Cumulative Water Use and Availability Study
for the Susquehanna River Basin

APPENDIX A

Consumptive Use Coefficients for North American Industry Classification System (NAICS) Codes

NAICS Number	NAICS Description	CU Coefficient	Reference
110000	Agriculture, Forestry, Fishing and Hunting	**0.9**	Domber & Hoffman (2004)
111219	Other Vegetable (except Potato) and Melon Farming	**0.9**	Domber & Hoffman (2004)
111336	Fruit and Tree Nut Combination Farming (Orchard)	**0.9**	Domber & Hoffman (2004)
111421	Nursery and Tree Production	**0.9**	Domber & Hoffman (2004)
112111	Beef Cattle Ranching and Farming	**0.9**	Shaffer & Runkle (2007)
112120	Dairy Cattle Farming	**0.9**	Shaffer & Runkle (2007)
112210	Hog and Pig Farming	**0.9**	Domber & Hoffman (2004)
112300	Poultry and Egg Production	**0.9**	Domber & Hoffman (2004)
112310	Chicken Egg Production	**0.9**	Domber & Hoffman (2004)
112330	Turkey Production	**0.9**	Domber & Hoffman (2004)
112511	Aquaculture	**0.05**	Domber & Hoffman (2004)
112511	Finfish Farming and Fish Hatcheries	**0.05**	Domber & Hoffman (2004)
112990	Livestock Farming	**0.9**	Shaffer & Runkle (2007)
210000	Mining	**0.12**	Domber & Hoffman (2004)
211111	Crude Petroleum and Natural Gas Extraction	**1**	SRBC
211112	Natural Gas Liquid Extraction	**0.11**	Domber & Hoffman (2004)
212000	Mining (except Oil and Gas)	**0.12**	Domber & Hoffman (2004)
212110	Coal Mining	**0.12**	Domber & Hoffman (2004)
212111	Bituminous Coal and Lignite Surface Mining	**0.12**	Domber & Hoffman (2004)
212112	Bituminous Coal Underground Mining	**0.12**	Domber & Hoffman (2004)
212113	Anthracite Mining	**0.12**	Domber & Hoffman (2004)
212310	Stone Mining and Quarrying	**0.12**	Domber & Hoffman (2004)
212312	Crushed and Broken Limestone Mining and Quarrying	**0.12**	Domber & Hoffman (2004)
212319	Other Crushed and Broken Stone Mining and Quarrying	**0.12**	Domber & Hoffman (2004)
212320	Sand, Gravel, Clay, and Ceramic and Refractory Minerals Mining and Quarrying	**0.12**	Domber & Hoffman (2004)
212321	Construction Sand and Gravel Mining	**0.12**	Domber & Hoffman (2004)
221100	Electric Power Generation, Transmission and Distribution	**0.02**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
221110	Electric Power Generation	**0.02**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
221111	Hydroelectric Power Generation	**0.03**	Domber & Hoffman (2004)
221112	Fossil Fuel Electric Power Generation	**0.02**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
221113	Nuclear Electric Power Generation	**0.02**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
221300	Water, Sewage and Other Systems	**0.15**	Shaffer & Runkle (2007)
221310	Water Supply and Irrigation Systems	**0.15**	Shaffer & Runkle (2007)
221320	Sewage Treatment Facilities	**0.15**	Shaffer & Runkle (2007)
236110	Residential Building Construction	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
236220	Commercial and Institutional Building Construction	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
237000	Heavy and Civil Engineering Construction	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
237120	Oil and Gas Pipeline and Related Structures Construction	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
238110	Poured Concrete Foundation and Structure Contractors	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)

NAICS Number	NAICS Description	CU Coefficient	Reference
311000	Food Manufacturing	**0.15**	Shaffer & Runkle (2007)
311111	Dog and Cat Food Manufacturing	**0.28**	Shaffer & Runkle (2007)
311119	Other Animal Food Manufacturing	**0.28**	Shaffer & Runkle (2007)
311222	Soybean Processing	**0.15**	Shaffer & Runkle (2007)
311300	Sugar and Confectionery Product Manufacturing	**0.1**	Domber & Hoffman (2004)
311320	Chocolate and Confectionery Manufacturing from Cacao Beans	**0.1**	Domber & Hoffman (2004)
311421	Canned Fruit and Vegetables	**0.14**	Shaffer & Runkle (2007)
311500	Dairy Product Manufacturing	**0.07**	Shaffer & Runkle (2007)
311513	Cheese Manufacturing	**0.09**	Shaffer & Runkle (2007)
311612	Meat Processed from Carcasses	**0.13**	Shaffer & Runkle (2007)
311613	Rendering and Meat Byproduct Processing	**0.13**	Shaffer & Runkle (2007)
311615	Poultry Processing	**0.08**	Shaffer & Runkle (2007)
311812	Commercial Bakeries	**0.33**	Shaffer & Runkle (2007)
311910	Snack Food Manufacturing	**0.06**	Shaffer & Runkle (2007)
312100	Beverage Manufacturing	**0.8**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
312111	Soft Drink Manufacturing	**0.8**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
312112	Bottled Water Manufacturing	**0.8**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
312120	Breweries	**0.8**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
312130	Grape Farming and Making Wine	**0.8**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
312220	Tobacco Product Manufacturing	**0.25**	Shaffer & Runkle (2007)
313000	Textile Mills	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
313200	Fabric Mills	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
315000	Apparel Manufacturing	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
321113	Sawmills	**0.14**	Shaffer & Runkle (2007)
322000	Paper Manufacturing	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
322120	Paper Mills	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
322130	Paperboard Mills	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
322212	Folding Paperboard Box Manufacturing	**0.07**	Shaffer & Runkle (2007)
322291	Sanitary Paper Product Manufacturing	**0.07**	Shaffer & Runkle (2007)
323110	Commercial Lithographic Printing	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
323119	Other Commercial Printing	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
324120	Asphalt Paving, Roofing, and Saturated Materials Manufacturing	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
324121	Asphalt Paving Mixture and Block Manufacturing	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
325000	Chemical Manufacturing	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)

NAICS Number	NAICS Description	CU Coefficient	Reference
325120	Industrial Gas Manufacturing	**0.1**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
325193	Ethyl Alcohol Manufacturing	**0.08**	Shaffer & Runkle (2007)
325314	Fertilizer (Mixing Only) Manufacturing	**0.35**	Shaffer & Runkle (2007)
325410	Pharmaceutical and Medicine Manufacturing	**0.04**	Shaffer & Runkle (2007)
325510	Paint and Coating Manufacturing	**0**	Shaffer & Runkle (2007)
325600	Soap, Cleaning Compound, and Toilet Preparation Manufacturing	**0.1**	Shaffer & Runkle (2007)
325611	Soap and Other Detergent Manufacturing	**0.14**	Shaffer & Runkle (2007)
326121	Unlaminated Plastics Profile Shape Manufacturing	**0.11**	Shaffer & Runkle (2007)
326122	Plastics Pipe and Pipe Fitting Manufacturing	**0.1**	Domber & Hoffman (2004)
326160	Plastics Bottle Manufacturing	**0.1**	Shaffer & Runkle (2007)
326199	All Other Plastics Product Manufacturing	**0.11**	Shaffer & Runkle (2007)
326200	Rubber Product Manufacturing	**0.11**	Shaffer & Runkle (2007)
326299	All Other Rubber Product Manufacturing	**0.11**	Shaffer & Runkle (2007)
327110	Pottery, Ceramics, and Plumbing Fixture Manufacturing	**0.1**	Domber & Hoffman (2004)
327120	Clay Building Material and Refractories Manufacturing	**0.5**	Shaffer & Runkle (2007)
327122	Ceramic Wall and Floor Tile Manufacturing	**0.1**	Domber & Hoffman (2004)
327211	Flat Glass Manufacturing	**0.1**	Domber & Hoffman (2004)
327213	Glass Container Manufacturing	0.17	Shaffer & Runkle (2007)
327300	Cement and Concrete Product Manufacturing	**0.1**	Domber & Hoffman (2004)
327320	Ready-Mix Concrete Manufacturing	**0.29**	Shaffer & Runkle (2007)
327331	Concrete Block and Brick Manufacturing	**0.4**	Shaffer & Runkle (2007)
327390	Other Concrete Product Manufacturing	**0.1**	Domber & Hoffman (2004)
327410	Lime Manufacturing	**0.26**	Shaffer & Runkle (2007)
327420	Gypsum Product Manufacturing	**0.59**	Shaffer & Runkle (2007)
327993	Mineral Wool Manufacturing	**0.29**	Shaffer & Runkle (2007)
331111	Iron and Steel Mill	**0.12**	Domber & Hoffman (2004)
331222	Steel Wire Drawing	**0.03**	Shaffer & Runkle (2007)
331315	Aluminum Sheet, Plate, and Foil Manufacturing	**0.1**	Domber & Hoffman (2004)
331420	Copper Rolling, Drawing, Extruding, and Alloying	**0.2**	Shaffer & Runkle (2007)
331511	Iron Foundries	**0.1**	Domber & Hoffman (2004)
332000	Fabricated Metal Product Manufacturing	**0.1**	Domber & Hoffman (2004)
332210	Cutlery and Handtool Manufacturing	**0.1**	Domber & Hoffman (2004)
332214	Kitchen Utensil, Pot, and Pan Manufacturing	**0.1**	Domber & Hoffman (2004)
332610	Spring and Wire Product Manufacturing	**0.1**	Domber & Hoffman (2004)
333131	Coal Breakers	**0.49**	Shaffer & Runkle (2007)
333313	Office Machinery Manufacturing	**0.1**	Domber & Hoffman (2004)
333315	Photographic and Photocopying Equipment Manufacturing	**0.1**	Domber & Hoffman (2004)
333415	Air-Conditioning and Warm Air Heating Equipment Units Manufacturing	**0.1**	Domber & Hoffman (2004)
333610	Engine, Turbine, and Power Transmission Equipment Manufacturing	**0.1**	Domber & Hoffman (2004)
333613	Power transmission equipment	0.0	Shaffer & Runkle (2007)
333618	Other Engine Equipment Manufacturing	**0.35**	Shaffer & Runkle (2007)
333991	Power-Driven Handtool Manufacturing	**0.13**	Shaffer & Runkle (2007)
334000	Computer and Electronic Product Manufacturing	**0.1**	Domber & Hoffman (2004)

NAICS Number	NAICS Description	CU Coefficient	Reference
334310	Audio and Video Equipment Manufacturing	**0.1**	Domber & Hoffman (2004)
334410	Semiconductor and Other Electronic Component Manufacturing	**0.1**	Domber & Hoffman (2004)
334413	Semiconductor and Related Device Manufacturing	**0.1**	Domber & Hoffman (2004)
334419	Other Electronic Component Manufacturing	**0.1**	Domber & Hoffman (2004)
334512	Heating and Cooling System Controls, Residential and Commercial, Manufacturing	**0**	Shaffer & Runkle (2007)
335310	Electrical Equipment Manufacturing	**0.1**	Domber & Hoffman (2004)
335920	Communication and Energy Wire and Cable Manufacturing	**0.1**	Domber & Hoffman (2004)
336111	Automobile Manufacturing	**0.1**	Domber & Hoffman (2004)
336991	Motorcycle, Bicycle, and Parts Manufacturing	**0.1**	Domber & Hoffman (2004)
336992	Military Armored Vehicle, Tank, and Tank Component Manufacturing	**0.1**	Domber & Hoffman (2004)
337100	Household and institutional Furniture and Kitchen Cabinet Manufacturing	**0.08**	Shaffer & Runkle (2007)
337110	Wood Kitchen Cabinet and Countertop Manufacturing	**0.05**	Shaffer & Runkle (2007)
337122	Nonupholstered Wood Household Furniture Manufacturing	**0.05**	Shaffer & Runkle (2007)
337215	Showcase, Partition, Shelving, and Locker Manufacturing	**0.1**	Domber & Hoffman (2004)
424420	Packaged Frozen Food Merchant Wholesalers	**0.1**	Domber & Hoffman (2004)
445000	Food and Beverage Stores	**0.1**	Domber & Hoffman (2004)
447110	Gasoline Stations with Convenience Stores	**0.15**	Shaffer & Runkle (2007)
453000	Miscellaneous Store Retailers	**0.15**	Shaffer & Runkle (2007)
482110	Rail Transportation	**0.1**	Domber & Hoffman (2004)
486210	Pipeline Transportation of Natural Gas	**0**	SRBC Project Review
488119	Airports, Civil, Operation and Maintenance	**0.15**	Shaffer & Runkle (2007)
493120	Refrigerated Warehousing and Storage	**0.15**	Shaffer & Runkle (2007)
517000	Telecommunications	**0.1**	Domber & Hoffman (2004)
530000	Real Estate and Rental and Leasing	**0.1**	Domber & Hoffman (2004)
531120	Conference Centers	**0.15**	Shaffer & Runkle (2007)
531210	Offices of Real Estate Agents and Brokers	**0.1**	Domber & Hoffman (2004)
541380	Testing Laboratories	**0.15**	Shaffer & Runkle (2007)
541710	Research and Development in the Physical, Engineering, and Life Sciences	**0.15**	Shaffer & Runkle (2007)
562212	Solid Waste Landfill	**0.1**	Domber & Hoffman (2004)
562213	Solid Waste Combustors and Incinerators	**0.1**	Domber & Hoffman (2004)
562900	Mine Reclamation Services	**0.1**	Domber & Hoffman (2004)
562900	Remediation and Other Waste Management Services	**0.1**	Domber & Hoffman (2004)
611110	Elementary and Secondary Schools	**0.15**	Shaffer & Runkle (2007)
611310	Colleges, Universities, and Professional Schools	**0.15**	Shaffer & Runkle (2007)
622110	General Medical and Surgical Hospitals	**0.1**	Shaffer & Runkle (2007)
623220	Residential Mental Health and Substance Abuse Facilities	**0.15**	Shaffer & Runkle (2007)
623311	Continuing Care Retirement Communities	**0.15**	Shaffer & Runkle (2007)
623312	Assisted Living Facilities for the Elderly	**0.15**	Shaffer & Runkle (2007)
711210	Spectator Sports	**0.1**	Domber & Hoffman (2004)
711212	Racetracks	**0.1**	Domber & Hoffman (2004)

NAICS Number	NAICS Description	CU Coefficient	Reference
712190	Nature Parks and Other Similar Institutions	**0.03**	Domber & Hoffman (2004)
713110	Amusement and Theme Parks	**0.1**	Domber & Hoffman (2004)
713900	Other Amusement and Recreation Industries	**0.1**	Domber & Hoffman (2004)
713910	Golf Courses and Country Clubs	**0.9**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
713920	Skiing Facilities	**0.15**	Domber & Hoffman (2004)
721110	Hotels (except Casino Hotels) and Motels	**0.15**	Shaffer & Runkle (2007)
721211	Campgrounds	**0.15**	Shaffer & Runkle (2007)
722511	Full-Service Restaurants	**0.15**	Shaffer & Runkle (2007)
813410	Civic & Social Organizations	**0.15**	Domber & Hoffman (2004); Shaffer & Runkle (2007)
922140	Correctional Institutions	**0.15**	Shaffer & Runkle (2007)
922160	Fire Protection	**0.2**	Shaffer & Runkle (2007)
928110	Military Bases	**0.1**	Shaffer & Runkle (2007)

APPENDIX B

Procedures Used to Estimate Unregulated Consumptive Use

Self-supplied Residential

1. Census Block Groups were obtained as a Geographic Information System (GIS) shapefile (US Census Bureau, 2010). The shapefile was clipped to the Susquehanna River Basin. New attribute fields were added to record the area of each block group within the Basin and also record the estimated population residing within the Basin. The estimated population residing within the Basin was calculated using a change-in-area ratio, assuming equal population distribution within each block group.

$$\left(\frac{Clipped\ Block\ Group\ Area}{Original\ Block\ Group\ Area}\right) \times Original\ Block\ Group\ Pop. = Clipped\ Block\ Group\ Pop.$$

2. Public Water Supply (PWS) service area GIS shapefiles were obtained for Pennsylvania (PADEP, 2012) and for Cecil (Cecil, 2012) and Harford (Harford, 2012) Counties in Maryland. PWS service areas were not available in a GIS format in New York. As a substitute, PWS point sources for community-based systems, including population served estimates, were obtained from the New York State Department of Health along with civil division boundaries from the New York State Office of Cyber Security.

3. PWS service areas were erased from census block groups in PA and MD. The resulting area was considered to include the self-supplied residential areas in PA and MD. Assuming equal population distribution, a change-in-area ratio was again used to estimate the population residing in the self-supplied areas.

$$\left(\frac{Self\ Supplied\ Area}{Clipped\ Block\ Group\ Area}\right) \times Clipped\ Block\ Group\ Pop. = Self\ Supplied\ Pop.$$

4. In New York, PWS population served estimates were subtracted from census block group populations using the following steps:
    a. For non-municipal PWS points (mobile home parks, retirement homes, private communities, etc.), population served was subtracted from the intersecting block group population (Figure B-1).

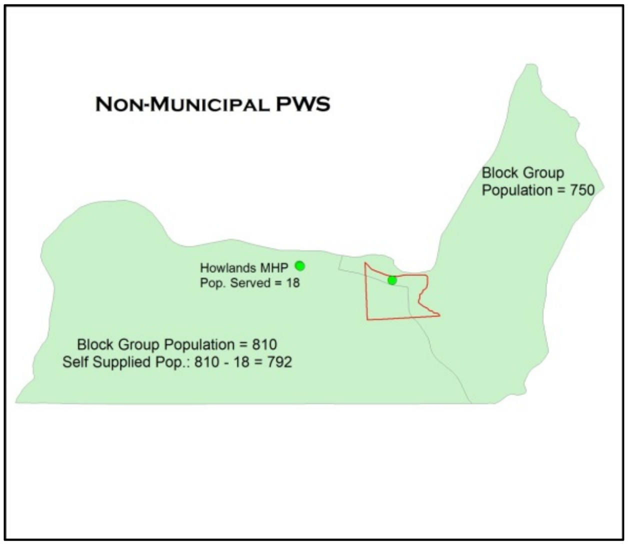

Figure B-1. Non-Municipal PWS Location Example

b. For municipal PWS points, point locations were disregarded because these PWS systems cover multiple block groups. Instead, the related civil boundary(s) was used as a guide representing a "PWS service area" and population served was subtracted from all intersecting block groups using census population ratios (Figure B-2).

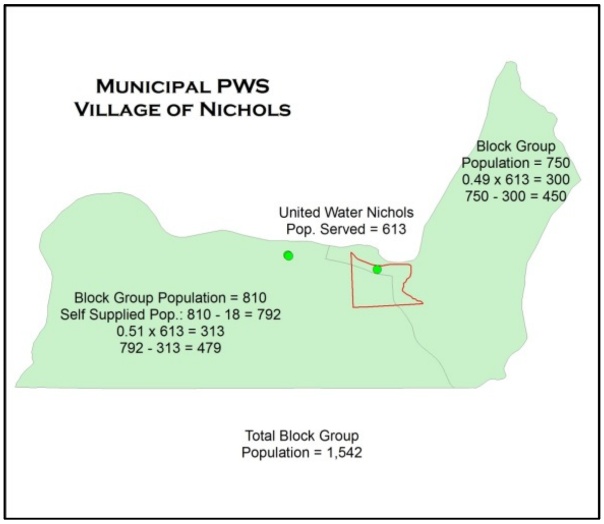

Figure B-2. ***Municipal PWS Example***

i. When intersecting block groups extended past the related civil boundary(s), the civil boundary(s) or "PWS service area" was erased from the block groups similar to the procedure used in Maryland and Pennsylvania (Figure B-3). This was done to better associate remaining population of block groups with the self-supplied residential area.

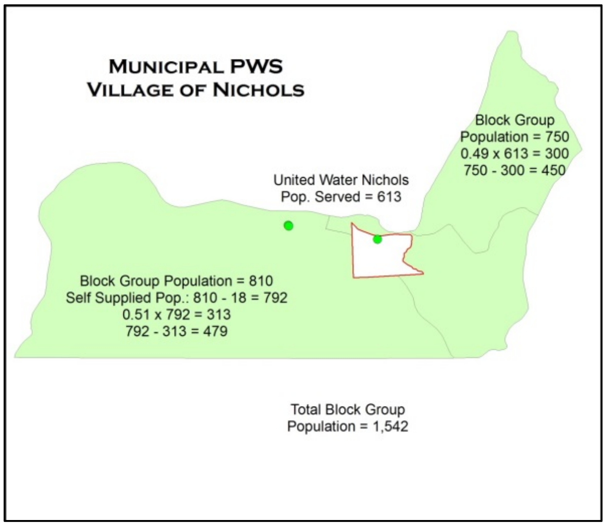

Figure B-3. ***Civil Boundary Erased from Intersecting Block Groups***

ii. When block groups did not extend past the related civil boundary(s), and the census population was higher than the PWS population served, the civil boundary(s) was not erased from the block groups (Figure B-4).

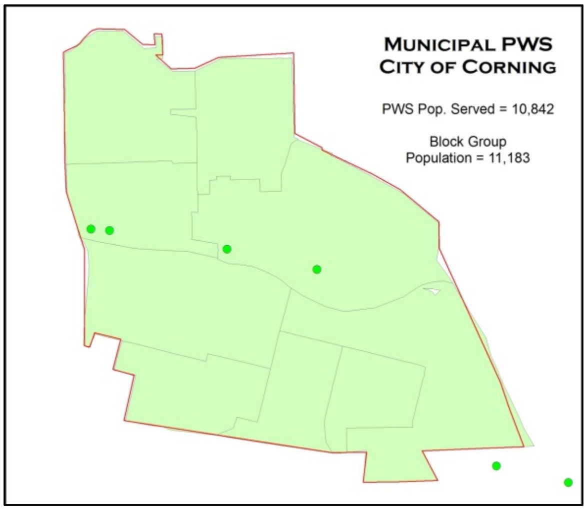

Figure B-4. ***City of Corning, Census Block Group Total Population was Higher than PWS Population Served***

iii. When block groups did not extend past the related civil boundary(s), and the census population was lower than the PWS population served, the block groups were removed.

c. Area values were recalculated using GIS for remaining census block group areas.
d. The remaining census block group area and population was considered to rely on self-supplied water for residential uses.

The Cumulative Water Use and Availability Study (CWUAS) further estimated self-supplied residential consumptive water use (CU) within 10-digit Hydrologic Unit Code (HUC-10) watersheds. Figure B-5 shows an example of estimating the population residing in the self-supplied area within the Quittapahilla Creek Watershed, using a change-in-area ratio and assuming equal population distribution.

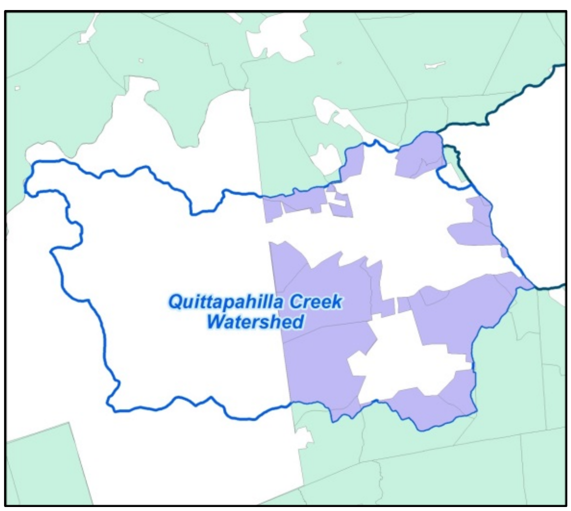

Figure B-5. ***Quittapahilla Creek Watershed Self-Supplied Residential Area***

$$\left(\frac{Quittapahilla\ Self\ Supplied\ Area}{Self\ Supplied\ Area}\right) \times Self\ Supplied\ Pop. = Quittapahilla\ Self\ Supplied\ Pop.$$

5. The resulting estimated population in the Quittapahilla Creek Watershed or HUC-10 watershed self-supplied area was multiplied by an assumed 75 gallon per capita per day (gpcd) average residential water demand (PADEP, 2006) and a 15 percent CU factor (Shaffer and Runkle, 2007) determining the total estimated CU for the self-supplied residential population.

$$Quittapahilla\ Self\ Supplied\ Pop.\ \times (75 gpcd \times 0.15) = Quittapahilla\ Self\ Supplied\ CU\ in\ gpd$$

Livestock

1. USDA Census of Agriculture data were used to tabulate numbers of the following livestock categories for each county in the Susquehanna River Basin (USDA, 2012):
   - Beef cows
   - Milk cows
   - Hogs/pigs
   - Sheep/lamb
   - Horses
   - Goats
   - Poultry (Layers, Pullets, Broilers, Turkeys)

2. CU factors (gallons/animal/day) were used to calculate average gallons per day (gpd) used by each livestock category (Jarrett, 2002). Table B-1 provides example Census of Agriculture data for Lebanon County, PA. Total animal counts for each livestock category were multiplied by the associated CU factors to determine total livestock CU (gpd) in each county of the Basin.

$$Total\ Animals\ \times CU\ Factor\ (gallons/animal/day) = Livestock\ CU\ (gpd)$$

Table B-1. Lebanon County, CU for Livestock by Animal Species

Livestock Category	Lebanon County Total Animals[1]	CU Factor (Gallons/Animal/Day)[2]	Lebanon County Livestock CU (gpd)
Beef Cows	1,701	15	25,515
Milk Cows	23,093	35	808,255
Hogs and Pigs	99,985	4	399,940
Sheep and Lamb	1,765	2	3,530
Horses	2,104	12	25,248
Goats	1,212	2	2,424
Layers	1,504,824	0.06	90,289
Pullets	765,681	0.06	45,941
Broilers	2,470,497	0.08	197,640
Turkeys	290,287	1.2	348,344
Lebanon County Total Livestock CU (gpd)			1,947,126

[1] USDA (2007) Census of Agriculture
[2] Jarrett, A.R. (2002) Agricultural Animal Consumptive Water Use Coefficients

3. In order to estimate livestock CU within HUC-10 watersheds, locations of livestock needed to be identified. An analysis of land use and locations of Concentrated Animal Feeding Operations (CAFOs) performed during the development of the Pennsylvania State Water Plan, Water Analysis Screening Tool (WAST) found that the majority of these locations were in land use areas categorized as cultivated crops in the 2000 Pennsylvania Land Cover dataset (Stuckey, 2008). More recent CAFO locations and water use permits, provided by the Pennsylvania Department of Environmental Protection (PADEP), were overlain on 2006 Chesapeake Bay land use data to verify results from the WAST. Comparison results between these updated datasets showed 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 (Table B-2).

Table B-2. CAFO and Livestock-Related Water Use Permits by Land Use Class

Land Use Class	Number of CAFOs	Percent	Number of Livestock Water Use Permits	Percent
Open Water	0	0	5	2
Low Urban	0	0	19	6
Medium Urban	11	5	11	3
High Urban	14	6	7	2
Developed Open Space	2	1	8	2
Barren	10	5	3	1
Deciduous Forest	16	7	38	12
Evergreen Forest	2	1	11	3
Mixed Forest	2	1	4	1
Grassland	2	1	3	1
Shrub Scrub	4	2	13	4
Cultivated Crop	119	53	115	35
Pasture/Hay	40	18	87	27
Emergent Wetland	0	0	1	0
Woody Wetland	0	0	2	1
Unconsolidated Shore	1	0	0	0
Total	**223**	**100**	**327**	**100**

4. Cultivated crop and pasture/hay areas were extracted from the 2006 Chesapeake Bay land use dataset and dissolved by county into a new GIS shapefile representing livestock area. Figure B-6 illustrates that 2006 Chesapeake Bay land use data are only available within the Basin; however, livestock CU values are countywide. A change-in-area ratio was applied to countywide livestock CU to estimate the in-basin CU of each county lying on the periphery of the Basin.

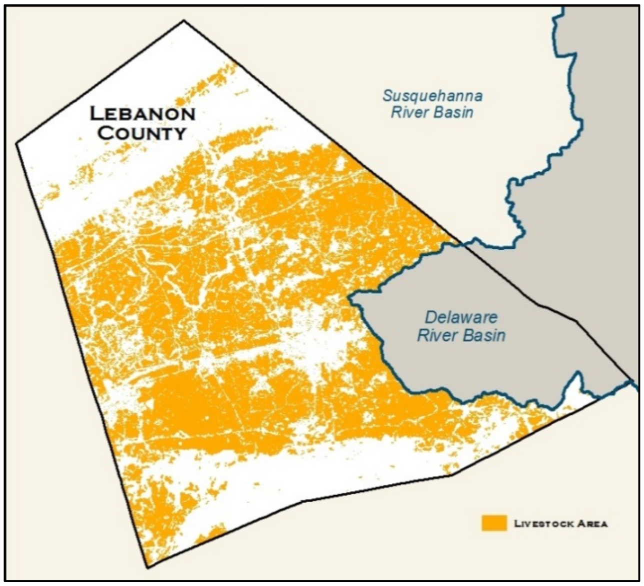

Figure B-6. Livestock Areas in the Susquehanna River Basin Portion of Lebanon County

$$Lebanon\ Livestock\ CU \times \left(\frac{Lebanon\ Basin\ Area}{Lebanon\ Area}\right) = Lebanon\ Basin\ Livestock\ CU$$

5. The livestock area shapefile was clipped to each HUC-10 watershed and the estimated livestock CU was calculated (Figure B-7).

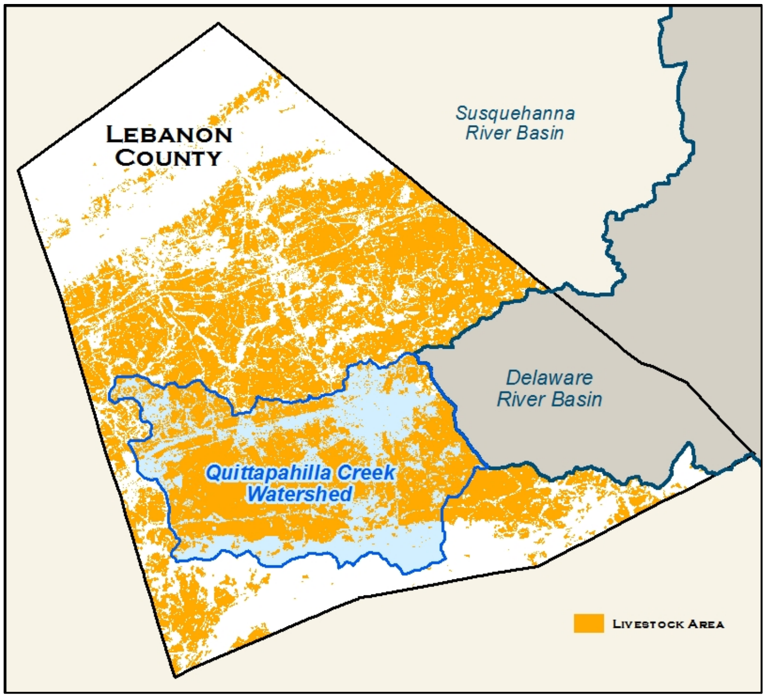

Figure B-7. Example HUC-10, Quittapahilla Creek Watershed

$$Lebanon\ Basin\ Livestock\ CU\ \times \left(\frac{Quittapahilla\ Livestock\ Area}{Lebanon\ Livestock\ Area}\right) = Quittapahilla\ Livestock\ CU\ (gpd)$$

Irrigation

1. Irrigated land by crop (acres) was retrieved from the United States Department of Agriculture (USDA) Census of Agriculture (USDA, 2012) for each county in the Basin.

2. Estimated quantities of water applied, by crop, in average acre-feet applied per acre, were retrieved for each state using the Census of Agriculture, Farm and Ranch Irrigation Surveys (FRIS) (USDA, 2013). Note that USDA instructs census participants to round 1 acre-foot to 326,000 gallons (USDA, 2012). These data were not reported by county, necessitating the use of state-wide averages. Table B-3 lists the crop categories within the Susquehanna River Basin.

Table B-3. Estimated Quantity of Water Applied by Crop (USDA, 2013)

Crop ID	Selected Crop	Average acre-feet applied per acre		
		MD	NY	PA
1	Corn for Grain & Silage[1]	0.6	0.3	0.1
2	Wheat for Grain or Seed	0.4	0.9	NA[3]
3	Barley for Grain or Seed	0.2	(D)[2]	0.4
4	Soybeans for Beans	0.5	(D)	0.4
5	Beans, Dry Edible	0.4	(D)	NA
6	Alfalfa and Silage	0.4	(D)	0.2
7	All Other Hay	0.1	0.2	1.0
8	Land in Vegetables	0.4	0.5	0.3
9	Berries	0.7	0.4	0.5
10	Orchards	0.8	0.7	0.3
11	All Other Crops	0.5	0.7	0.6
12	Pastureland	0.2	0.3	0.4

[1] Average acre-feet applied per acre values are averaged from Corn for Grain and Corn for Silage values
[2] Value withheld by USDA
[3] No irrigation reported for crop in state

3. In order to estimate irrigation CU within HUC-10 watersheds, crop-specific land cover GIS data from the Cropland Data Layer were obtained for all counties in the Basin (USDA, 2014). Land cover values within the Basin that could be paired with Census of Agriculture selected crops from Table B-3 were selected and converted into a new GIS shapefile (Table B-4).

Table B-4. Cropland Data Layer Values (USDA, 2014), Related Census of Agriculture Selected Crop, and Associated Census of Agriculture Table Reporting Irrigated Acres (USDA, 2013)

Data Value	Crop Name	Crop ID (Table 1)	Associated Census of Agriculture Table
1	Corn	1	26,27
5	Soybeans	4	26
12	Sweet Corn	8	29
21	Barley	3	26
23	Spring Wheat	2	26
24	Winter Wheat	2	26
26	Dbl Crop WinWht/Soy	2,4	26
36	Alfalfa	6	27
37	Other Hay	7	27
42	Dry Beans	5	26
43	Potatoes	8	29
44	Other Crops	11	28
49	Onions	8	29
50	Cucumbers	8	29
53	Peas	8	29
54	Tomatoes	8	29
55	Caneberries	9	33
58	Clover/Wildflowers	7	27
59	Sod/Grass Seed	7	27
66	Cherries	10	31
67	Peaches	10	31
68	Apples	10	31
69	Grapes	10	31
71	Other Tree Crops	10	31
176	Grass/Pasture	12	10
206	Carrots	8	29
216	Peppers	8	29
221	Strawberries	9	33
222	Squash	8	29
225	Dbl Crop WinWht/Corn	1,2	26,27
226	Dbl Crop Oats/Corn	1	26,27
229	Pumpkins	8	29
235	Dbl Crop Barley/Sorgh	3	26
236	Dbl Crop WinWht/Sorgh	2	26
237	Dbl Crop Barley/Corn	1,3	26,27
240	Dbl Crop Soybeans/Oats	4	26
241	Dbl Crop Corn/Soybeans	1,4	26,27
242	Blueberries	9	33
243	Cabbage	8	29
254	Dbl Crop Barley/Soybeans	3,4	26

4. The GIS shapefile was split into county specific sections, grouped/dissolved by Census of Agriculture selected crop ID, and acre values were calculated (Figure B-8).

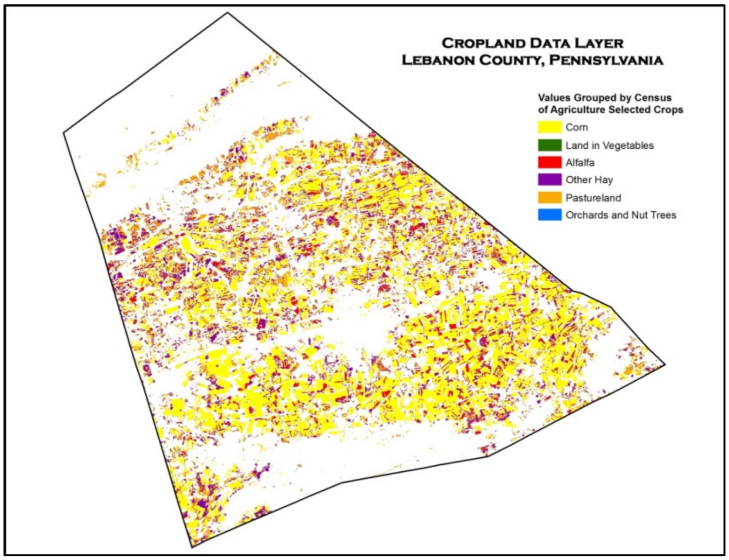

Figure B-8. Irrigated Cropland Data Layer Values Grouped by Census of Agriculture Selected Crop IDs in Lebanon County, PA (USGS, 2012 and 2013)

5. Attributes were added for average acre-feet of water applied per acre according to state, and irrigated land in acres according to county. Double crop values used an average of all relevant average acre-feet of water applied per acre values. Irrigated acre values were summed for all like crops (i.e., corn irrigated acre values were compiled using the following Census of Agriculture crops: Corn for Grain, Table 26 and Corn for Silage or Greenchop, Table 27).

6. The GIS shapefile was clipped to each HUC-10 watershed (Figure B-9).

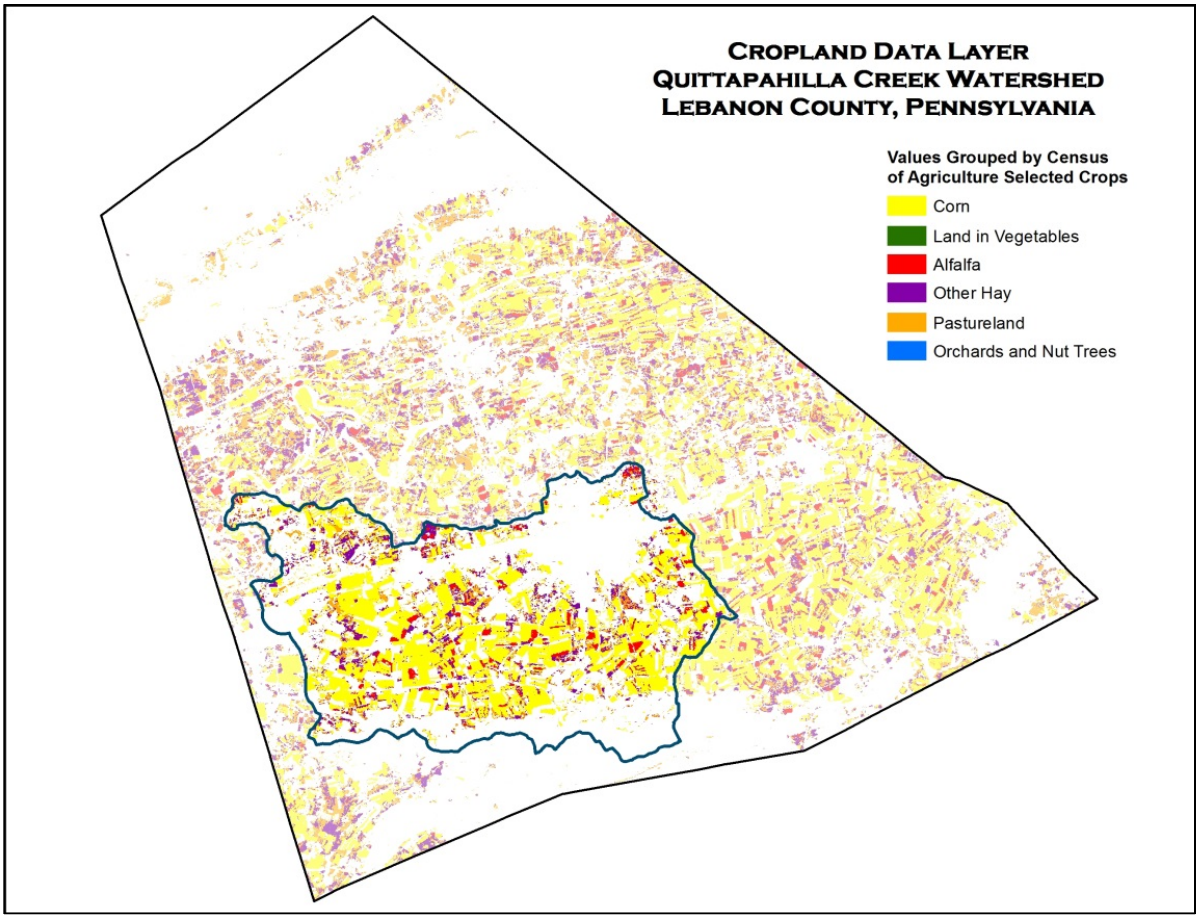

Figure B-9.   Example HUC-10, Quittapahilla Creek Watershed

7. A change-in-area ratio between Cropland Data Layer acres and Census of Agriculture reported irrigated acres for each crop was used to determine estimated Census of Agriculture reported irrigated acres per crop for each HUC-10 watershed.

$$\left(\frac{Quittapahilla\ Corn^{1}}{Lebanon\ Corn^{2}}\right) \times Lebanon\ Reported\ Corn^{3} = Quittapahilla\ Reported\ Corn^{4}$$

[1] Quittapahilla Creek Watershed cropland acres for corn
[2] Lebanon County cropland acres for corn (USDA, 2014)
[3] Lebanon County reported acres for corn (USDA, 2012)
[4] Quittapahilla Creek Watershed estimated reported acres for corn

8. Next, HUC-10 watershed estimated Census of Agriculture reported irrigated acres for each crop were multiplied by the average acre-feet of water applied per acre values for each crop.

$$Quittapahilla\ Reported\ Corn^{4} \times PA\ Corn\ Irrigation\ Factor^{5} = Quittapahilla\ Corn\ Irrigation\ (ac - ft)^{6}$$

[4] Quittapahilla Creek Watershed estimated reported acres for corn
[5] Pennsylvania average acre-ft applied per acre for corn (USDA, 2013)
[6] Quittapahilla Creek Watershed estimated average acre-ft of water applied for corn (census year)

9. HUC-10 watershed average acre-feet of water applied per acre (census year) values were then translated into gallons per day (gpd). The growing season throughout the Susquehanna River Basin generally lasts from May to October and on average, 77 percent of irrigation occurs between June and September (Jarrett, 2002). Water for irrigation was considered 100 percent consumptively used.

$$\frac{\left(Quitta.\,Corn\ Irrigation\ (ac-ft)^{6}\ \times 326{,}000\ \left(\frac{gal}{ac-ft}\right)\right)\times 0.77}{120} = Quitta.\,Corn\ Irrigation\ Water\ Use\ (gpd)^{7}$$

APPENDIX C

Procedures Used to Project 2030 Consumptive Use

Electric Power Generation

Water use for electric power generation facilities consists of diverting surface water and using it for cooling, then returning a portion of that water to the Basin. CU is the portion consumed in the cooling process that is not returned. The result of this analysis indicated the amount of freshwater needed to meet the U.S. Energy Information Administration's (EIA's) (2015) forecasted increases in electric generation capacity over the next 15 years within the Susquehanna River Basin. CU for electric power generation is primarily driven by a chosen cooling technology (once through, evaporative, dry, and combination cycles), which is indirectly related to the fuel source used for thermoelectric generation. Due to uncertainties of projected cooling technology for forecasted electric power generation capacities, this study assumed that the current (2014) composition of cooling methods will be reflected in new generation capacities within a 15-year outlook. Thus, projected CU has been related to energy capacities of individual fuel sources for electric power generation facilities.

Energy projections were examined by individual fuel sources per EIA's (2015) *Annual Energy Outlook 2015 with Projections to 2040*. EIA (2015) thermoelectric generation projections are based upon "energy models that are simplified representations of energy production and consumption, regulations, and producer and consumer behavior." Additional factors incorporated into energy models are known market, demographic and technological trends, macroeconomic growth rates, world fuel prices, policy changes, and U.S. labor force growth. Thermoelectric generation projections by EIA were defined for the period of 2014-2030 and for Electricity Market Module (EMM) Regions (Figure C-1) (Table C-1). EMM regions represent boundaries of similar electricity capacity planning, electricity fuel dispatching, and electricity finance and pricing (EIA, 2015). The Susquehanna River Basin is split between two separate EMM regions: Pennsylvania and Maryland are contained within the Reliability First Corporation/East EMM region and New York is contained within the Northeast Power Coordinating Council/Upstate New York EMM region.

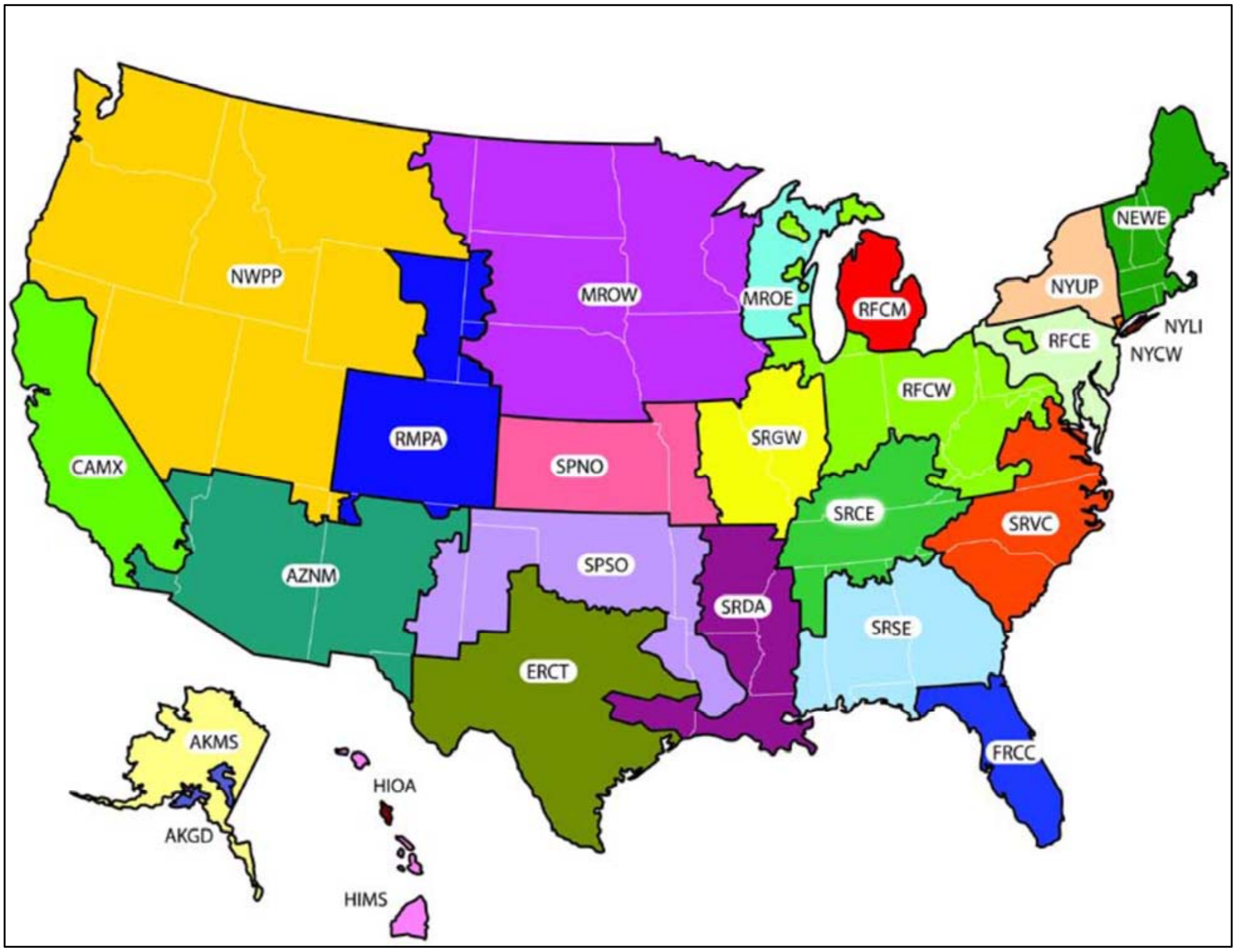

Figure C-1. Electric Market Module Supply Regions for the U.S. (EIA, 2015).

Table C-1. Projected Electric Power Generation to 2030 for Individual Fuel Sources per EMM Region

	East, Reference case			Upstate New York, Reference case		
Generation[1] by Fuel Type	**2015**	**2030**	**2030/2015 Growth Ratio**	**2015**	**2030**	**2030/2015 Growth Ratio**
Coal	78.04	84.09	1.0775	6.60	10.19	1.5449
Petroleum	0.56	0.49	0.8811	0.04	0.05	1.2632
Natural Gas	94.96	113.40	1.1942	32.39	16.89	0.5214
Nuclear	110.87	106.59	0.9614	25.42	25.53	1.0044
Renewable Sources	11.32	17.37	1.5342	30.26	35.15	1.1617

[1]Generation in billion-kilowatt hours

*Note that 2012 was the most recent year the Annual Energy Outlook report (EIA, 2015) was based on; electric power generation for 2014 was estimated.

A comprehensive database of existing electric power generating facilities in the United States, by energy source, was acquired from the EIA (2014). This point dataset represented operating and on-standby plants with a combined nameplate capacity of 1 megawatt (MW) or more. The current (2014) composition of electric power generation (megawatt capacity) per fuel source for the Susquehanna River Basin, based on EIA (2014) data, is illustrated in Figure C-2. Existing facilities within this dataset were extracted based upon their location within the Susquehanna Basin and EMM region. Electric power generation facilities that did not consumptively use water, such as hydroelectric, wind, and pumped storage, were excluded from the analysis. Also excluded were electric power generation facilities that acquired source water from public water supplies (PWS), as this additional CU is accounted for within consumptive use projections for PWS. A total of 50 facilities fueled by coal, petroleum, natural gas, nuclear, or renewable sources were located within the Susquehanna Basin. Of these, 26 were approved or permitted for water use by the Susquehanna River Basin Commission (Commission) or member jurisdiction agencies.

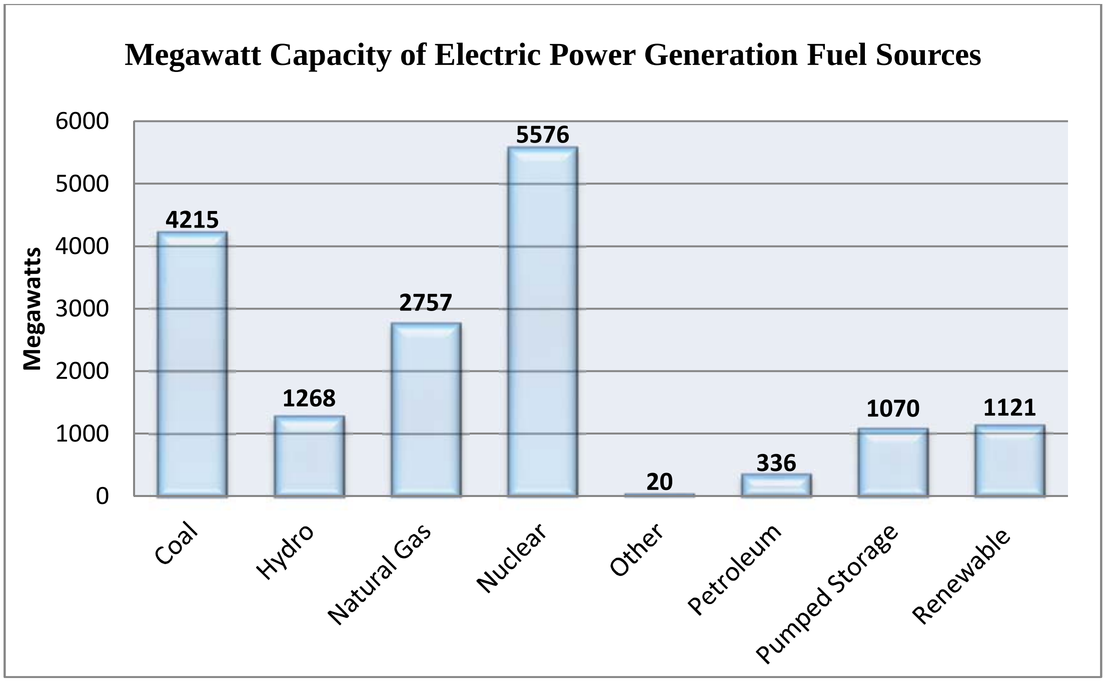

Figure C-2. Megawatt Capacity of Electric Power Generation Fuel Sources

Both approved and reported CU for electric power generation was related to the MW capacity of each facility, per fuel source, to determine an average approved and reported CU per MW capacity of each fuel type. This study assumed that the approved consumptive use for each electric power generation facility was representative of nameplate capacity (megawatt, MW) since this represents the maximum electric output a generator can produce without exceeding design thermal limits. Conversely, reported CU may be more reflective of the facilities' observed rate of energy transmitted over a period of time, expressed in megawatt hours (MWh). Due to a lack of reported MWh data for each electric power generation facility within the Basin, the MW capacity of each facility was used as a surrogate to estimate projected reported CU.

Unique CU to MW capacity per fuel source relationships were developed and utilized for approved facilities with water use records. For the 24 facilities that did not have available water use records, the average approved and reported CU per MW capacity, derived from the aforementioned relationships, was applied (Table C-2). Average approved and reported CU to

MW capacity could not be determined for petroleum fuel sources as there was only one facility located within the Basin that was fueled by petroleum. According to the Electric Power Research Institute (2008), average estimated plant cooling water withdrawals per unit of generation are the same for petroleum and natural gas fuel sources (27,500 gallons/MWh); therefore, the average approved and reported CU per MW capacity for natural gas was applied to petroleum fuel sources.

Table C-2. Average 2014 Approved and Reported Water Use per MW Capacity for Each Fuel Source

Megawatt Capacity by Fuel Type per Approved and Reported CU						
Fuel Type	**Facilities with CU Records**	**MW Capacity**	**Approved CU (mgd)**	**Reported CU (mgd)**	**Approved CU/MW**	**Reported CU/MW**
Coal	9	4282.7	67.60	25.75	0.0158	0.0060
Petroleum	1	NA	NA	NA	(0.0084)[1]	(0.0034)[1]
Natural Gas	8	2599.5	21.73	5.40	0.0084	0.0034
Nuclear	3	5575.8	116.20	60.49	0.0208	0.0108
Renewable Sources	5	107.5	3.46	1.79	0.0321	0.0166

[1]Average estimated plant cooling water withdrawals per unit of generation are the same for petroleum and natural gas fuel sources (EPRI, 2008), therefore, the average approved and reported water use per MW capacity for natural gas was applied to petroleum fuel sources.

The 2014 approved and reported CU per MW capacity of each fuel source was used as a baseline to project 2030 CU. EIA (2015) 2030/2014 electric generation ratios were applied to the existing (2014) MW capacity of each facility depending upon the EMM region and fuel source. The result is a theoretical 2030 MW capacity for each facility. Using the 2014 approved and reported CU per fuel source relationships, 2030 approved and reported CU was estimated based upon projected 2030 MW capacities of each facility. Total projected CU in 2030 accounted for baseline (2014) approved and reported locations and quantities and the estimated growth or decrease in CU in 2030. Reported use information from 2014 was determined by actual days used, rather than average annual use. Although, this calculation results in a higher value, these reported use rates represented the maximum CU demand.

Using the above methods, results indicated an additional 7.619 mgd of approved CU and 0.916 mgd of reported CU will be required by 2030 to support projected electric power generation within the Susquehanna River Basin. Results of this projection seem low given that this sector accounted for the second highest CU in 2014 and was historically regarded as the largest water user in the Basin. Emerging technologies, including dry (air) cooling methods that significantly reduce (close to 100 percent) CU compared to wet cooling systems, and more efficient generation systems, could be influencing results (USEPA, 2000). The distribution of projected growth or decrease in CU, separate from baseline conditions, was distributed to Aquatic Resource Classification (ARC) stream segments (SRBC, 2012) in proportion to current (2014) locations of CU within each ARC setting (Table C-3). Within a user-defined watershed, CU in 2030 was derived by multiplying the length (mi) of each ARC stream segment by the associated CU demand per mi^2 (Table C-4) plus 2014 baseline CU.

Table C-3. 2014 Approved and Reported Water Use per Aquatic Resource Classification (ARC) Segments

		Approved Use (mgd) Distribution			Reported Use (mgd) Distribution		
ARC	**Drainage Area (mi^2)**	**2014**	**2030**	**2030-2014**	**2010**	**2030**	**2030-2014**
1	<=10	5.990	7.410	1.420	2.494	3.114	0.620
2	>10<50	2.130	1.989	-0.141	1.642	1.487	-0.154
3	>=50<200	2.769	2.956	0.187	1.453	1.579	0.126
4	>=200<1,000	4.936	5.266	0.330	4.790	5.141	0.350
5	>=1,000<5,000	0.000	0.000	0.000	0.000	0.000	0.000
6	>=5,000	192.897	198.721	5.823	83.057	83.032	-0.025

Table C-4. Projected 2030 Approved and Reported Use per Stream Mile by ARC Setting

ARC	ARC Stream Length (mi)	2014 Facility Distribution	2030-2014 Approved CU per ARC (mgd/mi)	2030-2014 Reported CU per ARC (mgd/mi)
1	40464	16	0.000035	0.000015
2	4314	4	-0.000033	-0.000036
3	2139	5	0.000087	0.000059
4	1300	4	0.000254	0.000269
5	467	(3)[1]	(-0.002669)[1]	(-0.000011)[1]
6	583	14	0.007857	-0.000034

[1] 2014 Facility Distribution for ARC 5 streams incorporates 3 rescinded generation facilities as of 2015. 21.4% of the CU from ARC 6 stream segments was applied to ARC 5 stream segments to distribute additional CU for 2030 considering three active facilities previously existed within ARC 5 stream segments.

New generation and consequent approved and reported CU was allocated to ARC settings, assuming that new development will follow current patterns due to existing transmission infrastructure, population centers, and water availability for larger scale demands typically associated with large mainstem rivers. This short-term projection relied on the assumption that present day approvals or permits could potentially still be in effect in 2030. Many difficulties existed when attempting to accurately project new electric power generation facilities in a given area. This deficiency was addressed in the internal CWUAS tool which allows for the addition of a known pending facility and proposed CU amount to 2030 results. Pending facility locations can be determined by utilizing published statuses of Pennsylvania's plant additions and upgrades through 2015 (Pennsylvania Public Utility Commission, 2011) in addition to Commission knowledge of proposed projects and requested docket modifications. It is important to note that pending projects were not included in 2030 projection results utilized in the report findings.

Natural Gas Extraction

Future CU for natural gas extraction within the Susquehanna River Basin was based on projected well drilling and hydrofracturing activities to the year 2030. CU in 2030 was extrapolated based on the annual rate at which gas wells were hydraulically fractured and the average CU needed for well fracturing during calendar years 2010 through 2014. Although observed production rates were available for 2008 and 2009 (PADEP, 2015b), these annual datasets were omitted from the trend-line analysis due to a partial record in 2008 and the assumption that required infrastructure was not yet in place in 2009. The trend-line analysis indicated that 787 wells would be fractured annually for natural gas extraction by the end of 2030 (Figure C-3). This 2030 projected amount resulted in an increase of 219 hydraulically fractured wells per year, from a 2014 observed rate of 568 existing wells.

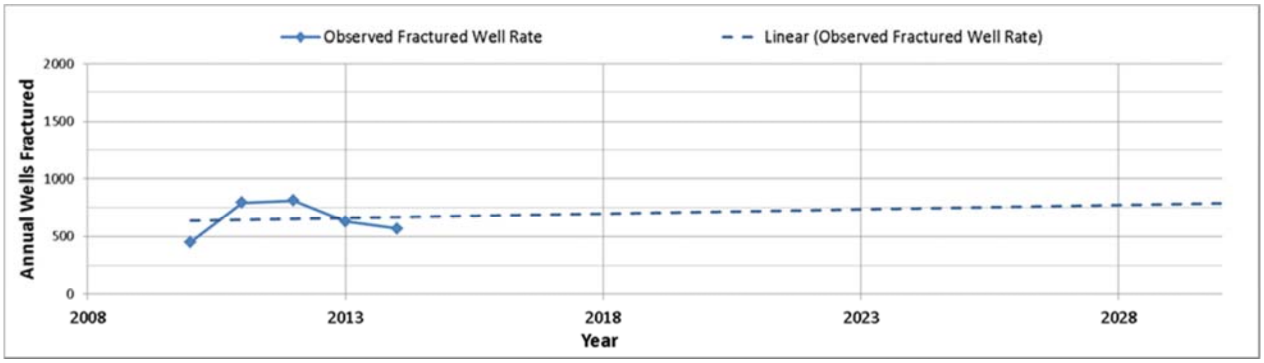

Figure C-3. Trend Line Analysis of Hydraulically Fractured Wells per Year in the Susquehanna River Basin from 2010-2014 Data, which is Extrapolated to 2030

The average CU amount for hydraulic fracturing processes ranged from approximately 2,040 mg in 2010 to approximately 4,065 mg in 2014. This increase in CU was directly related to industry infrastructure build-up and partly due to increasing lateral lengths of new wells. In 2014, approximately 568 wells were fractured resulting in 27.200 mgd of reported use, based on an average of 131 days of operation at each withdrawal source. A reported use rate of 7.16 mgal/well was developed from the 2014 reported CU and fractured wells relationship. This rate was applied to 787 projected fractured wells in 2030 totaling 5,634.9 mgal of water or 42.265 mgd, assuming the use is occurring 131 days a year (Table C-5).

Table C-5. Reported Use for 2030 using the 2014 Relationships of Average Annual Reported Use per Fractured Well and Average Days Used per Source

Year	Wells Fractured Annually	Reported Use (mgal)	Average Annual Reported Use per Well (mgal)	Average Withdrawal Occurrence per Source (days)	Reported Use (mgd) [1]	Reported Use (mgd) [2]
2014	568	4065.0	7.16	131	27.200	11.071
2030	**787**	**5634.9**	**7.16**	**131**	**42.265**	**14.688**

[1] Reported Use (mgd) is the withdrawal rate determined by the actual days a source was used (i.e., 131 days per year).
[2] Reported CU reflects annual rate averaged over 365 days per year. For both 2014 and 2030 reported use rates, 0.75 mgd of water supplied by PWS was excluded from the totals.

Yearly growing trends in withdrawal approvals for the natural gas industry began to flatten in 2014, potentially indicating an end to infrastructure expansion. Under this assumption, a projection for 2030 approved use was determined by comparing 2014 reported use to 2014 active approved use. The 2014 approved to reported use ratio was applied to the 2030 projected reported totals to estimate a projected 2030 approved use (Table C-6).

Table C-6. Active Approved and Reported Use Relationships from 2014 Used to Project Approved Use in 2030

Year	Active Approved Use (mgd)	Reported Use (mgd)	Active Approved / Reported Ratio
2014	97.910	27.200	3.600
2030	**152.137**	**42.265**	**3.600**

Quantities of water supplied to the gas industry from public water systems (PWS) were also considered in the 2030 CU projection. Although PWS's within the Pennsylvania portion of the Basin have been approved to provide up to 19.03 mgd (2014) of water to the natural gas industry, actual CU reported by the natural gas industry obtained from PWSs has decreased from approximately 2.5 mgd in 2010 to approximately 0.4 mgd in 2013. Therefore, PWS-supplied CU in 2030 was conservatively estimated to be 0.75 mgd. Because this portion of the gas-related demand was captured within the registered public water supply estimates and projections, 0.75 mgd was excluded from the total projected CU for the natural gas industry.

Based on current trends of withdrawal approval renewals largely due to established intakes and landowner agreements, it was assumed that most of the current withdrawal locations and quantities would still be active in 2030. To predict the spatial distribution of additional source water needed to support natural gas development in 2030, existing source locations and quantities were related to the number of fractured wells in Pennsylvania per Hydraulic Unit Code (HUC) 10 watershed boundary. The results indicated that increases in hydraulically fractured wells did not correlate positively with increases in gas-related water usage within the same HUC 10 watershed boundaries (R^2 of 0.36). This lack of strong correlation was not unlikely as many gas companies transport water across multiple watershed boundaries on a routine basis. Given these results, the distribution of existing source water locations and quantities used by the natural gas industry were examined by ARC, drainage area criteria (SRBC, 2012), similar to methods used to predict the spatial distribution of additional CU for electric power generation. The total projected 2030 approved and reported demand that exceeded the approved and reported totals in 2014, were distributed among ARC stream segments underlain by Marcellus Shale (Table C-7). The distribution was applied as a function of the percentage of existing (2014) approved withdrawal quantities per ARC stream segment.

Table C-7. The Portion of Total 2030 Projected Active Approved and Reported Use that was Distributed among ARC Settings

2030-2014 Active Approved Use (mgd)	2030-2014 Active Reported Use (mgd)
54.227	15.065

Given the uncertainty of unconventional well development in New York State within the 15-year period in which projections for the natural gas development are issued, increases in approved and reported uses in 2030 were distributed among ARC stream segments for a Pennsylvania-only scenario and a Pennsylvania and New York scenario. A current moratorium on hydraulic fracturing in New York State has been in effect since December 2014. As such, this analysis provided an alternate methodology that assumes the moratorium would end in 2018. An additional lag time of at least one year (to 2019) would be expected before the initiation of CU for natural gas development could be realized due to:

- time needed for state legislative approval of the Governor's action;
- finalization of regulatory permitting requirements; and
- time needed for the completion of Environmental Impact Statements currently required by New York State law.

This alternate methodology assumed that the same projected increase in hydraulically fractured wells (Figure C-3) would be evenly applied over Pennsylvania and New York portions of the Basin. This assumption was made based upon the following considerations:

- transmittal and storage infrastructure at or near capacity with current gas production in Pennsylvania;
- existing drilling infrastructure at close range to New York natural gas reserves; and
- the attractiveness to the industry of undeveloped Marcellus gas reserves in New York, while accounting for a potential decrease in production rates of Marcellus gas reserves in Pennsylvania by 2030.

For each scenario, an approved and reported CU demand per ARC stream segment, above 2014 baseline, was determined by dividing the demand by the lengths of each ARC within the relative portion of each state that overlaps the Marcellus Shale boundary. The total projected gas-related CU in 2030 was determined by calculating the new demand per mile of ARC stream length (Table C-8) plus CU quantities associated with any existing (2014) source locations within a user-defined watershed.

Table C-8. ARC Distribution of New 2030 Projected Approved and Reported Use for Both Pennsylvania and Pennsylvania and New York Scenarios

ARC	2014 Approved CU Distribution by ARC (%)	Pennsylvania Scenario			Pennsylvania and New York Scenario		
		Length (mi)[1]	2030-2014 Approved CU (mgd/mi)	2030-2014 Reported CU (mgd/mi)	Length (mi)[2]	2030-2014 Approved CU (mgd/mi)	2030-2014 Reported CU (mgd/mi)
1	4.3	26,268	0.0000892	0.0000248	35,833	0.0000654	0.0000182
2	11.8	2,787	0.0023021	0.0006395	3,723	0.0017233	0.0004787
3	24.6	1,327	0.0100489	0.0027917	1,836	0.0072630	0.0020177
4	20.9	823	0.0138021	0.0038343	1,127	0.0100791	0.0028000
5	18.7	262	0.0387799	0.0107733	467	0.0217566	0.0060441
6	19.6	416	0.0255135	0.0070878	416	0.0255135	0.0070878

[1]Length of ARC stream segments for the Pennsylvania scenario are representative of the overlap between ARC streams and Marcellus Shale boundary within Pennsylvania.
[2] The Length of ARC stream segments for the Pennsylvania and New York Scenario are representative of the overlap between ARC streams and Marcellus Shale boundary within both states.

Projected CU in 2030 accounts solely for Marcellus Shale development. There was greater uncertainty in projecting water use to 2030 for Utica Shale or other gas-containing geologic formation development within the Basin. Rapid development of the Utica Shale is possible due in part to the number of exploration wells recently drilled into the Utica and the transferability of existing permitting and water approvals from the Marcellus to the Utica. It is suggested, therefore, that CU projections for natural gas development within the Basin be flexible in the near-term and revised once water use information on Utica Shale and other gas-containing formations are made available from the gas industry.

<u>Public Water Supply</u>

CU projections for public water suppliers were estimated using county population projections. These county population projections were completed using the same methods identified by PA's Bureau of Watershed Management for the Act 220: State Water Plan (2006). The procedure utilized U.S. Census Bureau records from 1980, 1990, 2000, and 2010 for projecting decadal populations at the county level through the year 2030 (U.S. Department of Commerce, 2014). The method employed the Microsoft Excel FORECAST function, a least squares trending/regression function, to project 2030 county level populations. The 2030/2010 county-based population growth ratios were applied to 2014 approved and reported Public Water Supply (PWS) use depending upon the source location within the representative county. The 2030 approved and reported PWS use estimates were then multiplied by a consumptive use factor of 0.15. 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. 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 consumptive use factor (Shaffer and Runkle, 2007) to determine the total estimated consumptive use for the projected 2030 self-supplied residential population.

<u>Irrigation and Livestock</u>

To project irrigation and livestock related CU, county-based Agricultural Census datasets from 1997, 2002, 2007, and 2012 (USDA, 2014) were analyzed for the same livestock and crop categories used to estimate existing (2014) consumptive water. If records were disclosed for a specific crop or livestock category for one or more of the five-year datasets, the disclosed amount was averaged from available data preceding or existing after the specific disclosed year. The Microsoft Excel FORECAST function was used to project irrigated acres and livestock populations, per county, to 2030. Using the same methods for estimating existing (2014) CU for livestock and irrigation, CU coefficients for specific livestock (Jarrett, 2002) and estimated-irrigated quantities of water per crop ID (USDA, 2008) were used to derive projected 2030 CU for each corresponding livestock or crop category.

Because 60 percent of livestock-related water use permits were located in cultivated crop and pasture/hay land use classes, the majority of the livestock populations are assumed to exist in these land use classes. A change in area ratio between cultivated crop and pasture/hay land use classes was applied to the county-wide livestock CU to estimate livestock CU in 2030. CU for irrigation was spatially distributed by crop category identifiable throughout a crop-specific land cover (Cropland Data Layer) dataset from USDA (2010).

<u>Other Sectors</u>

For all other water use records captured within the CWUAS database, including manufacturing and non-manufacturing NAICS sectors, projected 2030 CU was estimated based on county population projections. Depending upon the source location of these facilities, 2014 approved and reported use were adjusted based upon the 2030/2014 population ratio per county.

APPENDIX D

Water Use, Water Capacity, and Water Availability Results for HUC-10 Watershed Pour Points

HUC-10 ID	Watershed Name	Hydrology Method	2014 Approved CU (mgd)	2014 Reported CU (mgd)	2030 Approved CU (mgd)	Water Capacity (mgd)[1]	Water Availability (2014 Approved CU) (mgd)[2]	Water Availability (2014 Reported CU) (mgd)[3]	Water Availability (2030 Approved CU) (mgd)[4]
0205010101	Canadarago Lake	Gage	0.1	0.1	0.1	30.6	30.5	30.5	30.5
0205010102	Cherry Valley Creek	Regression	0.1	0.1	0.1	21.5	21.4	21.5	21.4
0205010103	Schenevus Creek	Regression	0.1	0.1	0.1	25.4	25.3	25.3	25.3
0205010104	Charlotte Creek	Regression	0.2	0.2	0.2	38.5	38.3	38.3	38.3
0205010105	Otego Creek	Regression	0.3	0.1	0.3	25.5	25.2	25.4	25.2
0205010106	Headwaters Susquehanna River	Gage	2.0	0.9	2.0	161.4	159.4	160.5	159.4
0205010107	Wharton Creek	Regression	0.2	0.1	0.1	21.0	20.8	20.8	20.8
0205010108	Butternut Creek	Gage	0.2	0.1	0.1	31.5	31.3	31.4	31.4
0205010109	Unadilla River	Gage	1.4	0.9	1.2	134.7	133.4	133.8	133.5
0205010110	Ouleout Creek	Regression	0.1	0.1	0.1	28.4	28.3	28.3	28.3
0205010111	Upper Susquehanna River	Gage	3.1	1.5	3.0	243.1	240.0	241.6	240.1
0205010112	Middle Susquehanna River	Gage	5.5	3.1	5.4	402.8	397.3	399.8	397.4
0205010113	Lower Susquehanna River	Gage	25.0	7.8	25.8	483.5	458.5	475.7	457.6
0205010201	East Branch Tioughnioga River	Gage	2.2	0.9	2.2	46.1	43.9	45.2	43.9
0205010202	West Branch Tioughnioga River	Gage	2.4	0.9	2.4	24.5	22.1	23.6	22.1
0205010203	Otselic River	Gage	0.5	0.4	0.5	71.7	71.2	71.3	71.2
0205010204	Tioughnioga River	Gage	7.0	2.9	6.9	169.0	162.0	166.2	162.1
0205010205	Upper Chenango River	Gage	0.9	0.7	0.9	53.9	53.0	53.2	53.0
0205010206	Middle Chenango River	Gage	3.1	1.3	3.0	112.2	109.1	110.9	109.2
0205010207	Genegantslet Creek	Regression	0.1	0.1	0.1	21.5	21.4	21.4	21.4
0205010208	Lower Chenango River	Gage	14.7	6.5	14.1	356.1	341.5	349.6	342.0
0205010301	Nanticoke Creek	Regression	0.2	0.2	0.1	18.5	18.3	18.3	18.3
0205010302	Choconut Creek-Susquehanna River	Gage	44.7	15.6	44.7	817.7	773.0	802.1	773.0
0205010303	Catatonk Creek	Regression	0.3	0.3	0.3	26.9	26.6	26.7	26.6
0205010304	Owego Creek	Gage	1.0	0.7	0.9	71.1	70.2	70.4	70.2
0205010305	Pipe Creek-Susquehanna River	Gage	47.9	16.8	47.8	918.7	870.8	902.0	870.9
0205010306	Cayuta Creek	Regression	0.7	0.4	0.7	24.9	24.2	24.5	24.2
0205010307	Wappasening Creek-Susquehanna River	Gage	53.0	18.7	53.4	975.9	922.9	957.3	922.6
0205010401	Canacadea Creek	Gage	0.2	0.1	0.2	4.6	4.4	4.5	4.4
0205010402	Bennetts Creek	Regression	0.1	0.1	0.1	15.9	15.8	15.8	15.8
0205010403	Tuscarora Creek	Regression	0.4	0.2	0.4	15.1	14.7	14.9	14.7
0205010404	Canisteo River	Gage	11.5	2.3	11.6	53.3	41.8	51.0	41.7

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0205010405	Troups Creek	Regression	0.1	0.1	0.2	9.6	9.5	9.5	9.4
0205010406	Crooked Creek	Regression	0.1	0.1	0.3	16.5	16.3	16.3	16.1
0205010407	Mill Creek	Regression	0.1	0.1	0.2	9.8	9.7	9.7	9.6
0205010408	Cowanesque River	Gage	1.9	0.5	2.5	42.9	40.9	42.4	40.4
0205010409	Tioga River	Gage	23.3	5.0	24.7	128.6	105.3	123.6	103.9
0205010501	Upper Cohocton River	Gage	2.2	1.2	2.6	34.9	32.7	33.7	32.3
0205010502	Middle Cohocton River	Gage	4.6	2.1	5.2	47.8	43.2	45.6	42.5
0205010503	Lower Cohocton River	Gage	6.1	2.7	6.8	76.5	70.4	73.8	69.6
0205010504	Upper Chemung River	Gage	31.7	9.0	33.9	227.0	195.3	217.9	193.0
0205010505	Middle Chemung River	Gage	33.8	9.8	36.1	228.3	194.5	218.5	192.2
0205010506	Lower Chemung River	Gage	37.4	12.4	40.2	247.5	210.1	235.1	207.3
0205010601	Sugar Creek	Regression	3.8	1.5	4.0	22.3	18.5	20.8	18.3
0205010602	Schrader Creek	Regression	0.0	0.0	0.2	13.5	13.5	13.5	13.4
0205010603	Towanda Creek	Gage	1.5	0.8	1.9	43.4	42.0	42.6	41.5
0205010604	Wysox Creek	Regression	0.2	0.2	0.2	12.9	12.8	12.8	12.7
0205010605	Upper Susquehanna River	Gage	102.3	35.0	107.9	1342.9	1240.6	1307.9	1235.0
0205010606	East Branch Wyalusing Creek	Regression	0.8	0.7	0.8	12.6	11.8	11.9	11.8
0205010607	Wyalusing Creek	Regression	6.0	2.5	6.3	37.3	31.3	34.8	31.0
0205010608	Meshoppen Creek	Regression	4.2	2.1	4.3	18.9	14.7	16.9	14.6
0205010609	Mehoopany Creek	Regression	2.8	1.9	3.0	26.8	24.0	24.9	23.8
0205010610	East Branch Tunkhannock Creek	Regression	1.4	0.2	1.6	15.1	13.7	14.9	13.5
0205010611	South Branch Tunkhannock Creek	Regression	1.2	0.6	1.4	18.4	17.2	17.8	17.1
0205010612	Tunkhannock Creek	Gage	12.6	3.6	13.5	75.5	62.9	71.9	62.0
0205010613	Bowman Creek	Regression	2.4	1.6	2.6	30.1	27.7	28.5	27.4
0205010614	Lower Susquehanna River	Gage	144.0	51.6	153.6	1395.6	1251.7	1344.0	1242.0
0205010701	Lackawanna River	Gage	44.4	9.6	44.0	64.6	20.2	54.9	20.6
0205010702	Upper Susquehanna River	Gage	191.6	62.9	201.5	1471.9	1280.3	1409.0	1270.4
0205010703	Middle Susquehanna River	Gage	243.3	94.4	254.2	1508.5	1265.2	1414.0	1254.3
0205010704	Nescopeck Creek	Regression	4.5	1.9	4.8	31.7	27.2	29.7	26.8
0205010705	Huntington Creek	Regression	0.1	0.1	0.4	20.6	20.5	20.5	20.2
0205010706	Little Fishing Creek	Regression	0.1	0.1	0.2	8.0	7.9	7.9	7.8
0205010707	Fishing Creek	Gage	2.2	1.2	3.2	97.1	94.9	95.8	93.9

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0205010708	Catawissa Creek	Regression	4.1	1.6	4.4	26.0	21.9	24.4	21.6
0205010709	Roaring Creek	Regression	1.3	0.9	1.4	11.9	10.6	11.0	10.4
0205010710	Lower Susquehanna River	Gage	262.6	103.2	277.3	1820.7	1558.1	1717.5	1543.4
0205020101	Chest Creek	Regression	0.4	0.2	0.6	26.4	25.9	26.1	25.7
0205020102	Anderson Creek	Regression	3.2	2.2	3.5	17.1	13.9	14.9	13.6
0205020103	Clearfield Creek	Gage	4.0	0.7	4.8	78.1	74.0	77.3	73.3
0205020104	Upper West Branch Susquehanna River	Gage	14.6	5.6	17.0	219.2	204.6	213.6	202.2
0205020105	Moshannon Creek	Regression	3.5	1.4	4.6	77.9	74.4	76.5	73.3
0205020106	Mosquito Creek	Regression	0.7	0.0	0.9	16.9	16.1	16.9	16.0
0205020107	Lower West Branch Susquehanna River	Gage	28.3	11.5	34.2	391.7	363.3	380.2	357.4
0205020201	Sinnemahoning Portage Creek	Regression	0.1	0.1	0.2	17.2	17.1	17.1	17.1
0205020202	Driftwood Branch Sinnemahoning Creek	Gage	2.5	1.8	2.9	67.0	64.4	65.1	64.0
0205020203	Bennett Branch Sinnemahoning Creek	Regression	1.2	0.6	1.8	93.4	92.2	92.8	91.6
0205020204	First Fork Sinnemahoning Creek	Regression	0.3	0.3	0.9	62.8	62.5	62.5	61.9
0205020205	Sinnemahoning Creek	Gage	4.0	2.7	6.2	225.5	221.5	222.8	219.3
0205020301	Kettle Creek	Gage	0.1	0.1	0.7	63.7	63.6	63.6	63.0
0205020302	Upper West Branch Susquehanna River	Gage	32.5	14.7	42.1	651.3	618.7	636.6	609.2
0205020303	Young Womans Creek	Gage	0.0	0.0	0.1	22.3	22.3	22.3	22.2
0205020304	Lower West Branch Susquehanna River	Gage	54.4	22.1	70.6	794.3	739.9	772.2	723.7
0205020401	Spring Creek	Gage	10.5	4.3	12.7	10.9	0.4	6.6	-1.9
0205020402	Beech Creek	Gage	0.4	0.2	0.9	46.8	46.3	46.6	45.8
0205020403	Fishing Creek	Regression	2.6	1.2	3.1	35.3	32.7	34.1	32.2
0205020404	Bald Eagle Creek	Gage	16.9	6.6	21.5	119.0	102.1	112.4	97.5
0205020501	West Branch Pine Creek	Regression	0.1	0.1	0.2	16.9	16.8	16.8	16.7
0205020502	Upper Pine Creek	Gage	1.5	0.1	2.1	51.0	49.4	50.8	48.9
0205020503	Marsh Creek	Regression	1.7	1.1	1.8	10.1	8.4	9.0	8.3
0205020504	Babb Creek	Regression	2.9	0.6	3.1	18.0	15.1	17.4	14.9
0205020505	Little Pine Creek	Regression	0.1	0.1	0.3	35.1	35.0	35.0	34.8
0205020506	Lower Pine Creek	Gage	11.7	3.2	13.7	199.8	188.1	196.6	186.1
0205020601	Larrys Creek	Regression	1.6	1.3	1.8	17.1	15.4	15.8	15.3
0205020602	Lycoming Creek	Gage	7.3	2.6	7.8	62.1	54.8	59.5	54.3
0205020603	Upper Loyalsock Creek	Regression	0.0	0.0	0.3	34.2	34.2	34.2	33.9

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0205020604	Little Loyalsock Creek	Regression	0.2	0.2	0.3	14.4	14.2	14.2	14.1
0205020605	Lower Loyalsock Creek	Gage	2.2	0.4	3.3	120.0	117.9	119.6	116.8
0205020606	West Branch Susquehanna River	Gage	85.0	33.8	106.6	1151.0	1066.0	1117.2	1044.4
0205020607	Little Muncy Creek	Regression	1.4	0.1	1.5	10.8	9.4	10.6	9.2
0205020608	Muncy Creek	Regression	4.1	1.9	4.5	32.1	28.0	30.1	27.5
0205020609	White Deer Hole Creek	Regression	0.1	0.1	0.2	10.6	10.5	10.5	10.4
0205020610	Buffalo Creek	Regression	1.6	0.7	2.5	22.0	20.4	21.3	19.6
0205020611	Chillisquaque Creek	Gage	1.3	0.8	1.7	11.9	10.6	11.1	10.2
0205020612	West Branch Susquehanna River	Gage	125.3	52.1	150.5	1289.7	1164.4	1237.6	1139.2
0205030101	Shamokin Creek	Gage	3.9	1.4	4.2	13.8	10.0	12.4	9.7
0205030102	Pine Creek	Regression	0.3	0.3	0.5	23.8	23.5	23.6	23.3
0205030103	Middle Creek	Regression	1.2	0.9	1.7	27.5	26.3	26.6	25.8
0205030104	Penns Creek	Gage	4.2	3.7	6.7	107.8	103.6	104.2	101.2
0205030105	Mahanoy Creek	Regression	10.3	3.7	10.8	23.2	12.9	19.5	12.4
0205030106	West Branch Mahantango Creek	Regression	0.8	0.8	0.9	8.1	7.3	7.3	7.2
0205030107	Deep Creek	Regression	17.3	16.8	17.0	14.3	-3.0	-2.5	-2.7
0205030108	Mahantango Creek	Gage	20.5	20.1	20.9	25.3	4.8	5.2	4.4
0205030109	Wiconisco Creek	Regression	8.6	8.0	9.6	20.0	11.4	12.0	10.5
0205030110	Susquehanna River	Gage	443.0	194.8	491.5	3118.9	2675.9	2924.2	2627.5
0205030201	Upper Frankstown Branch Juniata River	Regression	1.8	0.9	1.9	18.4	16.7	17.5	16.5
0205030202	Beaverdam Branch	Regression	3.0	1.7	3.0	13.0	10.0	11.3	10.0
0205030203	Lower Frankstown Branch Juniata River	Gage	6.4	4.2	7.2	59.8	53.4	55.6	52.6
0205030204	Spruce Creek	Regression	2.3	0.8	2.8	5.6	3.3	4.8	2.7
0205030205	Little Juniata River	Gage	6.1	2.3	7.0	73.2	67.1	70.8	66.2
0205030206	Shaver Creek	Regression	0.1	0.1	0.2	7.5	7.3	7.3	7.2
0205030207	Standing Stone Creek	Regression	1.0	0.3	1.4	13.6	12.5	13.3	12.1
0205030208	Juniata River	Gage	11.8	7.3	14.3	142.8	131.0	135.5	128.5
0205030301	Upper Raystown Branch Juniata River	Regression	1.6	0.7	1.9	19.0	17.5	18.3	17.2
0205030302	Bobs Creek	Regression	0.2	0.2	0.3	11.2	11.0	11.0	10.9
0205030303	Dunning Creek	Gage	0.6	0.5	1.0	30.7	30.0	30.1	29.7
0205030304	Brush Creek	Regression	0.1	0.1	0.3	9.6	9.4	9.4	9.3
0205030305	Middle Raystown Branch Juniata River	Gage	2.8	1.7	4.3	82.5	79.7	80.8	78.2

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0205030306	Yellow Creek	Regression	0.5	0.3	0.7	11.9	11.3	11.5	11.2
0205030307	Great Trough Creek	Regression	0.2	0.1	0.4	13.3	13.1	13.1	12.9
0205030308	Lower Raystown Branch Juniata River	Gage	3.8	2.5	7.1	126.6	122.8	124.1	119.5
0205030401	Juniata River	Gage	16.5	10.8	24.1	298.8	282.4	288.0	274.7
0205030402	Sideling Hill Creek	Regression	0.2	0.2	0.4	11.8	11.6	11.6	11.4
0205030403	Blacklog Creek	Regression	0.1	0.1	0.2	5.2	5.1	5.1	5.0
0205030404	Aughwick Creek	Gage	0.7	0.7	1.7	40.7	40.1	40.1	39.0
0205030405	Upper Juniata River	Gage	17.7	11.2	26.8	318.9	301.2	307.7	292.0
0205030406	Honey Creek	Regression	1.5	0.9	1.6	15.5	14.1	14.6	13.9
0205030407	Kishacoquillas Creek	Gage	2.6	2.0	2.9	31.5	28.9	29.5	28.6
0205030408	Middle Juniata River	Gage	22.0	14.5	33.3	394.5	372.4	380.0	361.1
0205030409	Tuscarora Creek	Gage	0.8	0.7	1.5	31.9	31.1	31.2	30.4
0205030410	Cocolamus Creek	Regression	0.3	0.3	0.4	6.1	5.8	5.8	5.6
0205030411	Buffalo Creek	Regression	0.2	0.2	0.5	7.9	7.7	7.7	7.4
0205030412	Lower Juniata River	Gage	23.5	15.9	36.9	431.0	407.5	415.1	394.1
0205030501	Sherman Creek	Gage	0.8	0.8	1.7	35.5	34.7	34.7	33.8
0205030502	Upper Conodoguinet Creek	Regression	1.9	0.9	2.3	11.7	9.8	10.9	9.4
0205030503	Middle Conodoguinet Creek	Gage	5.4	3.8	6.8	38.4	32.9	34.6	31.6
0205030504	Lower Conodoguinet Creek	Gage	15.1	8.8	18.6	61.7	46.6	52.9	43.1
0205030505	Yellow Breeches Creek	Gage	6.8	4.3	8.1	23.4	16.6	19.1	15.4
0205030506	Upper Swatara Creek	Gage	5.4	2.9	6.0	41.9	36.5	39.0	36.0
0205030507	Little Swatara Creek	Regression	1.9	1.1	2.2	13.3	11.4	12.2	11.1
0205030508	Quittapahilla Creek	Gage	8.4	4.0	9.0	3.8	-4.5	-0.1	-5.1
0205030509	Lower Swatara Creek	Gage	32.0	16.9	35.3	92.0	60.1	75.1	56.7
0205030510	Susquehanna River	Gage	550.3	262.9	623.2	3976.4	3426.1	3713.5	3353.1
0205030601	South Branch Conewago Creek	Regression	11.3	5.9	13.9	7.2	-4.1	1.3	-6.7
0205030602	Upper Conewago Creek	Gage	14.6	7.8	17.6	22.3	7.8	14.5	4.7
0205030603	Bermudian Creek	Regression	2.0	1.4	1.9	12.5	10.5	11.1	10.6
0205030604	Little Conewago Creek	Regression	2.0	0.8	2.4	6.6	4.6	5.7	4.2
0205030605	Lower Conewago Creek	Gage	20.4	10.5	24.3	52.4	32.0	41.9	28.1
0205030606	South Branch Codorus Creek	Gage	7.3	3.3	8.8	8.5	1.3	5.2	-0.2
0205030607	Codorus Creek	Gage	5.2	1.4	5.8	25.0	19.7	23.6	19.2

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0205030608	Chiques Creek	Regression	3.9	3.0	4.4	7.2	3.3	4.2	2.8
0205030609	Cocalico Creek	Regression	3.5	2.5	4.0	13.8	10.3	11.3	9.8
0205030610	Little Conestoga Creek	Regression	5.2	2.4	6.1	0.0	-5.2	-2.4	-6.1
0205030611	Conestoga River	Gage	23.4	14.2	27.5	62.8	39.4	48.6	35.3
0205030612	Pequea Creek	Gage	2.9	2.7	3.3	14.8	11.9	12.0	11.5
0205030613	Muddy Creek	Regression	0.6	0.5	0.7	1.3	0.7	0.8	0.6
0205030614	East Branch Octoraro Creek	Regression	1.7	1.0	2.1	4.7	3.0	3.8	2.7
0205030615	Octoraro Creek	Regression	35.6	24.8	43.7	28.8	-6.7	4.1	-14.9
0205030616	Deer Creek	Gage	6.0	1.3	7.5	9.1	3.1	7.8	1.6
0205030617	Lower Susquehanna River	Gage	1034.8	367.0	1203.3	4371.2	3336.4	4004.3	3167.9

[1] (10 Year Baseflow - September P75 or P95) x 50%
[2] ((10 Year Baseflow - September P75 or P95) x 50%) - 2014 Approved CU
[3] ((10 Year Baseflow - September P75 or P95) x 50%) - 2014 Reported CU
[4] ((10 Year Baseflow - September P75 or P95) x 50%) - 2030 Approved CU

APPENDIX E

Ranges of Watershed Characteristics Used In the Regional Regression Analysis

Watershed Characteristic	Abbreviation	Source	Units	Min	Mean	Max
Alluvium	ALLUV	PADCNR; NYS Museum	Percentage	0	2.7	23.3
Average Slope	AVSLP	USGS	Degrees	2.7	8.3	15.2
Available Water Capacity	AWC	Schwarz and Alexander	Inches/Inch	0.1	0.1	0.2
Base Flow Index	BFI	USGS	Percentage	34.9	46.8	63.5
Carbonate Bedrock	CARB	PADCNR; NYS Museum; USGS	Percentage	0	18.1	92.8
Hydrostratigraphic Carbonate Rock Type	CARBHY	SRBC	Percentage	0	11.4	83.3
Clay in Soil	CLAY	Schwarz and Alexander	Percentage	12.6	20.2	34
Coal	COAL	PADEP	Percentage	0	8.4	100
Hydrostratigraphic Compositional Partings Rock Type	COMP	SRBC	Percentage	0	2	96.5
Drainage Area	DA	USGS	Square Miles	1.8	183.5	985.3
Hydrostratigraphic Diabase Rock Type	DIABAS	SRBC	Percentage	0	0.6	11.1
Mean Elevation	ELEV	USGS	Feet	515.9	1392.7	2194.6
Soil Erodibility Factor	ERODE	Schwarz and Alexander	Unitless	0.2	0.3	0.4
Hydrostratigraphic Flat Shale Rock Type	FLATSH	SRBC	Percentage	0	22	100
Hydrostratigraphic Flat Sandstone Rock Type	FLATSST	SRBC	Percentage	0	25.3	100
Hydrostratigraphic Folded Shale Rock Type	FLDSHL	SRBC	Percentage	0	18.3	75.6
Hydrostratigraphic Folded Sandstone Rock Type	FLDSS	SRBC	Percentage	0	19.8	96.7
Forest Biomass	FORBIO	USDA	Megagrams/ Hectare	8.6	83.1	170.2
Forest	FOREST	USGS	Percentage	10.6	61.1	94.9
Glaciation	GLAC	PADCNR	Percentage	0	40.5	100
Hydrologic Soil Group	HYGRP	Schwarz and Alexander	Unitless	2.1	2.6	3.3
Hydrostratigraphic Massive Rock Type	MASS	SRBC	Percentage	0	0.5	32.8
10/85 Mean Channel Slope	MNSLP	USGS	Feet/Mile	3.1	36.2	153.2
Mean Potential Evapotranspiration	PE	Trabucco, A.	Inches/Inch	34.6	38.3	42.7
Soil Permeability	PERM	Schwarz and Alexander	Inches/Hour	0.6	3.1	7.5
Annual Mean Precipitation	PREC	PRISM Group	Inches	35.8	43.3	52.3
Monthly Mean Precipitation (No. Denotes Month)	PREC1	PRISM Group	Inches	NA	NA	NA
Watershed Shape Factor	SHPFCT	SRBC	Unitless	1.6	2.9	5.7
Water Storage	STOR	USGS; USFWS	Percentage	0.1	1.9	15.7

Watershed Characteristic	Abbreviation	Source	Units	Min	Mean	Max
Stream Density	STRDEN	USGS	Miles/ Square Mile	0.8	1.7	2.7
Soil Thickness	THICK	Schwarz and Alexander	Inches	47.6	55.7	66
Till	TILL	PADCNR; NYS Museum	Percentage	0	35.6	100
Annual Mean Maximum Temperature	TMAX	PRISM Group	Fahrenheit	54.3	57.8	63.4
Monthly Mean Maximum Temperature (No. Denotes Month)	TMAX1-12	PRISM Group	Fahrenheit	NA	NA	NA
Annual Mean Minimum Temperature	TMIN	PRISM Group	Fahrenheit	33.9	37.6	43
Monthly Mean Minimum Temperature (No. Denotes Month)	TMIN1-12	PRISM Group	Fahrenheit	NA	NA	NA
Topographic Position Index Ridge Area	TPIRDG	Jenness, J.; USGS	Percentage	4.1	30.6	48.2
Topographic Position Index Slope Area	TPISLP	Jenness, J.; USGS	Percentage	5.3	17	39.3
Topographic Position Index Valley Area	TPIVAL	Jenness, J.; USGS	Percentage	38.6	52.4	66.4
Urban	URBAN	USGS	Percentage	0	3.1	20.4

APPENDIX F

Metadata for Watershed Characteristics Used in the Regional Regression Analysis

Name	Abbrev.	Source	Source Dataset	Time Period	Scale/ Resolution	Original Units	Regression Units	URL
Alluvium	ALLUV	PADCNR	Hardcopy maps	1975-1993	62,500 – 250,000	Square Meters	Percentage	http://www.dcnr.state.pa.us/topogeo/index.aspx
		NYS Museum	Surficial Geology	1999	250,000			https://www.nysm.nysed.gov/gis/
Average Slope	AVSLP	USGS	NED	2013	10 Meter	Meters	Degrees	http://viewer.nationalmap.gov/basic/
Available Water Capacity	AWC	Schwarz & Alexander	STATSGO	1995	250,000	Inches/Inch	Inches/Inch	
Base Flow Index	BFI	USGS	BFI	2003	1 Kilometer	Percentage	Percentage	http://water.usgs.gov/lookup/getspatial?bfi48grd
Carbonate Bedrock	CARB	PADCNR	Bedrock Geology	2001	250,000	Square Meters	Percentage	http://www.dcnr.state.pa.us/topogeo/index.aspx
		NYS Museum	Bedrock Geology	1999				https://www.nysm.nysed.gov/gis/
		USGS	General Geology	1992				
Hydrostrati-graphic Carbonate Rock Type	CARBHY	SRBC	Bedrock Geology	2004	250,000	Square Meters	Percentage	
Clay in Soil	CLAY	Schwarz & Alexander	STATSGO	1995	250,000	Percentage	Percentage	
Coal	COAL	PADEP	Various	1996-2013	24,000	Square Meters	Percentage	
Hydrostrati-graphic Compositional Partings Rock Type	COMP	SRBC	Bedrock Geology	2004	250,000	Square Meters	Percentage	
Drainage Area	DA	USGS	NED	1999	30 Meter	Meters	Square Miles	http://viewer.nationalmap.gov/basic/
Hydrostrati-graphic Diabase Rock Type	DIABAS	SRBC	Bedrock Geology	2004	250,000	Square Meters	Percentage	
Mean Elevation	ELEV	USGS	NED	2013	10 Meter	Meters	Feet	http://viewer.nationalmap.gov/basic/
Soil Erodibility Factor	ERODE	Schwarz & Alexander	STATSGO	1995	250,000	Unitless	Unitless	

Name	Abbrev.	Source	Source Dataset	Time Period	Scale/ Resolution	Original Units	Regression Units	URL
Hydrostrati-graphic Flat Sandstone Rock Type	FLATSST	SRBC	Bedrock Geology	2004	250,000	Square Meters	Percentage	
Hydrostrati-graphic Folded Shale Rock Type	FLDSHL	SRBC	Bedrock Geology	2004	250,000	Square Meters	Percentage	
Hydrostrati-graphic Folded Sandstone Rock Type	FLDSS	SRBC	Bedrock Geology	2004	250,000	Square Meters	Percentage	
Forest Biomass	FORBIO	USDA	U.S. Biomass Map	2006	30 Meter	Megagrams/ Hectare (Mg/H)	Megagrams/ Hectare (Mg/H)	http://data.fs.usda.gov/geodata/rastergateway/ biomass/conus_forest_biomass.php#3
Forest	FOREST	USGS	Chesapeake Bay Land Use	2006	30 Meter	Meters	Percentage	http://www.pasda.psu.edu
Glaciation	GLAC	PADCNR	Map 59	1997	1,500,00	Square Meters	Percentage	http://www.dcnr.state.pa.us/topogeo/index.aspx
Hydrologic Soil Group	HYGRP	Schwarz & Alexander	STATSGO	1995	250,000	Unitless	Unitless	
Hydrostrati-graphic Massive Rock Type	MASS	SRBC	Bedrock Geology	2004	250,000	Square Meters	Percentage	
10/85 Mean Channel Slope	MNSLP	USGS	NED	1999	30 Meter	Meters	Feet/Mile	http://viewer.nationalmap.gov/basic/
Mean Potential Evapotrans-piration	PE	Trabucco, A.	Global-PET	1950-2000	1 Kilometer	Millimeters	Inches	http://www.cgiar-csi.org/data/global-aridity-and-pet-database
Soil Permeability	PERM	Schwarz & Alexander	STATSGO	1995	250,000	Inches/Hour	Inches/Hour	
Annual Mean Precipitation	PREC	PRISM Group	30 Year Normals	2012	800 Meter	Millimeters*100	Inches	http://www.prism.oregonstate.edu/normals/
Monthly Mean Precipitation	PREC1-12	PRISM Group	30 Year Normals	2012	800 Meter	Millimeters*100	Inches	http://www.prism.oregonstate.edu/normals/
Watershed Shape Factor	SHPFCT	SRBC	DA	2015	30 Meter	$Length^2/DA$	Unitless	
Water Storage	STOR	USGS	NHD	2004	24,000	Square Meters	Percentage	http://nhd.usgs.gov/
		USFWS	NWI	2005				http://www.fws.gov/wetlands/

Name	Abbrev.	Source	Source Dataset	Time Period	Scale/ Resolution	Original Units	Regression Units	URL
Soil Thickness	THICK	Schwarz & Alexander	STATSGO	1995	250,000	Inches	Inches	
Till	TILL	PADCNR	Hardcopy maps	1975-1993	62,500 – 250,000	Square Meters	Percentage	http://www.dcnr.state.pa.us/topogeo/index.aspx
		NYS Museum	Surficial Geology	1999	250,000			https://www.nysm.nysed.gov/gis/
Annual Mean Maximum Temperature	TMAX	PRISM Group	30 Year Normals	2012	800 Meter	Celsius	Fahrenheit	http://www.prism.oregonstate.edu/normals/
Monthly Mean Maximum Temperature	TMAX1-12	PRISM Group	30 Year Normals	2012	800 Meter	Celsius	Fahrenheit	http://www.prism.oregonstate.edu/normals/
Annual Mean Minimum Temperature	TMIN	PRISM Group	30 Year Normals	2012	800 Meter	Celsius	Fahrenheit	http://www.prism.oregonstate.edu/normals/
Monthly Mean Minimum Temperature	TMIN1-12	PRISM Group	30 Year Normals	2012	800 Meter	Celsius	Fahrenheit	http://www.prism.oregonstate.edu/normals/
Topographic Position Index Ridge Area	TPIRDG	Jenness, J.	TPI v. 1.3a	2006	10 Meter	Meters	Percentage	http://www.jennessent.com/arcview/tpi.htm
		USGS	NED	2013				http://viewer.nationalmap.gov/basic/
Topographic Position Index Slope Area	TPISLP	Jenness, J.	TPI v. 1.3a	2006	10 Meter	Meters	Percentage	http://www.jennessent.com/arcview/tpi.htm
		USGS	NED	2013				http://viewer.nationalmap.gov/basic/
Topographic Position Index Valley Area	TPIVAL	Jenness, J.	TPI v. 1.3a	2006	10 Meter	Meters	Percentage	http://www.jennessent.com/arcview/tpi.htm
		USGS	NED	2013				http://viewer.nationalmap.gov/basic/
Urban	URBAN	USGS	Chesapeake Bay Land Use	2006	30 Meter	Meters	Percentage	http://www.pasda.psu.edu

APPENDIX G

Regression Equations Developed as Part of the Hydrologic Analyses

Statistic	Region	Regression Equation	Std. Error
ELOHA	-	$10^{-8.27104}(DA)^{1.03345}(PREC)^{3.48825}(100BFI)^{1.05116}(CLAY+1)^{-7.08615}(COAL+1)^{1.45322}(CARBHY+1)^{2.71320}(FLATSST+1)^{0.54603}$	27%
ADF	-	$10^{-3.95382}(DA)^{1.03257}(PREC)^{2.02373}(ELEV)^{0.24249}$	9%
7Q10	NG	$10^{-4.91465}(DA)^{1.32853}(ERODE)^{2.08695}(STRDEN)^{-2.08590}(CARB+1)^{4.47745}(ALLUV+1)^{-57.20942}(TPIRDG+1)^{29.93425}(TPISLP+1)^{21.48124}(FLATSST+1)^{-1.91536}$	57%
	G	$10^{-7.76080}(DA)^{1.23804}(100BFI)^{3.65173}$	67%
BF2	-	$10^{-5.73760}(DA)^{1.01445}(PREC)^{2.23814}(ELEV)^{0.45681}(100BFI)^{0.53954}(STRDEN)^{-0.29243}(TPIVAL+1)^{-1.22249}(CARBHY+1)^{0.43350}$	14%
BF5	-	$10^{-6.59556}(DA)^{1.02712}(PREC)^{2.22465}(ELEV)^{0.50125}(100BFI)^{0.78986}(STRDEN)^{-0.25558}(FLDSHL+1)^{-0.25774}$	16%
BF10	-	$10^{-8.05052}(DA)^{1.04730}(PREC)^{2.35452}(ELEV)^{0.68134}(100BFI)^{1.10738}(FLDSHL+1)^{-0.38250}$	18%
BF25	-	$10^{-8.21450}(DA)^{1.04768}(PREC)^{2.18741}(ELEV)^{0.76714}(100BFI)^{1.16967}(FLDSHL+1)^{-0.43388}$	21%
BF50	-	$10^{-8.79416}(DA)^{1.03352}(PREC)^{2.31446}(ELEV)^{0.86618}(100BFI)^{1.20173}(FLDSHL+1)^{-0.42427}$	21%
BF_Avg	-	$10^{-5.53002}(DA)^{1.01542}(PREC)^{2.07100}(ELEV)^{0.46435}(100BFI)^{0.56338}(STRDEN)^{-0.26427}(TPIVAL+1)^{-1.22185}(CARBHY+1)^{0.40286}$	14%
P50_1	-	$10^{-2.75458}(DA)^{1.04374}(PREC1)^{1.44633}(ELEV)^{0.29894}(100BFI)^{0.64053}$	15%
P50_2	-	$10^{-0.63587}(DA)^{1.03657}(PREC2)^{1.42722}(PERM)^{0.06801}(COAL+1)^{0.25313}$	14%
P50_3	-	$10^{1.56031}(DA)^{1.03093}(PREC3)^{1.20909}(TMAX3)^{-1.41321}(FORBIO)^{0.18386}(FLDSHL+1)^{0.21221}(FLATSH+1)^{0.27589}$	10%
P50_4	-	$10^{9.03970}(DA)^{1.06564}(PREC4)^{1.12008}(PE)^{-5.92267}(AVSLP)^{0.12400}(HYGRP)^{-0.49703}(TILL+1)^{-0.26662}$	12%
P50_5	-	$10^{5.12419}(DA)^{1.04730}(PREC5)^{1.70888}(TMAX5)^{-4.18929}(100BFI)^{0.81188}(STRDEN)^{-0.28296}(FOREST+1)^{1.26720}(CARBHY+1)^{0.44095}(FLDSHL+1)^{-0.45207}$	15%
P50_6	-	$10^{-2.07657}(DA)^{1.04522}(PREC6)^{1.89580}(AWC)^{0.95326}(100BFI)^{1.12542}(CLAY+1)^{-7.92398}(FOREST+1)^{0.99002}(COAL+1)^{1.06904}(CARBHY+1)^{2.06756}$	24%
P50_7	-	$10^{-7.68150}(DA)^{1.08485}(PREC7)^{2.50294}(THICK)^{1.86173}(100BFI)^{1.21697}(FOREST+1)^{0.79687}(COAL+1)^{1.08340}(CARBHY+1)^{1.52323}(FLDSS+1)^{0.42089}$	30%
P50_8	-	$10^{-5.85967}(DA)^{1.07590}(PREC8)^{2.55430}(THICK)^{1.40606}(ERODE)^{0.96437}(100BFI)^{1.38269}(CLAY+1)^{-8.20047}(COAL+1)^{2.13925}(CARBHY+1)^{2.87828}(FLATSH+1)^{-0.86645}$	36%
P50_9	-	$10^{-7.97389}(DA)^{1.20918}(PREC9)^{3.82871}(MNSLP)^{0.19817}(THICK)^{2.40211}(COAL+1)^{1.60797}(CARBHY+1)^{2.31194}$	38%
P50_10	-	$10^{-7.68445}(DA)^{1.09248}(PREC10)^{3.89958}(FORBIO)^{-0.32019}(THICK)^{1.63336}(ELEV)^{1.08531}(URBAN+1)^{4.34214}(CARB+1)^{0.63982}(GLAC+1)^{-0.60077}(ALLUV+1)^{-3.05057}(TPIVAL+1)^{-4.13224}$	34%
P50_11	-	$10^{2.01112}(DA)^{1.00511}(PREC11)^{2.79584}(TMAX11)^{4.38355}(PE)^{-8.19208}(AVSLP)^{0.58303}(AWC)^{-0.66323}(TPIRDG+1)^{2.41248}(TPISLP+1)^{5.31457}(CARBHY+1)^{1.23969}$	19%
P50_12	-	$10^{3.35780}(DA)^{1.02812}(PREC12)^{1.71365}(TMAX12)^{-3.13204}(100BFI)^{0.39581}(COAL+1)^{0.25547}$	16%
P75_1	NG	$10^{7.02943}(DA)^{1.08093}(PE)^{-3.93653}(STRDEN)^{-0.53572}(TPIVAL+1)^{-5.15665}(FLATSST+1)^{-0.76380}$	20%
	G	$10^{-6.55651}(DA)^{1.07909}(PREC1)^{1.47764}(ELEV)^{0.87036}(100BFI)^{1.65133}$	15%
P75_2	NG	$10^{4.61234}(DA)^{1.06933}(PE)^{-2.44262}(SHPFCT)^{-0.19528}(STRDEN)^{-0.59241}(TPIVAL+1)^{-3.88728}(FLATSST)^{-0.76665}$	17%
	G	$10^{-0.52579}(DA)^{1.01291}(PREC2)^{1.47712}(HYGRP)^{-0.73862}(STOR+1)^{3.16197}$	16%
P75_3	NG	$10^{7.52233}(DA)^{1.07285}(PREC3)^{2.07983}(PE)^{-5.44989}$	15%
	G	$10^{7.33918}(DA)^{1.05438}(PREC3)^{1.38780}(TMAX3)^{-4.86122}(CLAY+1)^{-2.93327}(FLDSHL+1)^{0.92740}(FLDSS+1)^{0.38868}$	8%
P75_4	NG	$10^{5.43590}(DA)^{1.06806}(PE)^{-3.47737}(HYGRP)^{-0.66200}(STRDEN)^{-0.49675}(ALLUV+1)^{-8.03672}(TPIRDG+1)^{3.09897}(TPISLP+1)^{1.60277}$	14%
	G	$10^{7.70576}(DA)^{1.04303}(PREC4)^{1.77025}(PE)^{-5.52697}(PERM)^{0.14690}(STRDEN)^{0.50803}(COAL+1)^{-1.05705}(TPISLP+1)^{-1.99604}$	10%
P75_5	NG	$10^{10.35150}(DA)^{1.08754}(PREC5)^{1.63124}(PE)^{-6.77637}(HYGRP)^{-1.53892}(STRDEN)^{-0.81303}$	16%
	G	$10^{-2.15401}(DA)^{1.02739}(PREC5)^{1.09691}(FORBIO)^{0.74856}(STOR+1)^{8.28203}(TPISLP+1)^{-4.12033}$	13%
P75_6	NG	$10^{0.89500}(DA)^{0.97114}(MNSLP)^{-0.17922}(PERM)^{0.48172}(ERODE)^{1.52494}(ELEV)^{0.49699}(STRDEN)^{-1.28804}(CARB+1)^{1.03320}(TPIVAL+1)^{-8.44222}(FLATSST+1)^{-0.79555}$	19%
	G	$10^{-8.62961}(DA)^{1.33192}(FORBIO)^{1.95759}(MNSLP)^{0.36371}(100BFI)^{2.71072}(FOREST+1)^{-5.85294}$	25%
P75_7	NG	$10^{-3.25476}(DA)^{1.07557}(ERODE)^{1.38262}(ELEV)^{0.61953}(STRDEN)^{-1.79215}(CARB+1)^{1.56676}(TPIRDG+1)^{10.82291}(TPISLP+1)^{9.77948}(FLATSST+1)^{-1.56978}$	24%

Statistic	Region	Regression Equation	Std. Error
	G	$10^{-6.42224}(DA)^{1.16245}(PREC7)^{3.70810}(100BFI)^{1.86141}$	37%
P75_8	NG	$10^{-7.80619}(DA)^{1.13388}(THICK)^{4.16448}(STRDEN)^{-1.89670}(FLATSH+1)^{1.16041}$	50%
	G	$10^{22.78958}(DA)^{1.15373}(TMAX8)^{-16.55894}(100BFI)^{4.49846}(ALLUV+1)^{3.96077}(FLATSH+1)^{-1.52803}$	37%
P75_9	NG	$10^{2.78322}(DA)^{1.14363}(ERODE)^{1.95645}(STRDEN)^{-1.69760}(URBAN+1)^{3.32471}(CARB+1)^{2.39258}(ALLUV+1)^{-76.72875}(TPIRDG+1)^{5.45712}(TPIVAL+1)^{-16.04444}(FLATSST+1)^{-1.05278}$	27%
	G	$10^{19.19374}(DA)^{1.35708}(PE)^{-16.63983}(MNSLP)^{0.44870}(100BFI)^{2.75371}(ALLUV+1)^{6.21452}(FLDSHL+1)^{1.47761}(FLATSH+1)^{-1.62329}$	31%
P75_10	NG	$10^{2.53846}(DA)^{1.06941}(AVSLP)^{0.67293}(ERODE)^{1.11564}(STRDEN)^{-1.59048}(CARB+1)^{1.98441}(ALLUV+1)^{-19.11093}(TPIVAL+1)^{-16.06225}(FLATSST+1)^{-1.22990}$	30%
	G	$10^{13.53144}(DA)^{1.03441}(PREC10)^{2.66151}(PE)^{-10.15138}(ALLUV+1)^{4.39355}(FLATSH+1)^{-1.67024}$	34%
P75_11	NG	$10^{0.24571}(DA)^{0.98465}(PREC11)^{2.60423}(PERM)^{0.64460}(ERODE)^{1.97412}(URBAN+1)^{5.67643}(CARB+1)^{1.21430}(TPIVAL+1)^{-8.19549}$	26%
	G	$10^{-3.03504}(DA)^{1.07826}(PREC11)^{4.53042}(PERM)^{-0.22134}$	34%
P75_12	NG	$10^{8.91606}(DA)^{1.00781}(PREC12)^{1.54036}(PE)^{-5.93145}(URBAN+1)^{4.25887}(TPIVAL+1)^{-2.98885}$	24%
	G	$10^{3.63631}(DA)^{1.04628}(PREC12)^{2.36598}(TMAX12)^{-3.27610}$	17%
P95_1	NG	$10^{0.59604}(DA)^{1.11809}(URBAN+1)^{7.69006}(TPIVAL+1)^{-8.08225}$	49%
	G	$10^{-5.99849}(DA)^{1.11107}(PREC1)^{3.10965}(THICK)^{2.17501}(1+ALLUV)^{2.21592}$	24%
P95_2	NG	$10^{0.30798}(DA)^{1.07685}(ELEV)^{0.28954}(STRDEN)^{-0.96895}(CARB+1)^{0.52098}(TPIVAL+1)^{-8.21454}(FLATSST+1)^{-0.92707}$	23%
	G	$10^{-1.50598}(DA)^{1.05850}(PREC2)^{2.35132}$	24%
P95_3	NG	$10^{-2.41938}(DA)^{1.12412}(PREC3)^{1.66789}(ERODE)^{0.57528}(ELEV)^{0.51766}(STRDEN)^{-0.81570}$	18%
	G	$10^{-4.74807}(DA)^{1.06524}(FORBIO)^{0.28819}(PERM)^{-0.11701}(100BFI)^{2.67238}(CLAY+1)^{-6.70582}(URBAN+1)^{-4.23197}(FLATSH+1)^{-0.49563}$	14%
P95_4	NG	$10^{10.81725}(DA)^{1.09473}(PREC4)^{1.21477}(PE)^{-7.02121}(HYGRP)^{-1.26735}(STRDEN)^{-0.51374}$	17%
	G	$10^{15.51790}(DA)^{1.02756}(TMIN4)^{-2.96967}(PE)^{-8.05539}(FORBIO)^{0.43422}(AVSLP)^{0.51414}(1+STOR)^{6.48571}(FLDSHL+1)^{1.42158}$	13%
P95_5	NG	$10^{-0.03259}(DA)^{1.08376}(AVSLP)^{0.25344}(HYGRP)^{-1.37429}(ELEV)^{0.34223}(STRDEN)^{-1.30185}(TPIVAL+1)^{-4.51246}(FLATSST+1)^{-0.62768}$	21%
	G	$10^{-2.17555}(DA)^{1.04494}(PREC5)^{2.39433}(PERM)^{0.19674}(STRDEN)^{1.11063}$	26%
P95_6	NG	$10^{12.07877}(DA)^{1.13992}(PE)^{-6.25420}(ERODE)^{1.29677}(STRDEN)^{-1.33243}(FOREST+1)^{1.66401}(CARB+1)^{1.82563}(ALLUV+1)^{-16.58854}(TPIVAL+1)^{-11.89929}(FLATSST+1)^{-1.71489}$	24%
	G	$10^{-10.46416}(DA)^{1.42286}(FORBIO)^{2.58724}(MNSLP)^{0.38297}(100BFI)^{3.06709}(FOREST+1)^{-8.01857}$	34%
P95_7	NG	$10^{-3.88387}(DA)^{1.22985}(ERODE)^{1.53301}(STRDEN)^{-2.03296}(CARB+1)^{3.31220}(ALLUV+1)^{-38.49485}(TPIRDG+1)^{24.31629}(TPISLP+1)^{17.77321}(FLATSST+1)^{-1.54350}$	42%
	G	$10^{-9.13609}(DA)^{1.22819}(PREC7)^{3.41745}(100BFI)^{3.13694}(STRDEN)^{1.86779}(1+FLATSH)^{-0.64664}$	47%
P95_8	NG	$10^{-4.09409}(DA)^{1.27322}(ERODE)^{2.14446}(STRDEN)^{-2.22138}(CARB+1)^{3.67165}(ALLUV+1)^{-46.43938}(TPIRDG+1)^{27.19798}(TPISLP+1)^{19.03172}(FLATSST+1)^{-1.87667}$	49%
	G	$10^{86.49926}(DA)^{1.71871}(TMAX8)^{-54.04838}(MNSLP)^{0.71615}(100BFI)^{7.20124}(1+ALLUV)^{6.65763}(FLDSHL+1)^{2.78384}(FLATSH+1)^{-0.83547}$	37%
P95_9	NG	$10^{-4.45824}(DA)^{1.02310}(PERM)^{1.96629}(THICK)^{2.99718}(ERODE)^{5.59363}(URBAN+1)^{8.76334}(CARB+1)^{2.10346}(COAL+1)^{1.75078}$	54%
	G	$10^{-5.10816}(DA)^{1.32894}(PREC9)^{5.10448}$	65%
P95_10	NG	$10^{-3.02119}(DA)^{1.13973}(ERODE)^{1.94292}(STRDEN)^{-1.34158}(URBAN+1)^{5.37324}(CARB+1)^{2.45195}(TPIRDG+1)^{20.20826}(TPISLP+1)^{13.59644}(FLATSST+1)^{-1.84932}$	41%
	G	$10^{-3.18241}(DA)^{1.17017}(PREC10)^{2.93518}$	49%
P95_11	NG	$10^{-2.35164}(DA)^{1.03945}(PREC11)^{2.30170}(PERM)^{1.20662}(ERODE)^{4.26017}(URBAN+1)^{9.86143}(STOR+1)^{29.73475}(CARB+1)^{2.44732}(TPIRDG+1)^{10.10064}(TPISLP+1)^{6.89307}$	35%
	G	$10^{-2.06061}(DA)^{1.04059}(PREC11)^{1.73530}(STOR+1)^{7.57540}$	34%
P95_12	NG	$10^{-23.76891}(DA)^{0.94256}(THICK)^{1.59425}(URBAN+1)^{8.10134}(TPIRDG+1)^{56.71329}(TPISLP+1)^{52.70294}(TPIVAL+1)^{56.63657}(FLATSH+1)^{-0.77381}$	32%
	G	$10^{8.59489}(DA)^{1.08466}(PREC12)^{2.55055}(PE)^{-6.78813}$	33%

APPENDIX H

Water Capacity Results for Candidate Metrics

This appendix provides Basinwide results for the four candidate water capacity metrics analyzed during the study. These results helped to inform and guide the selection of the water capacity threshold. It should be reiterated that 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, water capacity was greatest in mainstem river watersheds, including the Susquehanna, West Branch Susquehanna, Chemung, and Juniata Rivers. These results are apparent in Table H-1, which lists water capacity for the four candidate metrics by subbasin pour point. Total water capacity estimates for the Lower Susquehanna, which doubled as Basinwide results due to the cumulative nature of the study, were well over 1,000 mgd for each of the four candidate water capacity metrics. It can be seen that subbasin water capacity typically exceeded well over 100 mgd, and often over 1,000 mgd, for each of the metrics. Outside of the Lower Susquehanna, water capacity was greatest for the Middle Susquehanna, followed by the West Branch and Upper Susquehanna. The Chemung exhibited the lowest water capacities, as a function of drainage area size as well as regional climatic and geologic conditions including mean annual precipitation and former glaciation. The ELOHA and September P50 minus September P95 metrics resulted in the most conservative estimates of water capacity, respectively. Results for the former were a function of the narrower margin used for defining capacity, while those of the latter were a function of flow duration curve characteristics and associated ecosystem flow recommendations, particularly for the seasonal flow component.

Table H-1. Four Candidate Water Capacity Metrics by Subbasin Pour Point

Map ID	Subbasin Name	DA (mi^2)	BF10 (mgd)	BF10-Sep. P95 (mgd)	Sep. P50-Sep. P95 (mgd)	ELOHA (mgd)
A	Upper Susquehanna	4,945.0	2,241.1	1,951.9	484.1	271.4
B	Chemung	2,595.5	569.6	495.0	133.2	65.5
C	Middle Susquehanna	11,310.5	4,344.9	3,641.4	1,133.4	537.4
D	West Branch Susquehanna	6,978.7	3,093.1	2,579.3	783.8	407.0
E	Juniata	3,403.5	1,143.9	861.9	340.3	160.6
F	Lower Susquehanna	27,501.7	10,814.4	8,742.5	3,135.3	1,506.4

Figure H-1 depicts water capacity expressed as 10-year baseflow for HUC-10 watersheds in the Basin. Based on this metric, water capacity was estimated to be over 10,000 mgd for the Basin as a whole. As shown in Table H-1, water capacity was also notable for the Middle Susquehanna and West Branch Susquehanna subbasins, totaling over 4,000 and 3,000 mgd, respectively. The 10-year baseflow water capacity for the Chemung was the lowest, estimated at approximately 570 mgd. Table H-2 lists ten tributary watersheds with the lowest water capacity based on this metric. As would be expected, the list was dominated by smaller headwater watersheds possessing lower baseflow quantities as a function of contributing drainage as well as local climatic, topographic, and geologic watershed characteristics. This metric resulted in abundant water capacity throughout the Basin with only 16 (9 percent) HUC-10 watersheds having 25 mgd or less and none less than 10 mgd.

Table H-2. Tributary HUC-10 Watershed Pour Points with Lowest Water Capacity Expressed as 10-Year Baseflow

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	BF10 (mgd)
1	Canacadea Creek	0205010401	58.3	14.4
2	Little Conestoga Creek	0205030610	65.5	15.3
3	Little Conewago Creek	0205030604	65.4	16.1
4	Cocolamus Creek	0205030410	64.2	17.8
5	Little Fishing Creek	0205010706	68.3	19.3
6	Troups Creek	0205010405	67.8	20.4
7	Buffalo Creek	0205030411	71.7	20.5
8	Shaver Creek	0205030206	63.0	20.8
9	South Branch Conewago Creek	0205030601	73.5	20.9
10	Blacklog Creek	0205030403	72.6	21.4

Figure H-2 shows water capacity defined as 10-year baseflow minus September P75/P95 flow for HUC-10 watersheds in the Basin. For this metric, water capacity was assessed to be over 8,500 mgd for the Basin overall. As outlined in Table H-1, water capacity was substantial for the Middle Susquehanna and West Branch Susquehanna, equating to over 3,000 and 2,000 mgd, respectively. The 10-year baseflow minus September P75/P95 flow water capacity for the Chemung was again the lowest, estimated at just under 500 mgd. Table H-3 lists ten tributary watersheds with the lowest water capacity based on this metric. Similar to the 10-year baseflow results, the list included headwater watersheds possessing many of the same watershed characteristics. Of particular note, water capacity was estimated to be 0.0 mgd for Little Conestoga Creek Watershed. 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 tended to yield higher baseflows. Flow duration curves for high baseflow streams are typically not as steep as those of flashier freestone systems. Accordingly, the low flow margin tends to be truncated, resulting in lower estimates of water capacity using this method. Accounting for the low flow margin doubled the number of HUC-10 pour points with less than 25 mgd of water capacity. Five watersheds were estimated to have no more than 5 mgd of water capacity.

Table H-3. Tributary HUC-10 Watershed Pour Points with Lowest Water Capacity Expressed as 10-Year Baseflow Minus September P75/P95 Flow

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	BF10- Sep. P75/95 (mgd)
1	Little Conestoga Creek	0205030610	65.5	0.0
2	Muddy Creek	0205030613	138.4	2.6
3	Quittapahilla Creek	0205030508	77.3	7.7
4	Canacadea Creek	0205010401	58.3	9.2
5	East Branch Octoraro Creek	0205030614	90.7	9.5
6	Blacklog Creek	0205030403	72.6	10.5
7	Spruce Creek	0205030204	109.1	11.1
8	Cocolamus Creek	0205030410	64.2	12.1
9	Little Conewago Creek	0205030604	65.4	13.2
10	South Branch Conewago Creek	0205030601	73.5	14.4

Figure H-3 depicts water capacity expressed as September P50 flow minus September P75/P95 flow for HUC-10 watersheds in the Basin. Based on this metric, water capacity was estimated to be over 3,000 mgd for the Basin as a whole. As shown in Table H-1, water capacity was also notable for the Middle Susquehanna, totaling over 1,000 mgd. The September P50 flow minus September P75/P95 flow water capacity for the Chemung was the lowest, estimated at approximately 135 mgd. Twelve tributary watersheds were estimated to have 0 water capacity based on this metric (Table H-4). These watersheds were generally located in the Juniata and Lower Susquehanna subbasins, with the majority in the former. Several watersheds with drainage areas approaching or greater than 100 square miles were also listed, including Schenevus Creek, Spruce Creek, Honey Creek, Standing Stone Creek, Sideling Hill Creek, Upper Raystown Branch Juniata River, East Branch Octoraro Creek, and Muddy Creek. Again, portions of these watersheds were underlain by carbonate bedrock which often yields higher baseflows that can truncate the low flow margin and result in lower estimates of water capacity. Furthermore, 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. Basinwide results were drastically different for this metric as 104 (61 percent) watersheds had a water capacity less than 25 mgd, with 66 (39 percent) less than 10 mgd.

Table H-4. Tributary HUC-10 Watershed Pour Points with 0 Water Capacity Expressed as September P50 Flow Minus September P75/P95 Flow

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	Sep. P50- Sep. P75/95 (mgd)
1	Schenevus Creek	0205010103	119.8	0.0
2	Spruce Creek	0205030204	109.1	0.0
3	Honey Creek	0205030406	93.7	0.0
4	Standing Stone Creek	0205030207	132.4	0.0
5	Shaver Creek	0205030206	63.0	0.0
6	Blacklog Creek	0205030403	72.6	0.0
7	Sideling Hill Creek	0205030402	96.7	0.0
8	Little Conestoga Creek	0205030610	65.5	0.0
9	Upper Raystown Branch Juniata River	0205030301	161.1	0.0
10	Brush Creek	0205030304	86.0	0.0
11	East Branch Octoraro Creek	0205030614	90.7	0.0
12	Muddy Creek	0205030613	138.4	0.0

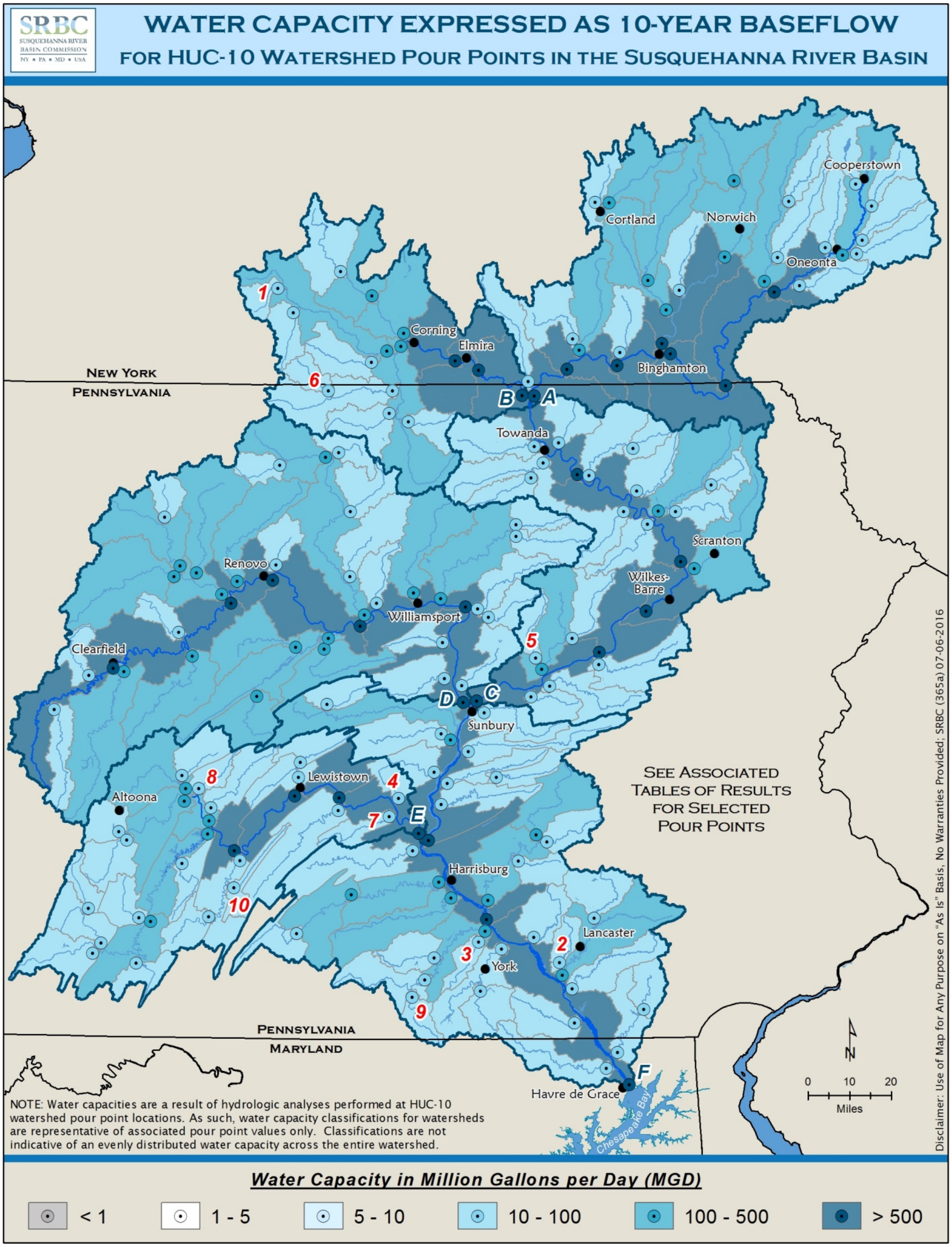

Figure H-1. Water Capacity Expressed as 10-Year Baseflow for HUC-10 Watershed Pour Points

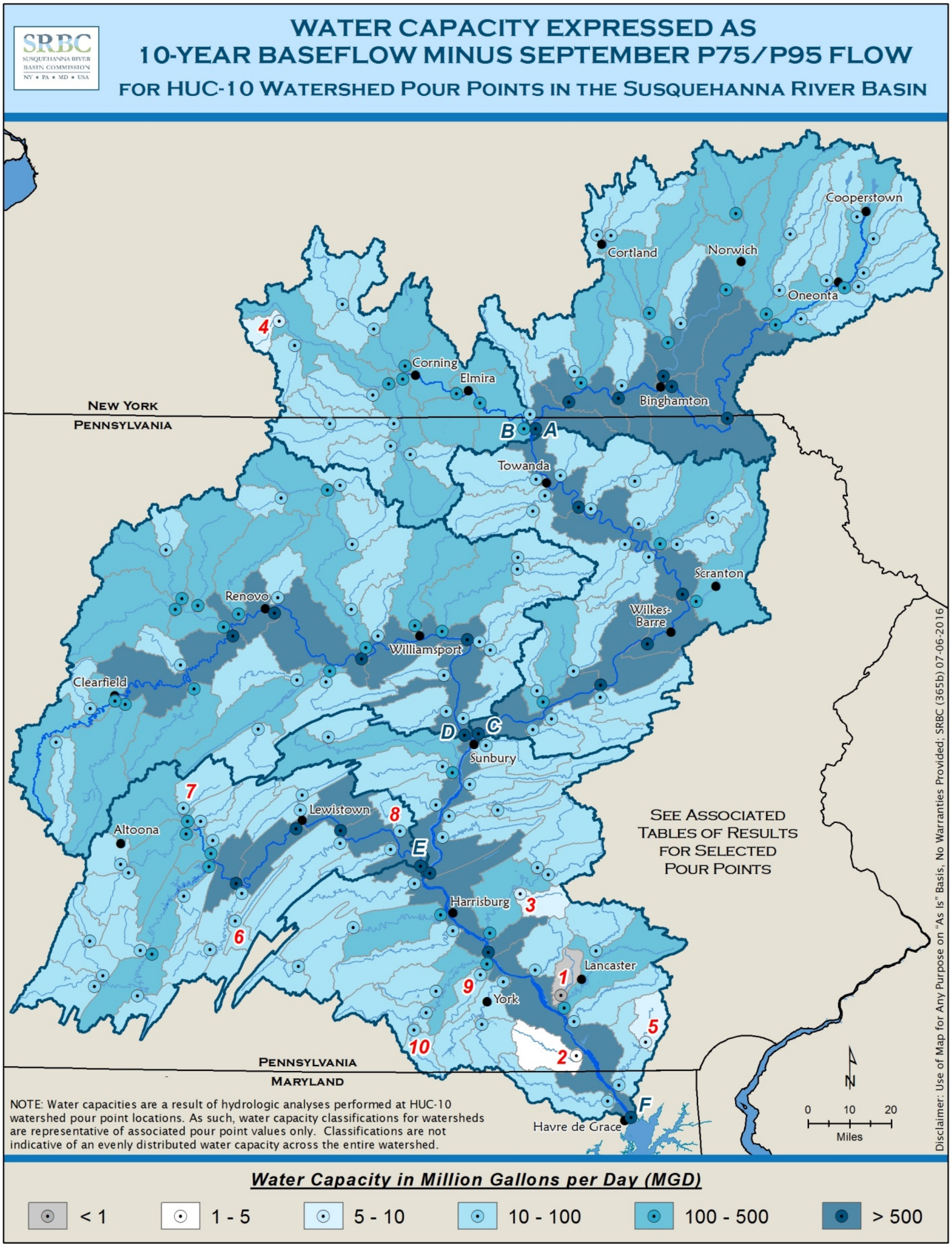

Figure H-2. ***Water Capacity Expressed as 10-Year Baseflow Minus September P75/P95 Flow for HUC-10 Watershed Pour Points***

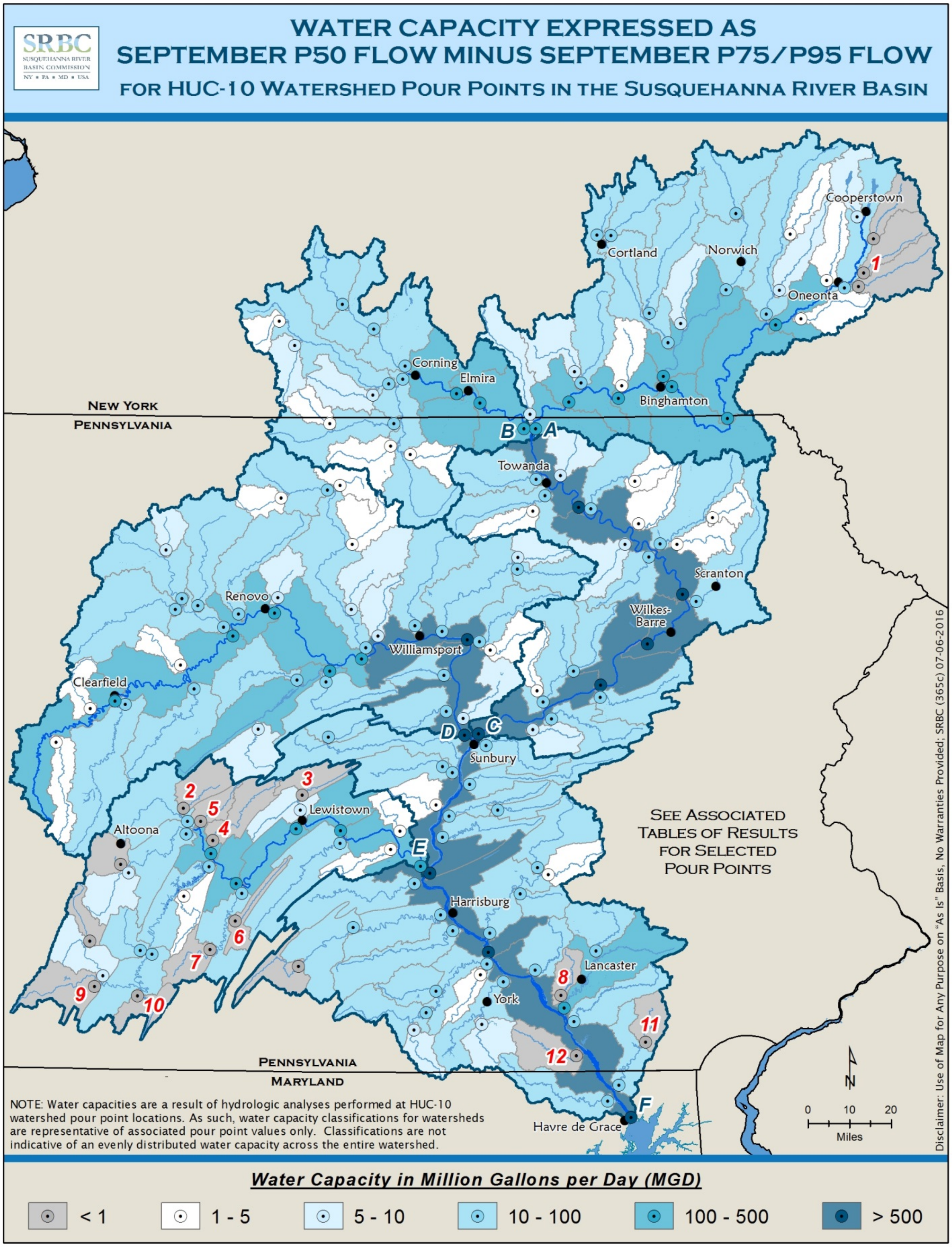

Figure H-3. Water Capacity Expressed as September P50 Flow Minus September P75/P95 Flow for HUC-10 Watershed Pour Points

Figure H-4 depicts water capacity expressed based on ELOHA for HUC-10 watersheds in the Basin. Using this metric, water capacity was estimated to be over 1,500 mgd for the Basin as a whole. Water capacity for the Middle Susquehanna and West Branch Susquehanna were high once again, totaling over 500 and 400 mgd, respectively (Table H-1). As with all other metrics, the ELOHA-based water capacity for the Chemung was the lowest, estimated at approximately 65 mgd. Table H-5 lists ten tributary watersheds with the lowest water capacity based on the ELOHA metric. As would be expected, the list was dominated by smaller headwater watersheds possessing lower streamflow quantities as a function of contributing drainage as well as local climatic, topographic, and geologic watershed characteristics. Since the ELOHA metric was strongly influenced by limiting alteration of a bracketed range of seasonal flows to a certain percentage, these smaller flashier systems with steeper flow duration curves produced much lower estimates of water capacity. Being the most conservative metric evaluated, more watersheds were identified as having less than 25 mgd and less than 10 mgd of water capacity than for the other metrics at 127 (75 percent) and 96 (56 percent), respectively.

Table H-5. Tributary HUC-10 Watershed Pour Points with Lowest Water Capacity Expressed as ELOHA

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	ELOHA (mgd)
1	Troups Creek	0205010405	67.8	1.2
2	Tuscarora Creek	0205010403	128.2	1.5
3	Brush Creek	0205030304	86.0	1.6
4	Mill Creek	0205010407	75.5	1.6
5	Shaver Creek	0205030206	63.0	1.7
6	Marsh Creek	0205020503	81.2	1.7
7	Bennetts Creek	0205010402	95.5	1.9
8	Wysox Creek	0205010604	102.1	1.9
9	Bobs Creek	0205030302	65.2	1.9
10	Little Fishing Creek	0205010706	68.3	2.0

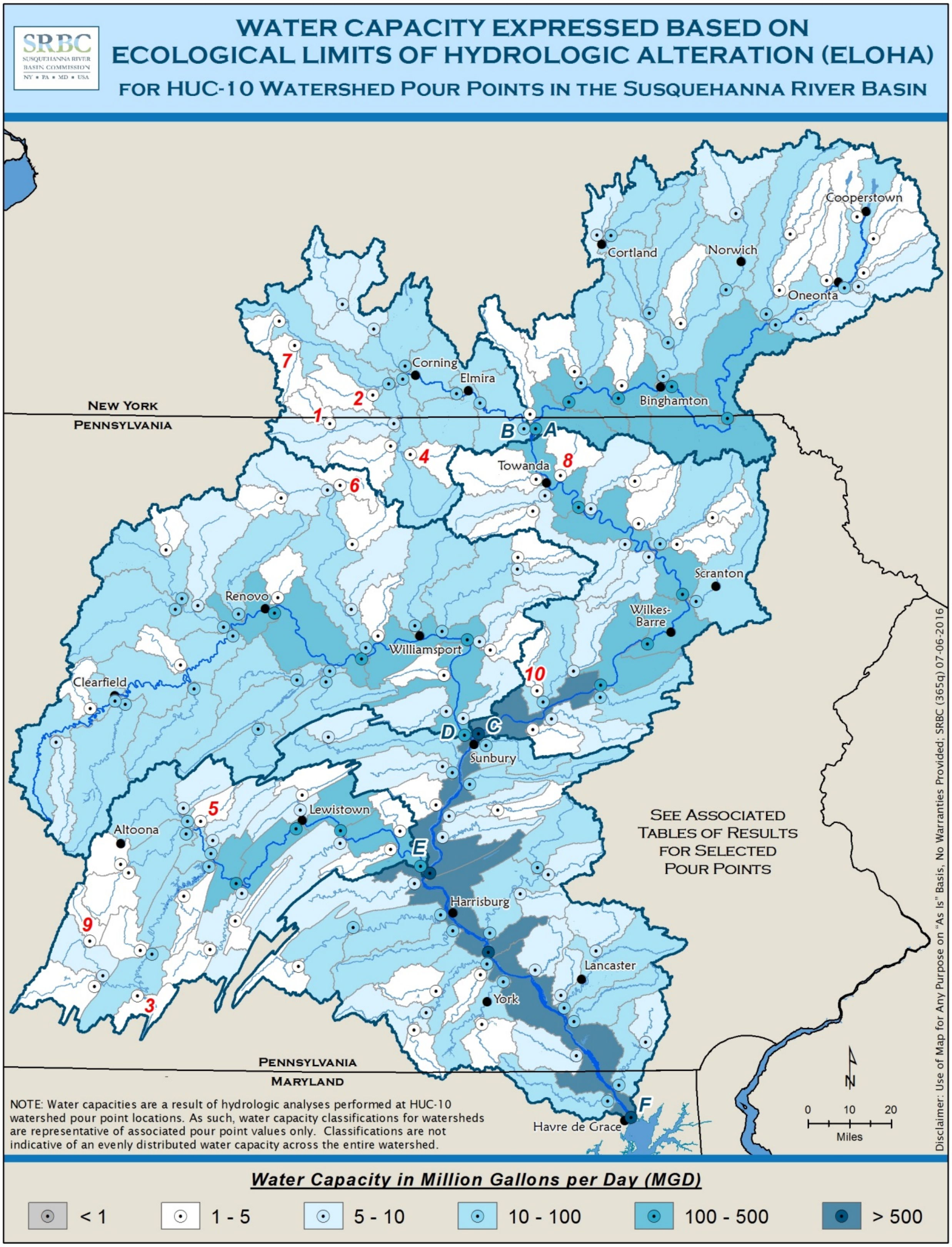

Figure H-4. Water Capacity Expressed Based On ELOHA for HUC-10 Watershed Pour Points

APPENDIX I

Water Availability Results for Candidate Water Capacity Metrics

This appendix describes the examination of approved CU versus the candidate water capacity metrics, described in Appendix H, and the historically used 7Q10 flow statistic. The results of these analyses were used as a criterion, identified in Section 4.2 of the report, for informing the selection of a water capacity threshold for assessing water availability. The performance of each metric was evaluated with respect to differentiating against total approved CU for HUC-10 watersheds throughout the Basin. Again, it should be reiterated that results were representative of calculations performed at pour point locations and should not be construed as representative of uniform conditions throughout each respective watershed.

Previous Metrics vs. Consumptive Use

Even though 7Q10 was deemed unsuitable for use as an environmental flow management threshold in recent studies, previous metrics used by the Commission and other regional water management agencies, for regulatory and planning purposes, were grounded on this flow statistic (SRBC, 2008 & 2012; DePhilip and Moberg, 2010). 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 a passby flow condition would be required if withdrawal impacts were 10 percent or greater of the 7Q10 flow for the stream. As discussed, the Pennsylvania State Water Plan watershed screenings were performed using criteria based on the 7Q10 threshold, specifically 30 percent of 7Q10 for Class A trout streams in carbonate areas and 50 percent of 7Q10 for all other streams. As 7Q10 has been entrenched as a threshold for water management in the Susquehanna River Basin, the study compared cumulative CU against 7Q10 as part of the initial evaluation of water capacity metrics as a benchmark for comparisons of historically identified sensitive or stressed watersheds. Figure I-1 shows water availability expressed as the Pennsylvania State Water Plan initial screening criteria minus total approved CU for HUC-10 watersheds in the Basin. Table I-1 lists the top 10 watersheds in terms of water availability less than 0 mgd based on these criteria. Again, these watersheds were used in the study process to validate water availability results associated with the various water capacity metrics evaluated.

Table I-1. Top 10 Watershed Pour Points in Terms of Water Availability Less Than 0 Based on PA State Water Plan Initial Screening Criteria Minus Total 2014 Approved CU

Map ID	Watershed Name	HUC-10 ID	PA State Water Plan ISC	PA State Water Plan ISC (mgd)	Total Approved CU (mgd)	Water Availability (mgd)
1	Lower Susquehanna River	0205030617	50% 7Q10	950.8	1,034.8	-84.1
2	Lackawanna River	0205010701	50% 7Q10	12.0	44.4	-32.4
3	Mahantango Creek	0205030108	50% 7Q10	2.2	20.5	-18.4
4	Octoraro Creek	0205030615	50% 7Q10	17.9	35.6	-17.6
5	Lower Conewago Creek	0205030605	50% 7Q10	3.8	20.4	-16.7
6	Deep Creek	0205030107	50% 7Q10	0.6	17.3	-16.6
7	Upper Conewago Creek	0205030602	50% 7Q10	1.6	14.6	-13.0
8	South Branch Conewago Creek	0205030601	50% 7Q10	0.8	11.3	-10.5
9	Tioga River	0205010409	50% 7Q10	14.5	23.3	-8.8
10	Lower Swatara Creek	0205030509	50% 7Q10	24.1	32.0	-7.9

Candidate Water Capacity Metrics vs. Consumptive Use

The candidate water capacity metrics presented in Appendix H were also compared against cumulative total approved CU to inform the selection of a water capacity threshold. Figure I-2 displays water availability expressed as 10-year baseflow minus total approved CU for HUC-10 watershed pour points. Watersheds drained by mainstem rivers were found to have water availabilities greater than 500 mgd based on this water capacity metric (Table I-2). Table I-3 includes tributary watersheds with the lowest water availability based on this metric. All but one watershed, South Branch Conewago Creek, resulted in water availability greater than 10 mgd according to this criterion. Additionally, the fact that only 18 (11 percent) pour points had less than 25 mgd, further substantiated that this scenario produced overly abundant results. Note that South Branch Conewago Creek and South Branch Codorus Creek were also listed in the previous tables generated from evaluation of previously identified sensitive watersheds (Table 14) and metrics (Table I-1).

Table I-2. Water Availabilities Based on Candidate Water Capacity Metrics Minus Total 2014 Approved CU for Subbasin Pour Points

Map ID	Subbasin Name	DA (mi^2)	BF10-App. CU (mgd)	BF10-Sep. P95-App CU (mgd)	Sep. P50-Sep. P95-App. CU (mgd)	ELOHA-App. CU (mgd)
A	Upper Susquehanna	4,945.0	2,188.1	1,898.9	431.0	218.4
B	Chemung	2,595.5	532.3	457.6	95.8	28.2
C	Middle Susquehanna	11,310.5	4,082.3	3,378.8	870.8	274.8
D	West Branch Susquehanna	6,978.7	2,967.8	2,454.0	658.5	281.7
E	Juniata	3,403.5	1,120.4	838.5	316.9	137.1
F	Lower Susquehanna	27,501.7	9,839.8	7,767.9	2,160.7	531.8

Table I-3. Lowest Tributary Watershed Pour Points in Terms of Water Availability Based on 10-Year Baseflow Minus Total 2014 Approved CU

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	Water Availability (mgd)
1	South Branch Conewago Creek	0205030601	73.5	9.6
2	Little Conestoga Creek	0205030610	65.5	10.1
3	Little Conewago Creek	0205030604	65.4	14.2
4	Canacadea Creek	0205010401	58.3	14.2
5	South Branch Codorus Creek	0205030606	116.8	15.9
6	Deep Creek	0205030107	77.0	16.1
7	Cocolamus Creek	0205030410	64.2	17.5
8	Little Fishing Creek	0205010706	68.3	19.1
9	Buffalo Creek	0205030411	71.7	20.2
10	Troups Creek	0205010405	67.8	20.3

Figure I-3 shows water availability expressed as 10-year baseflow minus September P75/P95 flow minus total approved CU for HUC-10 watersheds in the Basin. With the exception of the Chemung subbasin, watersheds drained by mainstem rivers were noted to have water availabilities greater than 500 mgd based on this water capacity metric (Table I-2). Results showed that 132 (78 percent) watersheds had greater than 25 mgd and all but eight watersheds had greater than 10 mgd of availability according to this standard. Four of these had water availabilities less than 5 mgd, with Little Conestoga River and Quittapahilla Creek exhibiting water availability less than 0 (Table I-4). Once again, the previously identified sensitive watersheds of South Branch Conewago Creek and South Branch Codorus Creek were called out by this availability scenario.

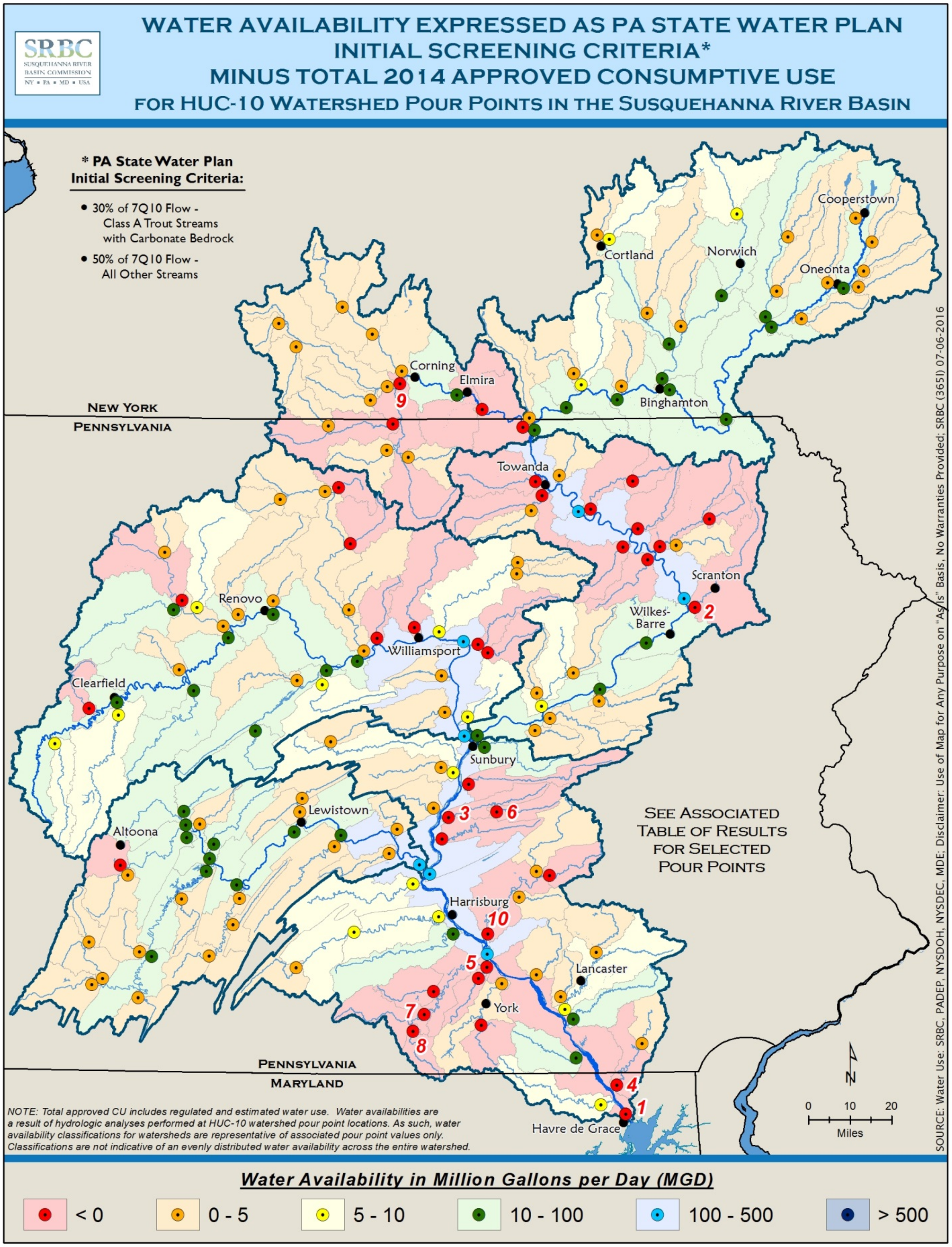

Figure I-1. ***Water Availability Expressed as PA State Water Plan Initial Screening Criteria Minus Total 2014 Approved CU for HUC-10 Watershed Pour Points***

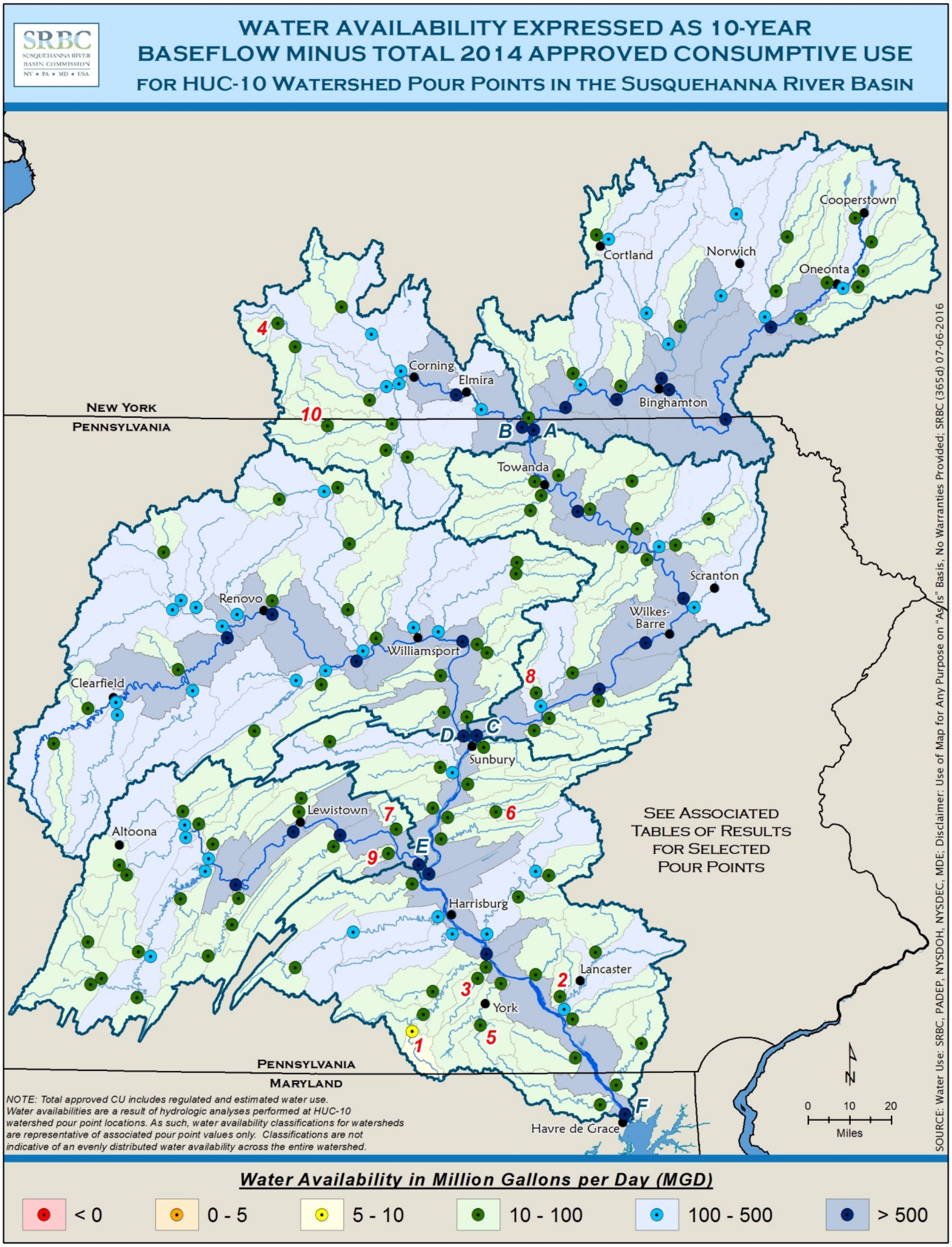

Figure I-2. Water Availability Expressed as 10-Year Baseflow Minus Total 2014 Approved CU for HUC-10 Watershed Pour Points

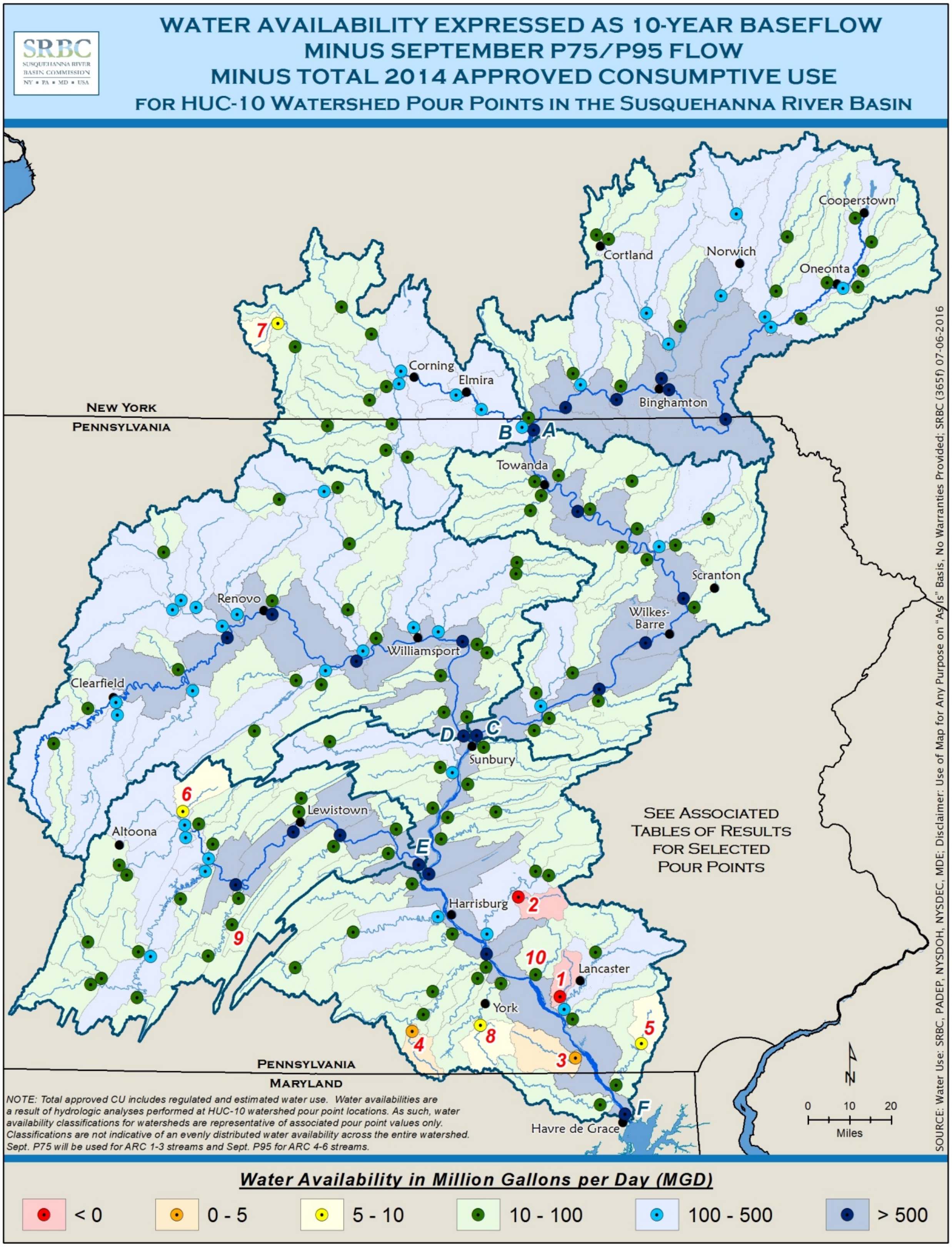

Figure I-3. ***Water Availability Expressed as 10-Year Baseflow Minus September P75/P95 Flow Minus Total 2014 Approved CU for HUC-10 Watershed Pour Points***

Table I-4. Lowest Tributary Watershed Pour Points in Terms of Water Availability Based on 10-Year Baseflow Minus September P75/P95 Flow Minus Total 2014 Approved CU

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	Water Availability (mgd)
1	Little Conestoga Creek	0205030610	65.5	-5.2
2	Quittapahilla Creek	0205030508	77.3	-0.7
3	Muddy Creek	0205030613	138.4	2.0
4	South Branch Conewago Creek	0205030601	73.5	3.1
5	East Branch Octoraro Creek	0205030614	90.7	7.8
6	Spruce Creek	0205030204	109.1	8.8
7	Canacadea Creek	0205010401	58.3	9.0
8	South Branch Codorus Creek	0205030606	116.8	9.8
9	Blacklog Creek	0205030403	72.6	10.4
10	Chiques Creek	0205030608	126.0	10.6

Figure I-4 presents water availability expressed as September P50 flow minus September P75/P95 flow minus total approved CU for HUC-10 watersheds in the Basin. Along with the Lower Susquehanna, watersheds drained by the Middle Susquehanna and West Branch Susquehanna were shown to have water availabilities greater than 500 mgd based on this water capacity metric (Table I-2). This metric produced dramatically different results when compared to the first two scenarios. Twenty-five of the 170 HUC-10 watersheds exhibited water availability less than 0 according to this criterion. Furthermore, 112 (66 percent) watersheds had less than 25 mgd, of which 81 (48 percent), had less than 10 mgd available. Table I-5 contains the lowest tributary watersheds in terms of water availability applying this metric. Note that several of these watersheds, specifically Mahantango Creek, Deep Creek, and South Branch Conewago Creek, were also listed in Tables 14 and I-2 as being stressed.

Figure I-5 illustrates water availability expressed as the ELOHA metric minus total approved CU for HUC-10 watersheds in the Basin. Only the entire Susquehanna River Watershed, Lower Susquehanna subbasin, was found to have water availability greater than 500 mgd based on this water capacity metric (Table I-2). Ten watersheds expressed water availability less than 0 according to this criterion. This metric proved to be the most stringent as 134 (79 percent) watersheds had availabilities less than 25 mgd and 113 (66 percent) with no more than 10 mgd. Table I-6 includes the lowest tributary watersheds in terms of water availability considering ELOHA as a metric. Note again that Tables 14 and I-2 also included the top eight watersheds.

In summary, Table I-2 lists water availabilities based on the candidate water capacity metrics for major subbasin pour points in the Basin. A comparison of the metrics indicated the correlation between water availability and cumulative drainage area. As such, water availability was relatively less in the Chemung and Juniata as compared to the larger mainstem Susquehanna and West Branch Susquehanna subbasin pour points. A comparison of the water capacity metrics also indicated that the ELOHA metric was the most stringent, even though the September P50 flow minus September P75/P95 flow metric produced more negatively balanced watersheds. As such, these metrics proved too restrictive to be utilized as effective basinwide water management thresholds. In contrast, the 10-year baseflow results reflected overly abundant water availability, but made no provision for ecosystem flow needs or unaccounted for water and emergencies, and therefore could not be accepted as a basinwide indicator. The 10-year baseflow minus September P75/P95 low flow margin metric, coupled with a safety factor, proved to be the most acceptable metric for basinwide water resources management based on the criteria outlined in Section 4.2 of the study.

Table I-5. Lowest Tributary Watershed Pour Points in Terms of Water Availability Based on September P50 Flow Minus September P75/P95 Flow Minus Total 2014 Approved CU

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	Water Availability (mgd)
1	Mahantango Creek	0205030108	164.6	-10.0
2	Octoraro Creek	0205030615	210.3	-5.9
3	Deep Creek	0205030107	77.0	-5.6
4	Little Conestoga Creek	0205030610	65.5	-5.2
5	South Branch Conewago Creek	0205030601	73.5	-3.0
6	Beaverdam Branch	0205030202	87.2	-3.0
7	Spruce Creek	0205030204	109.1	-2.3
8	Anderson Creek	0205020102	77.7	-2.2
9	East Branch Octoraro Creek	0205030614	90.7	-1.7
10	Upper Raystown Branch Juniata River	0205030301	161.1	-1.6

Table I-6. Lowest Tributary Watershed Pour Points in Terms of Water Availability Based on ELOHA Minus Total 2014 Approved CU

Map ID	Watershed Name	HUC-10 ID	DA (mi^2)	Water Availability (mgd)
1	Octoraro Creek	0205030615	210.3	-24.2
2	Lackawanna River	0205010701	347.7	-23.4
3	Mahantango Creek	0205030108	164.6	-12.6
4	Deep Creek	0205030107	77.0	-12.3
5	South Branch Conewago Creek	0205030601	73.5	-8.2
6	Upper Conewago Creek	0205030602	219.7	-7.9
7	Lower Conewago Creek	0205030605	515.6	-4.8
8	South Branch Codorus Creek	0205030606	116.8	-2.9
9	Wiconisco Creek	0205030109	116.4	-2.0
10	Sugar Creek	0205010601	188.1	-0.2

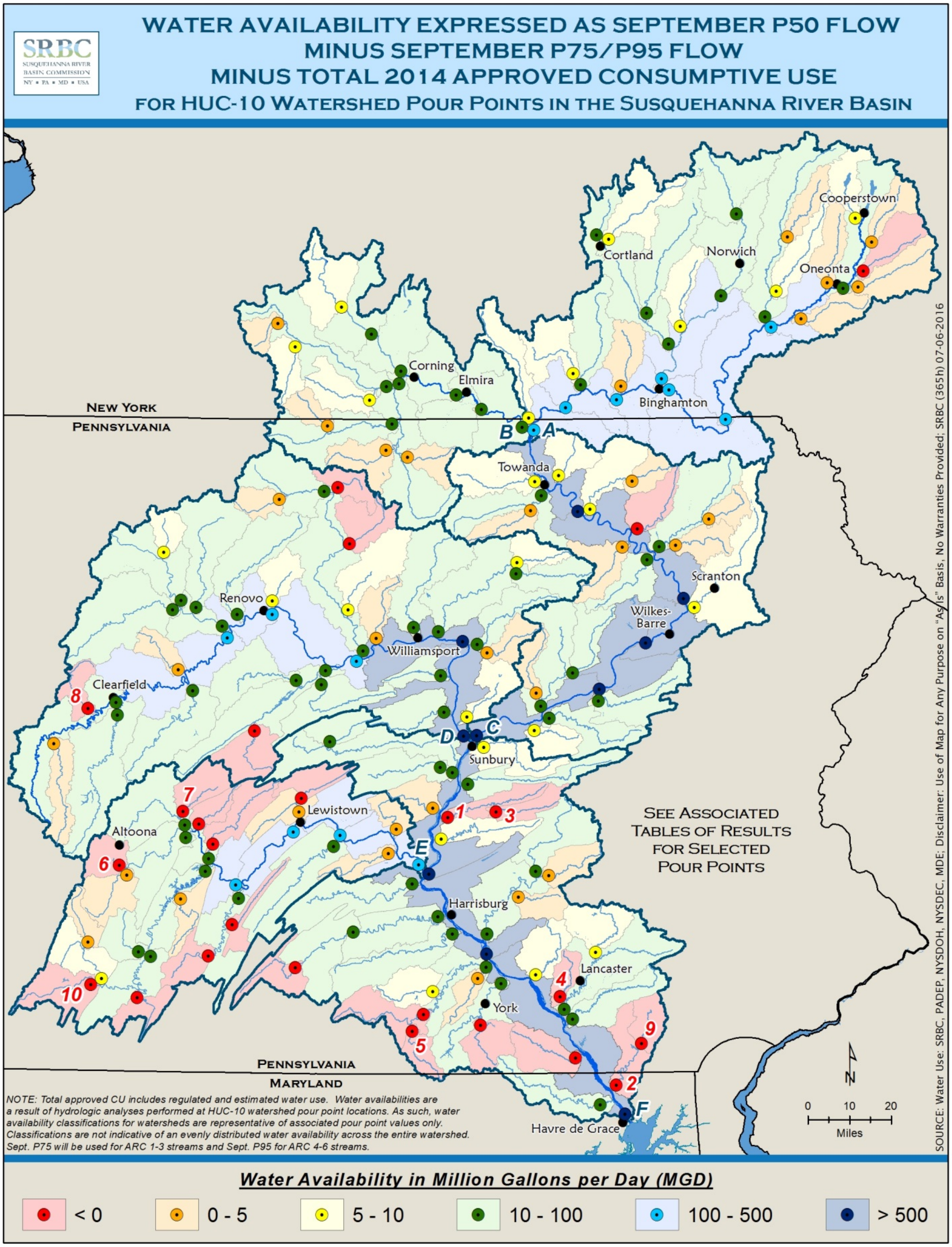

Figure I-4. ***Water Availability Expressed as September P50 Flow Minus September P75/P95 Flow Minus Total 2014 Approved CU for HUC-10 Watershed Pour Points***

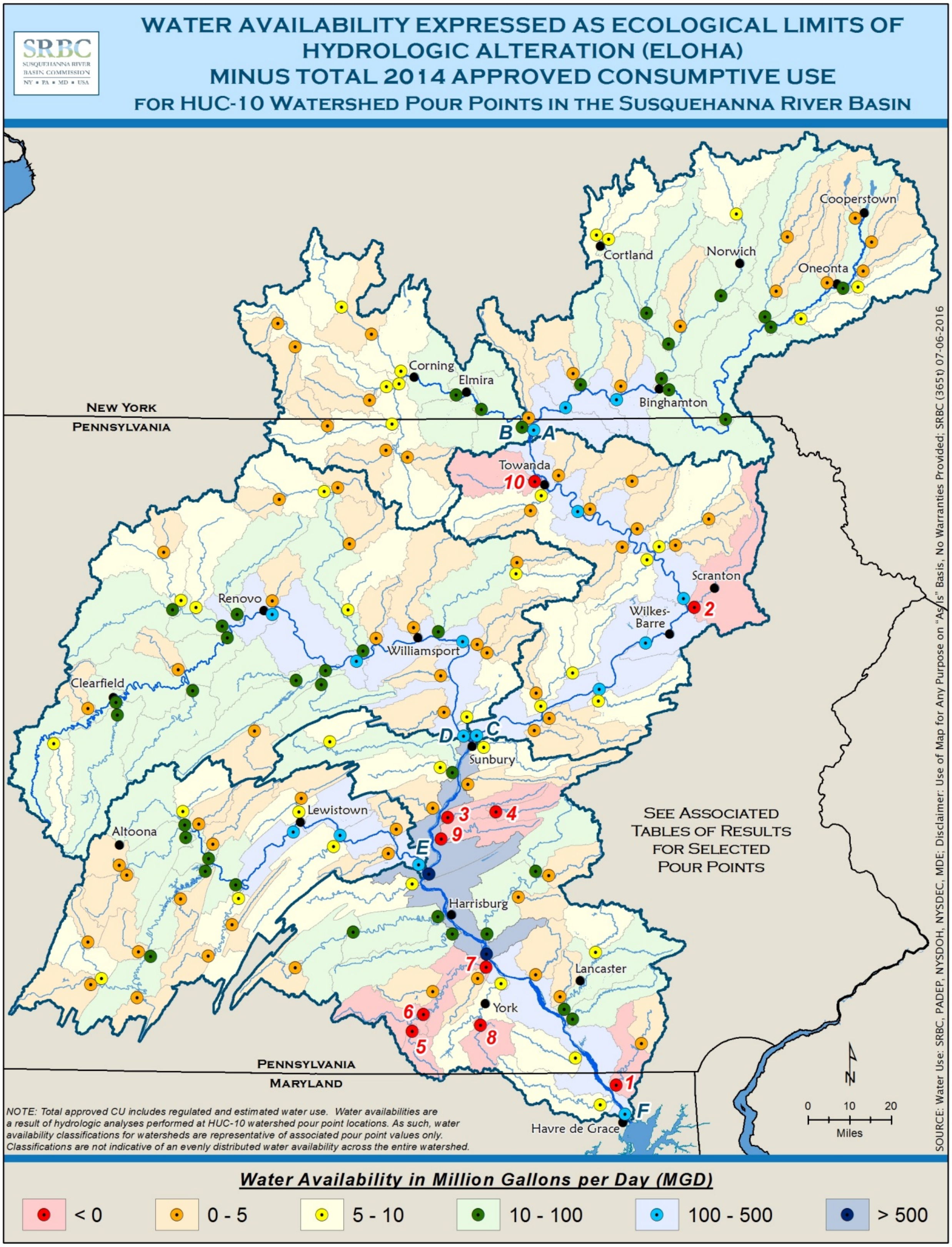

Figure I-5. Water Availability Expressed as ELOHA Minus Total 2014 Approved CU for HUC-10 Watershed Pour Points

APPENDIX J

Focus Watersheds Analysis for Candidate Water Capacity Metrics

In order to more thoroughly evaluate candidate water capacity metrics for water availability applications, three focus watersheds were selected and examined. Separate from previous evaluations of candidate water capacity metrics at a HUC-10 scale, the focus watershed assessments were completed for nested watersheds ranging from 11 to 114 mi^2. Water availability was examined at five pour points in each focus watershed using the four candidate water capacity metrics minus total approved CU. The focus watersheds, described below, were chosen in an attempt to compare water availability results to previous studies and/or areas of concern. Passby flows and other mitigation measures were not factored into the analysis.

South Branch Conewago Creek Watershed

Total approved CU in the South Branch Conewago Creek Watershed (HUC-10 ID 0205030601) totaled 11.3 mgd, with total reported CU accounting for just over half at 5.9 mgd. Water capacity amounts were determined by regression equations, using a P75 low flow margin and the non-glaciated variables.

Table J-1 lists all factors used in determining water availability scenarios within the South Branch Conewago Creek Watershed. Figure J-1 depicts four maps for each resultant water availability. Results were heavily influenced by the Borough of Hanover withdrawals that exist in the SBC 4 and UNT 1 subwatersheds and by the Bonneauville Shale Belt WCA that limits recharge. The 10-year baseflow scenario showed a negative water availability balance in the headwaters but rebounding in the downstream subwatersheds. The 10-year baseflow minus September P75 metric indicated negatively balanced headwater subwatersheds. SBC 1 and 2 subwatersheds continued to show gaining availability. The final two scenarios of September P50 minus September P75 and ELOHA were more stringent water capacity metrics and thus showed all subwatersheds with a negative balance. Each scenario produced results similar to PADEP findings and supported the Commission's PSA and WCA determinations (PADEP, 2010; SRBC, 2005).

Table J-1. Total 2014 Approved CU, Candidate Water Capacity Metrics, and Resultant Water Availabilities for South Branch Conewago Creek Watershed Pour Points

MAP ID	App. CU (mgd)	BF10 (mgd)	BF10-Sep. P75 (mgd)	Sep. P50-Sep. P75 (mgd)	ELOHA (mgd)	BF10-App. CU (mgd)	BF10-P75-App. CU (mgd)	P50-P75-App. CU (mgd)	ELOHA-App. CU (mgd)
SBC1	11.3	20.9	14.4	8.3	3.1	9.6	3.1	-3.0	-8.2
SBC2	10.7	18.5	12.8	8.9	2.8	7.9	2.1	-1.7	-7.9
SBC3	10.5	10.6	8.0	2.7	1.3	0.1	-2.5	-7.8	-9.2
SBC4	10.4	7.3	5.8	0.9	0.8	-3.1	-4.6	-9.5	-9.7
UNT1	4.8	2.5	1.4	3.3	0.5	-2.4	-3.4	-1.6	-4.4

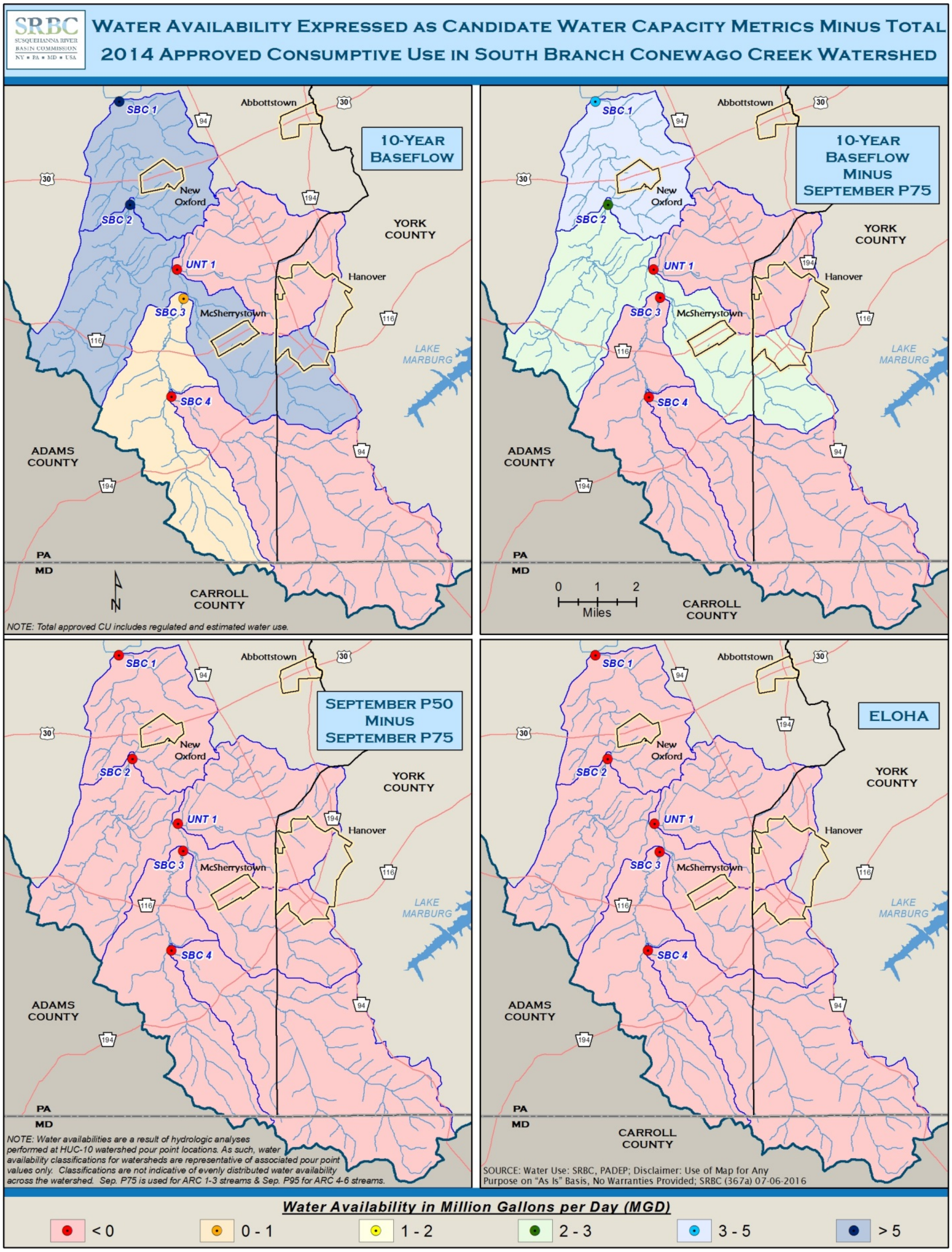

Figure J-1. Water Availability Expressed as Candidate Water Capacity Metrics Minus Total 2014 Approved CU in South Branch Conewago Creek Watershed

Halter Creek Watershed

Total approved CU in the Halter Creek Watershed (HUC-10 ID 0205030201) totaled 1.4 mgd, with reported CU accounting for less than 30 percent at 0.4 mgd. Water capacity amounts were determined by regression equations, using a P75 low flow margin and the non-glaciated variables.

Water use, capacity, and availability results are shown in Table J-2. Figure J-2 includes four maps of water availability scenarios. Water availability results were predominantly influenced by concentrated withdrawal locations. The 10-year baseflow scenario showed a gaining water availability balance from the headwaters down to the mouth, portraying a sustainable system. The 10-year baseflow minus September P75 metric began to reflect the Roaring Spring withdrawals causing a negative balance in subwatershed HLT 2. The confluence of Plum Creek appeared to offset the negative balance downstream in subwatershed HLT 1. The final two scenarios of September P50 minus the low flow margin and ELOHA indicated progressively worse water availability balances although subwatershed HLT 2 remained the only negative subwatershed. All of the scenarios except 10-year baseflow supported the Commission's Roaring Spring Area PSA determination and the Morrison Cove Study findings of unsustainable water availability, specifically in Halter Creek (SRBC 2005 & 2011). During P95 passby flow conditions, one withdrawal would cease from the Roaring Spring, changing subwatershed HLT 2 from a negative balance to having 0.1 mgd of availability in the 10-year baseflow minus the low flow margin of safety scenario only.

Table J-2. Total 2014 Approved CU, Candidate Water Capacity Metrics, and Resultant Water Availabilities for Halter Creek Watershed Pour Points

MAP ID	App. CU (mgd)	BF10 (mgd)	BF10-Sep. P75 (mgd)	Sep. P50-Sep. P75 (mgd)	ELOHA (mgd)	BF10-App. CU (mgd)	BF10-P75-App. CU (mgd)	P50-P75-App. CU (mgd)	ELOHA-App. CU (mgd)
HLT1	1.4	10.6	5.9	4.3	1.5	9.2	4.6	3.0	0.1
HLT2	1.2	4.6	1.0	0.9	0.8	3.4	-0.2	-0.3	-0.4
HLT3	0.3	4.0	1.7	1.8	0.7	3.7	1.4	1.5	0.4
PLM1	0.4	5.3	4.0	2.2	0.7	4.9	3.6	1.8	0.3
PLM2	0.1	2.9	2.1	1.4	0.4	2.8	1.9	1.2	0.3

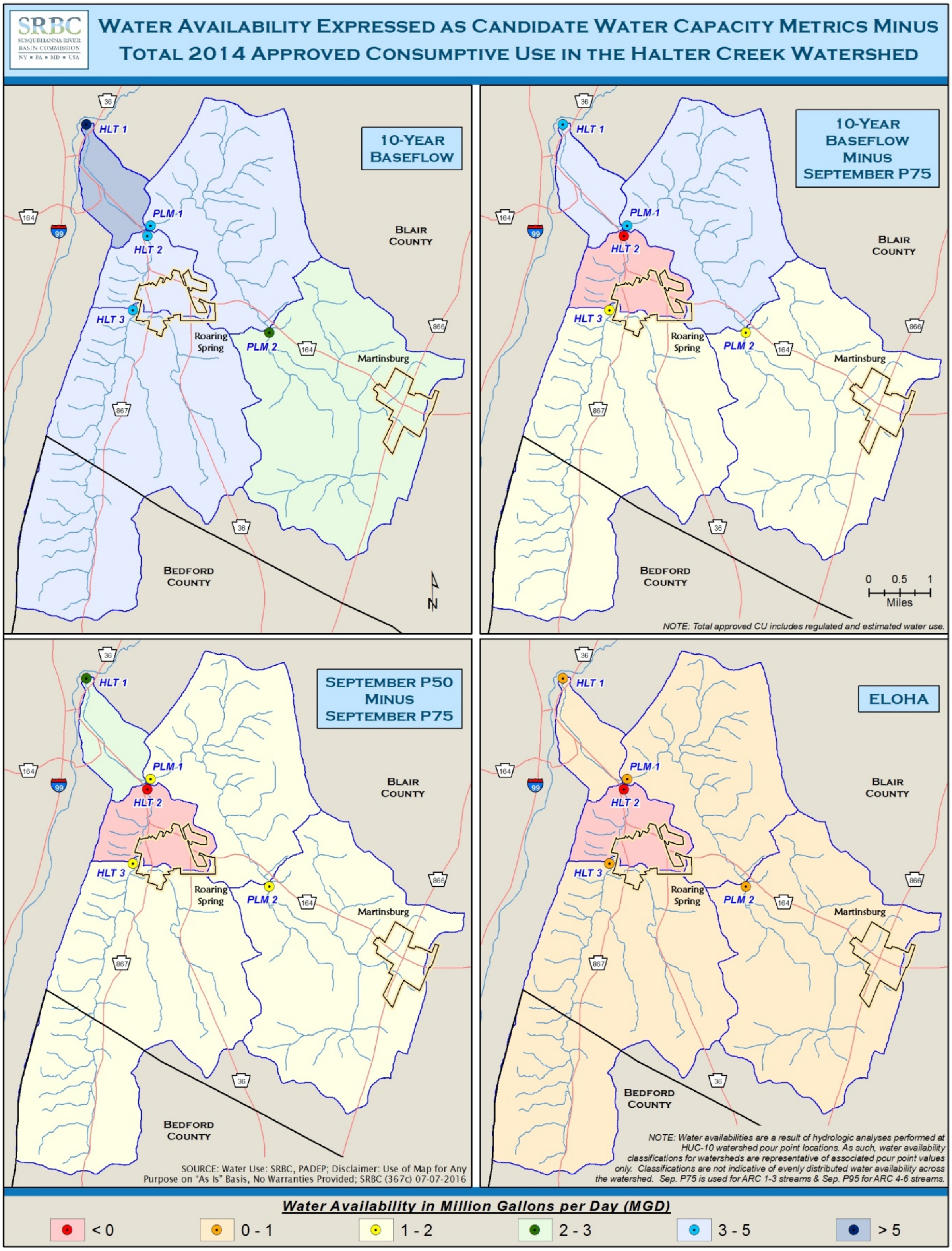

Figure J-2. Water Availability Expressed as Candidate Water Capacity Metrics Minus Total 2014 Approved CU in the Halter Creek Watershed

Meshoppen Creek Watershed

Total approved CU in the Meshoppen Creek Watershed (HUC-10 ID 0205010608) totaled 4.2 mgd, with reported CU accounting for half at 2.1 mgd. Water capacity amounts were determined by regression equations, using a P75 low flow margin and the non-glaciated variables.

Table J-3 provides water use, capacity, and availability results. Maps depicting water availability results are shown in Figure J-3. Water availability in the Meshoppen Creek Watershed was dominated by natural gas industry withdrawal approvals that were considered 100 percent consumptive. The 10-year baseflow and the 10-year baseflow minus September P75 scenarios showed high water availability balances across the watershed. The September P50 minus P75 and the ELOHA scenarios indicated significantly different water availability balances. These water capacity metrics resulted in negative water availability balances in the Meshoppen Creek subwatersheds with the September P50 minus September P75 metric showing a negative balance for all subwatersheds. However, during P95 passby flow conditions, all five natural gas industry surface water withdrawals must cease operations, adding 3.805 mgd to the water availability balance. With the passby flow requirements in place, the Meshoppen Creek Watershed appeared to have sustainable water resources.

Table J-3. Total 2014 Approved CU, Candidate Water Capacity Metrics, and Resultant Water Availabilities for Meshoppen Creek Watershed Pour Points

MAP ID	App. CU (mgd)	BF10 (mgd)	BF10- Sep. P75 (mgd)	Sep. P50- Sep. P75 (mgd)	ELOHA (mgd)	BF10- App. CU (mgd)	BF10-P75- App. CU (mgd)	P50-P75- App. CU (mgd)	ELOHA- App. CU (mgd)
MSH1	4.2	43.6	37.8	3.5	4.8	39.4	33.7	-0.7	0.7
MSH2	3.7	20.9	18.4	1.2	2.4	17.2	14.7	-2.5	-1.4
MSH3	1.0	14.0	12.3	0.7	1.6	12.9	11.2	-0.4	0.5
LMS1	0.2	4.2	3.8	0.4	0.5	4.0	3.6	0.2	0.2
WHT1	0.1	15.0	13.2	1.5	1.6	15.0	13.1	1.4	1.6

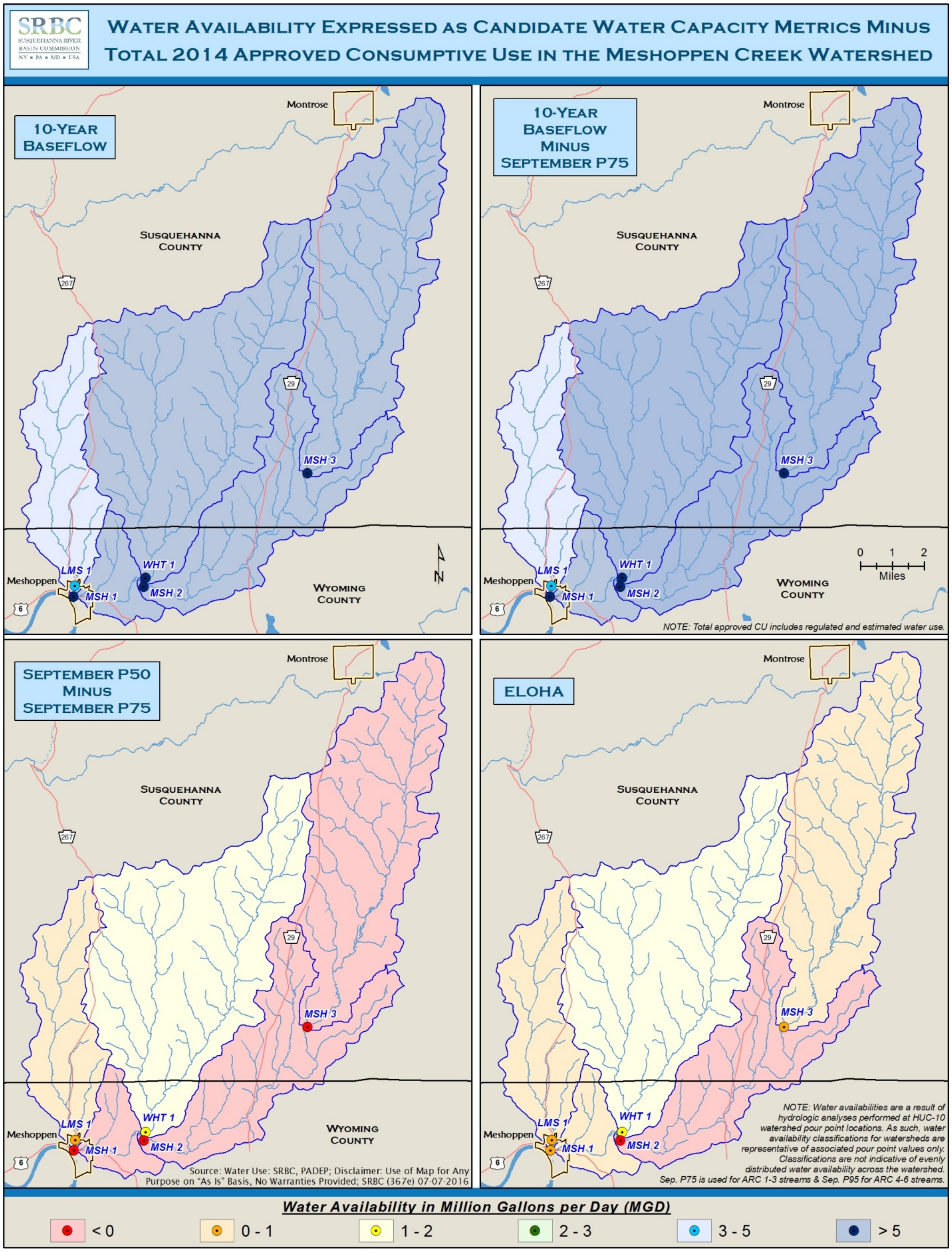

Figure J-3. Water Availability Expressed as Candidate Water Capacity Metrics Minus Total 2014 Approved CU in the Meshoppen Creek Watershed