain gardens, dry wells, infiltration filters, etc. Criteria for applicability of these other measures would focus on insuring a direct connection to water quantity improvements during low flow conditions via reductions in water use, utilization of water storage, increased groundwater recharge, and others.

7.0 PLANNING TOOLS

Two planning tools were developed to better leverage study findings and advance the applicability of the comprehensive water use database and water capacity metrics for assessing water availability throughout the Basin. It is anticipated that these study components will continue to be updated and analyzed in support of Commission regulatory and planning activities. The tools are intended to enhance interagency coordination and data sharing, inform water resources management decision making, and provide increased transparency for the regulated community, Basin stakeholders, and the general public.

7.1 Cumulative Water Use and Availability Study Tool

Commission staff developed an interactive, step-by-step, GIS-based web tool that leverages both database and geospatial functionality to estimate water use, capacity, and availability at user-defined pour point locations within the Basin (Figure 23). The CWUAS tool is intended to be used by the Commission and its member jurisdictions to inform regulatory and planning actions. The tool is envisioned to serve as a screening mechanism for identifying watersheds with existing and/or projected water availability concerns. It is also intended to aid staff during project reviews in evaluating proposed water uses versus existing cumulative CU, considering grandfathered and unregulated uses, conducting water availability analyses, determining passby flow and CU mitigation requirements, etc. Additionally, the tool is expected to guide future planning activities and studies, and inform policy decisions regarding designation and management of WCAs, PSAs, and other special protected areas in the Basin.



CWUASID: CU_4012
Facility Name: Byler Golf Management, Inc., Iron Valley Golf Course
Source Name: Total CU
Consumptive Use Factor: 0
Approved Water Use: 0.3
Reported Water Use: 0.043
Industry: Golf Courses and Country Clubs
Zoom to

Regulated Water Use Records (Highlighted records indicate duplicates)

CWUASID	Agency	Facility	Source	Approved Water Use (mgd)	Reported Water Use (mgd)	Industry	Consumptive Use Factor	
CU_4012	SRBC	Byler Golf Management, Inc., Iron Valley Golf Course	Total CU	0.3	0.043	Golf Courses and Country Clubs	0	Details
SRBC_2100	SRBC	Byler Golf Management, Inc., Iron Valley Golf Course	Well B	0.14	0.0272	Golf Courses and Country Clubs	0.9	Details
SRBC_1618	SRBC	Byler Golf Management, Inc., Iron Valley Golf Course	Well Lb-814	0.3	0.0488	Golf Courses and Country Clubs	0.9	Details

Figure 23. Screenshot of CWUAS Tool

The CWUAS Tool allows users to delineate a watershed from a defined pour point location using an ArcHydro hydrologically enforced digital elevation model (DEM) and the high resolution National Hydrography Dataset (NHD). The derived watershed is then used to select water use points from the database and extract watershed characteristics from a series of GIS data layers. Users are able to screen water use records for accuracy and make any necessary adjustments to refine cumulative CU quantities. Estimated, unregulated and projected future water use can also be calculated. The aforementioned steps rely on ArcGIS Server geoprocessing services. Next, streamflow statistics are computed using USGS stream gage data and drainage area ratio adjustments for gaged reaches, and developed regional regression equations for ungaged reaches. The four short-listed water capacity metrics, derived from the flow statistics, are then presented. Once the user selects a metric with an optional safety factor, water availability can be calculated using the following equation:

$$\textit{Water Capacity} - \textit{Water Use (CU)} = \textit{Water Availability} \tag{4}$$

Water availability results, based on both approved and reported CU, are provided. These results can be further refined by simulating various existing or potential PM&E measures, such as water use reductions, passby flows, CU mitigation releases, etc. An adjusted water availability result is then presented reflecting any simulated PM&E practices. The final step provides an option to save a detailed report documenting all data inputs and user specified selections. Individual projects initiated in the tool can be saved at any point throughout the process, and continued or edited at a later time. The tool will receive updated Commission water use records on a quarterly basis and updated member state records annually. Estimated and projected water use, streamflow statistics, watershed characteristics, regression equations, and related components will be reviewed at least every ten years.

7.2 Cumulative Water Use and Availability Study Web Map

A publically accessible, interactive web map was also developed for use by project sponsors, consultants, agencies, non-governmental organizations, academicians, etc. The tool is available among the suite of mapping applications found on the Commission website. It displays Basinwide map layers depicting approved and reported CU, water capacity, and water availability summarized by HUC-10 watershed (Figure 24). Users can select a watershed of interest and identify key attributes related to water use, capacity, and availability. The web map depicts general Basin trends, shows cumulative results, and can be used for preliminary assessments of proposed water resources development projects. The HUC-10 watershed results and information will be refreshed annually following updates to member state water use records.

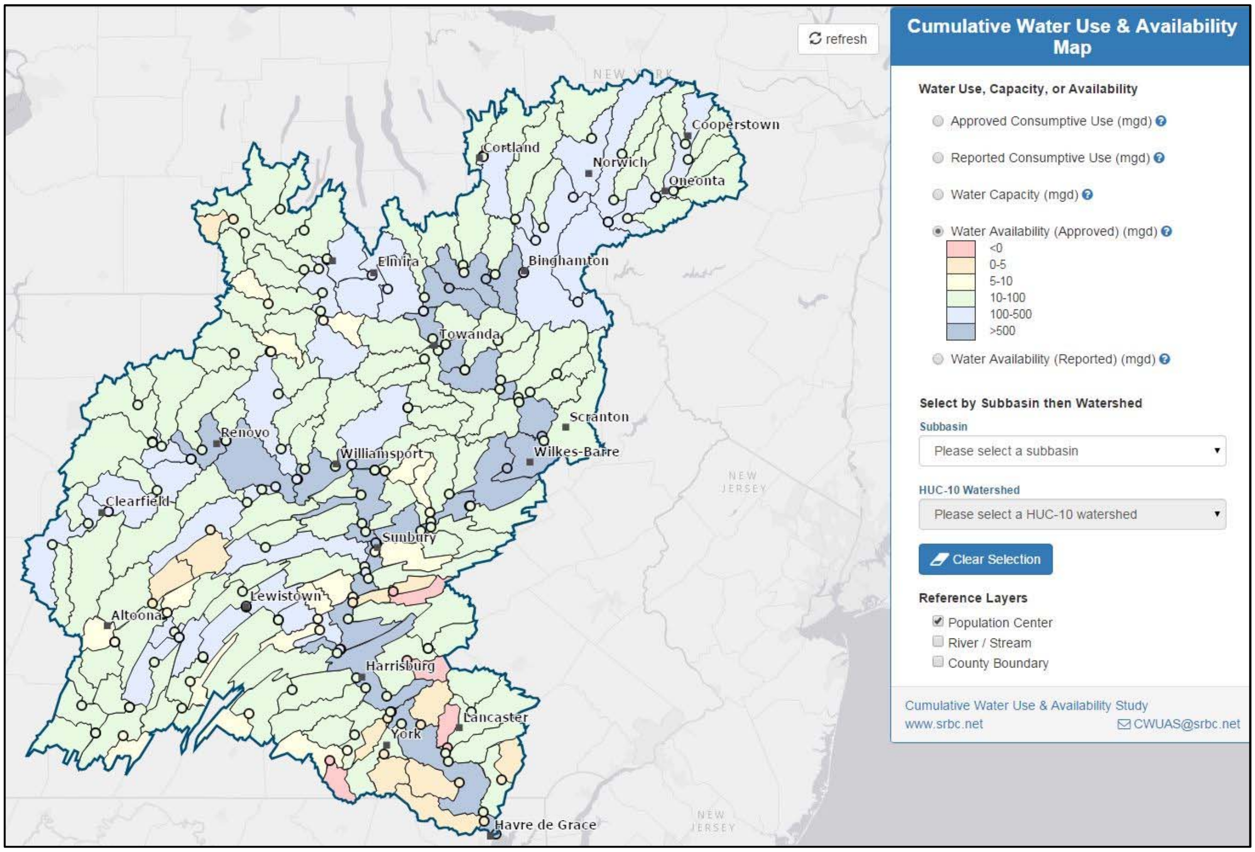


Figure 24. Screenshot of CWUAS Web Map

8.0 ASSUMPTIONS AND LIMITATIONS

When interpreting study results and contemplating management actions, it is important to consider the assumptions and limitations associated with the various input datasets and analyses performed. An overarching limitation was related to spatial scale, which focused on HUC-10 watersheds and the cumulative drainage upgradient of their respective pour points. The study results cited are only valid at specific HUC-10 watershed pour points and should not be assumed to be indicative of an evenly distributed value across an entire watershed. Furthermore, results associated with a particular pour point were influenced by the entire cumulative drainage area contributing to the watershed outlet, rather than the individual HUC-10 watershed boundary.

The comprehensive water use database integrated Commission and member state datasets, which represented five unique sources of information with different water use attributes. Data deduplication was performed based on similarities in project names and locations. Discrepancies in facility names or coordinate information could have negated identification of duplicate records and resulted in double counting of water use. The study focused on CU as the water use metric for evaluating water availability in contrast to surface water or groundwater availability analyses, which often consider storage and lag effects. Priority was given to Commission CU data, which was supplemented with Commission and member state water withdrawal records. Withdrawal data were translated to CU values by applying published CU coefficients associated with specific NAICS codes. Since not all member state databases utilized NAICS codes, state-specific industry codes were translated to NAICS codes based on best professional judgment. Additionally, a published CU coefficient for a given industry type might not adequately estimate CU for each specific facility represented within that sector.

Regulated water use data were noted to be most reliable, while additional verification is warranted to improve understanding of grandfathered, registered, and estimated uses. Approved and reported water use data were leveraged where available, with reported use substituted for missing approved values when necessary. Since the study focused on compiling CU on an annual time-step, largely based on approved quantities, the results reflected a worst case scenario in which all users were operating concurrently at full capacity. This condition, while representing a conservative estimate of CU for planning purposes, is unlikely considering demand fluctuations, seasonal uses, and back-up sources. Reported CU amounts were based on actual days used per year versus an annual average. However, since annual reporting for certain industry sectors is voluntary, reported CU data for some registered water uses could date back as far as 2003. Assumptions and limitations associated with estimated unregulated and projected water use are discussed in Appendix B and C, respectively. Projected CU based on industry trend and forecast data provided insight into future conditions, although Basin-specific shifts in water demand are dynamic and best gleaned through pre-application coordination.

Watershed boundaries were delineated using a hydrologically enforced DEM based on the high resolution NHD representing known stream locations and HUC-12 watershed high walls. Slightly varying scales/resolutions in these input datasets could produce inaccurate watersheds. Watersheds delineated upgradient of designated pour points were based on topographic drainage areas. Groundwater withdrawals and associated CU were also selected based on topographic boundaries, despite groundwater areas of contribution often not coinciding with surface drainage features. Watershed characteristics were derived from best available GIS layers for the Basin, though these data often reflected varying time periods, spatial scales, and resolutions. Basin stream segments were classified as gaged or ungaged using reference gage selection criteria and professional judgment, although project specific considerations could warrant deviations. Leveraging USGS stream gage data, and developing regional regression equations, provided a solid hydrologic framework for evaluating water capacity in gaged and ungaged watersheds. However, the drainage area ratio method assumes streamflow is the same per unit area and there are standard errors to consider regarding regression-based streamflow statistics. Watersheds affected by reservoir regulation, unique hydrogeologic features, or other anomalies require site specific hydrologic analyses for verifying water capacity.

Assessing water availability by subbasin, HUC-10 watershed, and focus watershed provided insight into the significance of spatial scale in influencing and interpreting results. Availability can vary substantially within a given watershed, particularly in settings with large water users or inter-basin diversions. Watersheds with ample water availability could contain subwatersheds that are potentially stressed, and vice versa. Since ecosystem flow recommendations were the same for flashy and high baseflow streams, and flow duration curves are flatter for the latter, smaller carbonate watersheds tended to have truncated low flow margins and, thus, more limited water capacity and availability. Because availability was calculated based on approved CU, the results represented a worst case scenario in which all water uses were occurring simultaneously at peak capability. The water availability calculations assumed CU was satisfied directly from baseflow, without consideration of storage. The safety factor applied in the selected water capacity metric added a conservative level of reserved capacity, but may need to be reassessed over time, perhaps even being varied based on watershed type or use designation. Watersheds with water availability approaching or less than zero do not necessarily imply dry stream reaches during baseflow conditions due to the conservative factors described previously. The various PM&E measures simulated during the study reflected a combination of permit and hypothetical requirements. But, they by no means reflected all of the practices in place for individual projects throughout the Basin.

9.0 CONCLUSIONS

The CWUAS represents the most comprehensive evaluation of water use and availability throughout the Basin conducted to date. Development of a comprehensive water use database, integrating Commission, member state, and estimated data, allowed staff to conduct an inclusive assessment of cumulative CU for the Basin on a HUC-10 watershed basis. The selected water capacity threshold used in calculating water availability integrated a sustainable limit for water development, protection of low flows, and a safety factor to assure short-term resource availability and long-term balance between healthy ecosystems and economic viability. The newly-developed CWUAS Tool and Web Map will be instrumental in providing users with the ability to interactively investigate water use and availability conditions for Basin watersheds. Incorporation of PM&E measures afforded the opportunity to quantify the effects of various management actions on water use and availability in the Basin.

9.1 Water Use Findings

Approved 2014 CU for the Basin aligned reasonably well with previous projections, despite recent increases attributed to natural gas development. Reported CU was typically a third less than approved CU, due to factors including intra-annual demand fluctuations, seasonal/intermittent uses, and the practice of securing redundant sources. Consistent with previous estimates, the majority of Basin CU was associated with the PWS (including diversions) and electric power generation sectors. Natural gas sector CU represented a small fraction of the Basin total, although quantities can be significant relative to the headwater settings where development has predominantly occurred. Cumulative CU was greatest in the Middle and Lower Susquehanna Subbasins, and mainstem river watersheds throughout the Basin, as a function of drainage size, population centers, large projects, and aggregate CU. Approved CU was noted to be greater than 50 mgd for only 7 percent of HUC-10 watersheds in the Basin, all of which were sub-drainages of mainstem rivers. In contrast, approved CU was estimated to be less than 5 mgd for 65 percent, and less than 1 mgd for 32 percent, of the watersheds in the Basin. These findings indicate that the majority of Basin watersheds have been subject to only moderate or minor water resources development, likely as a function of isolated settings, rugged topography, and smaller drainage sizes. As such, cumulative water use in the Basin tends to be concentrated in larger watersheds and, particularly, regions surrounding major population centers.

9.2 Water Capacity Findings

Water capacity was noted to be greatest for the Middle and Lower Susquehanna subbasins and least for the Chemung and Juniata subbasins, as a function of precipitation patterns and cumulative drainage size. Watersheds traversed by mainstem rivers and major tributaries exhibit the largest water capacities. These larger drainages possess natural yields most suited to accommodate more significant water resources development. Water capacity was found to be greater than 10 mgd for 88 percent of HUC-10 watersheds in the Basin. These results suggest that water capacity is adequate to support at least moderate water resources development for most Basin watersheds. This includes water capacity for accommodating ecosystem flow needs and reserved water capacity for unaccounted for demands during the 10-year baseflow management condition. The lowest water capacities were estimated for headwater settings with drainage areas generally less than 100 square miles. Limited water capacity in these watersheds is influenced by limited drainage sizes, relatively low mean annual precipitation, and resultant low flow yields. The majority of watersheds with the lowest water capacity are located in the Juniata and Lower Susquehanna subbasins. Many of these watersheds were underlain by carbonate bedrock, which typically produces higher baseflows and more gradually sloping flow duration curves. Consequently, the low flow margin for these systems was truncated resulting in more limited water capacity.

9.3 Water Availability Findings

Water capacity for most Basin watersheds was determined to be adequate to satisfy existing CU and avoid water demand conflicts. Water availability was found to be greater than 10 mgd for 82 percent, and greater than 25 mgd for 54 percent, of HUC-10 watersheds based on total approved CU. Many of these watersheds are drained by mainstem rivers or major tributaries in which greater water availability is driven by larger drainage sizes, more water capacity, and relatively minor or moderate CU. These systems represent the most sustainable sources of water supply in the Basin. In contrast, water availability was noted to be less than 10 mgd for 18 percent, and less than 5 mgd for 9 percent, of HUC-10 watersheds. The lowest availabilities are typically associated with headwater watersheds as a function of reduced drainage sizes and associated limited water capacity. The majority of watersheds with water availability less than 5 mgd are located in the Lower Susquehanna subbasin. These findings are noteworthy considering CU quantities were found to be greatest for more intensively developed watersheds in the lower portion of the Basin. A number of watersheds with drainage areas greater than 100 square miles were also noted as having more limited water availability. These results suggest that water management efforts should be prioritized for these collective areas to ensure future water resources development occurs in a sustainable manner.

9.4 Protection, Mitigation, and Enhancement Findings

Implementation of various PM&E measures was found to be effective in curtailing, reducing, or offsetting CU, to varying degrees, during low flow conditions. The combined influence of water use reductions, passby flows, and CU mitigation releases during simulated drought conditions resulted in over 100 mgd of CU offsets in mainstem Susquehanna River watersheds downstream of the New York state line. Significant offsets were also noted in mainstem river and major tributary watersheds downstream of USACE reservoirs in the Upper Susquehanna, Chemung, and West Branch Susquehanna subbasins. These results provide insight into the effectiveness of the Commission's CU mitigation strategy, which has traditionally focused on developing water storage or environmental improvements for making low flow augmentation releases. Several tributary HUC-10 watersheds in the northern tier of Pennsylvania and Lower Susquehanna subbasin also reflected substantial CU offsets from combined PM&E measures. This was driven by numerous natural gas withdrawals being conditioned with passby flow requirements in the upper Basin, and water use reductions associated with large PWS systems in the lower Basin. However, it was also observed that PM&E measures have not always been implemented in watersheds with the most limited water availability, which represents an opportunity for future water resources management. Furthermore, future efforts are expected to integrate a more inclusive list of prospective water quantity PM&E practices.

10.0 RECOMMENDATIONS

The methods, results, and conclusions discussed in the previous sections influenced the formulation of a set of study recommendations. The recommendations were tailored to address either (1) future improvements in evaluating cumulative water use and availability in the Basin; or (2) water resources planning and management strategies for addressing water use versus availability conflicts. They are intended to provide a guide for implementation by Commission staff, partner agencies, and other water resources professionals involved in the development, utilization, and/or management of the water resources of the Basin.

<u>Quantification of Water Use</u>

1. Verify water use and discharge information associated with significant projects (>100,000 gpd) located in watersheds with relatively high cumulative CU including, but

not limited to, the Octoraro Creek, Mahantango Creek, Lower Swatara Creek, Deep Creek, Conestoga River, Lower Conewago Creek, and Lackawanna River Watersheds.

2. Take steps to fill existing information gaps regarding accurate valuations of grandfathered and other unregulated water uses, particularly for watersheds with significant water use and/or limited water availability.

3. Incorporate incentives into water withdrawal and CU regulations, and associated regulatory processes, to more closely align requested/approved water use quantities with actual required/reported amounts and reasonably foreseeable needs, and make appropriate adjustments during project renewals and modifications.

4. Coordinate with member jurisdictions to continue to improve accuracy and consistency of water use datasets, including facility/source locations, permitted/reported quantities, and water use rates/periods, and explore mechanisms to more efficiently share and integrate updated water use datasets between agencies.

Estimation of Water Capacity

1. Verify low flow conditions, through continuous streamflow monitoring or field investigations during drought events, for watersheds with relatively low water capacity including, but not limited to, the Little Conestoga Creek, Muddy Creek, Quittapahilla Creek, Canacadea Creek, East Branch Octoraro Creek, and Blacklog Creek Watersheds.

2. Validate existing, and identify any additional, WCAs with limited water capacity available to support water resources development as a function of local watershed characteristics and hydrologic conditions.

3. Maintain and periodically update computed streamflow statistics for key USGS reference gages, associated regional regression equations, and related analytical tools for estimating hydrology, streamflow statistics, and water capacity for Basin watersheds.

Assessment of Water Availability

1. Conduct finer scale water availability analyses and/or detailed water budgets, in partnership with local stakeholders, for watersheds with relatively low water availability including, but not limited to, the Octoraro Creek, Little Conestoga Creek, Quittapahilla Creek, South Branch Conewago Creek, Deep Creek, Spring Creek, Muddy Creek, and South Branch Codorus Creek Watersheds.

2. Validate existing, and identify any additional, PSAs with limited water availability as a function of low water capacity and/or high existing/projected cumulative water use anticipated to exceed long-term sustainability of water resources or cause conflicts among water users.

3. Utilize study findings, and associated planning tools, during the review of proposed projects to evaluate cumulative water use, account for grandfathered and unregulated uses, assess *de minimis* withdrawals, inform designation/management of sensitive areas (e.g., WCAs, PSAs, and CWPAs), and prioritize implementation of PM&E measures.

4. Collect field/operational data, conduct focused short-term studies, and document water supply issues during low flow or drought events to improve understanding of actual water use and availability under stressed hydrologic conditions.

Implementation of PM&E Measures

1. Continue to implement regulatory standards and policies intended to condition water withdrawal projects with passby flow and conservation release requirements, and require mitigation for CU, particularly in watersheds with limited water availability.

2. Develop criteria for implementing limitations on water uses based on reasonably foreseeable needs of projects and refine water conservation standards for regulated projects, particularly in watersheds identified as critical or potentially stressed.

3. Coordinate with member jurisdictions to incorporate PM&E measures associated with water use permits into water use databases for use in accurately assessing their effects on water use and availability.

Future Maintenance and Enhancements

1. Update the comprehensive water use database annually and refine/expand water use estimates and projections on a frequency of at least once every 10 years.

2. Compile and incorporate seasonal or monthly water use, capacity, and availability patterns to improve the temporal resolution of future water use and availability analyses, particularly for priority watersheds.

3. To compliment water use projections, develop projected water capacity estimates based on forecasted changes in climate patterns, land use, and restoration efforts for comprehensively assessing future water resources conditions.

4. Incorporate additional functionality in the CWUAS Tool and Web Map to expand utility for regulatory and planning applications, including passby flow determinations, groundwater availability analyses, enhanced graphical/tabular outputs, and additional PM&E measures.

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