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SURFACE WATER AVAILABILITY IN SELECT TRIBUTARIES OF THE DELAWARE RIVER BASIN

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Managing, Protecting and Improving
the Water Resources of the
Delaware River Basin since 1961



Surface Water Availability in Select Tributaries of the Delaware River Basin

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This report is not a rule, regulation or guidance and has no legal significance. References to dockets and their respective requirements are solely for informational purposes. Although certain definitions in this report are derived from the Delaware River Basin Compact and implementing regulations, all definitions, regardless of their sources, are provided solely to assist readers in understanding the data and other information presented herein.

AUTHORIZATION

This work is being conducted in accordance with Article 3 Section 3.6(c) of the Delaware River Basin Compact (PL 87-328, 75 Stat. 688). More specifically, the project is outlined in Section 2.2.1.1.1 (Water Supply Planning for a Sustainable Water Future 2060) of the DRBC Water Resources Program FY2024–2026 (DRBC, 2023a).

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EXECUTIVE SUMMARY

The water resources of the Delaware River Basin (DRB or “Basin”) provide drinking water for more than 14 million people. Water withdrawals across the Basin to support public water supply (PWS) in calendar year 2024 totaled approximately 0.8 billion gallons per day (BGD), while an additional approximately 5.3 BGD day was withdrawn to support thermoelectric power generation, irrigation, industry, out-of-Basin diversions, and other uses. This report describes the development and application of a model, SWEET (Surface Water Estimation and Evaluation Tool), to analyze in-stream surface water availability at specific PWS withdrawal locations in non-tidal tributaries to the Delaware River. The objective of this surface water availability analysis is to evaluate whether there would be enough water present in the Basin’s non-tidal tributaries to meet recent average withdrawal volumes from those tributaries during a repeat of dry periods that have occurred in the DRB over 1960–2010, including the 1960s drought of record (DoR) and 1998–2002 drought.

This study encompasses six watersheds that provide water supply to support PWS, thermoelectric power generation, industry, irrigation, and other uses in Pennsylvania and Delaware: Brodhead Creek, Brandywine-Christina River, Lehigh River, Neshaminy Creek, Chester-Ridley-Crum Creeks, and Schuylkill River. These watersheds include all PWS sources in the DRB that withdraw from non-tidal, run-of-river tributary intakes. Within these six watersheds, surface water availability was evaluated at 54 withdrawal locations (“points”) by applying recent average water demands to hydrologic conditions (HC) observed from 1960 to 2010, with a focus on PWS withdrawals. These 54 points include 75%, by volume, of the non-main stem PWS withdrawals in the DRB. To evaluate availability for additional PWS withdrawals in the DRB, a supplemental methodology, accounting for tidal processes, mainstem flow management, and/or impoundment operations, would be needed.

SWEET compares recent average withdrawal volumes (from the perspective of the model these are “intended” withdrawal volumes) with the available streamflow during HC1960–2010 at each specified point. If intended withdrawal is less than the available streamflow on any day, that withdrawal point is “flagged” for potential surface water availability challenges. Streamflow at each point is estimated using a combination of “unaltered” flow (from the United States Geologic Survey [USGS] Delaware River Basin Streamflow Estimator Tool [DRB-SET]), groundwater withdrawals from within the catchment, returns to the stream (from National Pollutant Discharge Elimination System [NPDES] data), and upstream surface water withdrawals. Estimated streamflow in SWEET is reasonably consistent with observed data from USGS gages, though during low flow periods, streamflow is often under-estimated in SWEET. As a result, when a point is not flagged, it is highly likely to maintain adequate supply during a repeat of the DoR. When a point is flagged, further study into the potential for supply challenges for that utility may be warranted, but the result is not a prediction that such impacts will occur.

Many surface water withdrawal points in the DRB are subject to pass-by flow (PBF) requirements, which indicate a volume of streamflow that should be allowed to “pass by” after a withdrawal is

taken. Of the 54 points analyzed in SWEET, 22 have pass-by flow requirements that were included in the SWEET model. If streamflow approaches the PBF value, a limited withdrawal amount may be taken to preserve streamflow at or above the PBF value; if streamflow drops below the PBF value, no water should be withdrawn.

Of the 54 points where in-stream surface water availability was evaluated, nearly two-thirds (32), including 17 PWS withdrawals, met their current withdrawal volumes on every modeled day under repeated hydrologic conditions (HC) from 1960 to 2010, including a repeat DoR. Of these 32 unimpacted points, only two have a PBF requirement in place, and most withdraw less than 40% of available streamflow even during the driest periods. These results show that the majority of tributary PWS surface water withdrawal locations in the DRB are expected to have sufficient in-stream water to meet their needs during a repeat drought of record.

The remaining 22 flagged points are modeled as unable to take their intended daily withdrawal volume at least some of the time during HC1960–2010. These points include 9 PWS intakes, 3 thermoelectric power generation intakes, 5 golf intakes, 3 ski intakes, and 2 industrial intakes. The Lehigh River watershed had the largest number of flagged points—10—while Neshaminy Creek watershed had no flagged points. The Schuylkill River, Brodhead Creek, Brandywine-Christina River, and Chester-Ridley-Crum Creek watersheds had 4, 3, 3, and 2 flagged points, respectively. All but two withdrawal locations included in the model with a PBF were flagged for further study, indicating that PBFs are an important consideration for water availability.

Each of the 9 impacted PWS points is given detailed consideration. A singular point may not be reflective of a PWS supply system as a whole, and each of those points have site-specific mitigating factors not included in the SWEET model, such as alternate sources, reservoirs or supply storage, and/or interconnections. In light of these considerations and the conservative nature of the SWEET model, the majority of impacted PWS points are not expected to face surface water availability concerns during a repeat DoR. Two flagged points with remaining potential concerns are located in the Lehigh River watershed, an area often flagged for water availability issues as existing tools cannot yet appropriately simulate its karst geology.

In addition to the baseline scenario discussed above, availability results were generated for three hypothetical model scenarios: (1) A future demand scenario, for which recent withdrawal trends were projected to the year 2060, (2) a drought management scenario, for which conservation releases and pass-by flow requirements were adjusted to represent drought conditions where applicable, and (3) an ecological pass-by flows scenario that applied hypothetical PBFs using a methodology that emphasizes ecological needs. The results from these scenarios were compared to the baseline scenario described above.

Overall, results from this study demonstrate that most of the Basin's in-stream tributary surface water withdrawals for PWS would be able to maintain present-day withdrawal volumes during a future drought. A few points were flagged for potential availability concerns, notably in the Lehigh River watershed, and would need further study to quantify possible supply challenges in the context of site-specific operations. The results also emphasize that up-to-date data is critical to

represent the Basin's water availability; data and tools relied on for this study include the DRB-SET model, NPDES discharge data, state withdrawal data, and USGS gages. SWEET results highlighted that PBF requirements influence water availability at individual points; thus, water availability results presented here would likely change if these regulatory values were adjusted. The tool, SWEET, developed and applied in this study has many potential future applications, including:

- Incorporating data and impacts from recent dry periods in fall 2024 and fall 2025;
- Computing how much additional storage may be needed to meet demand under specific conditions;
- Evaluating how water loss impacts water availability;
- Supporting evaluation for newly proposed surface water intakes; and
- Studying the impacts of climate change on water availability.

This study represents an important step in evaluating surface water availability in the Delaware River Basin.

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LIST OF ACRONYMS AND ABBREVIATIONS

7Q10	7-day low-flow that occurs once every 10 years
ARC	Aquatic Resource Class
BG	billion gallons
BGD	billion gallons per day
BGY	billion gallons per year
CU	consumptive use
CY	calendar year
DE	Delaware
DEM	digital elevation model
DNREC	Delaware Department of Natural Resources and Environmental Control
DRB	Delaware River Basin
DRBC	Delaware River Basin Commission
DRB–SET	Delaware River Basin–Streamflow Estimator Tool
ECHO	Enforcement and Compliance History Online
EPA	United States Environmental Protection Agency
FY	fiscal year
GIS	geospatial information systems
GW	groundwater
HC	hydrologic conditions
HCA	Hazleton City Authority
KRA	Key Result Area
LCA	Lehigh County Authority
LGS	Limerick Generating Station
MG	million gallons
MGD	million gallons per day
MGY	million gallons per year

NBMA	Northampton Borough Municipal Authority
NFWF	National Fish and Wildlife Foundation
NJ	New Jersey
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resource Conservation Service
NY	New York
PA	Pennsylvania
PADEP	Pennsylvania Department of Environmental Protection
PAWC	Pennsylvania American Water Company
PBF	pass-by flow
PFAS	per- and polyfluoroalkyl substances
PRISM	Parameter-elevation Relationships on Independent Slopes Model
PWD	Philadelphia Water Department
PWS	public water supply
QA/QC	quality assurance and quality control
SRB	Susquehanna River Basin
SRBC	Susquehanna River Basin Commission
SSURGO	Soil Survey Geographic Database
SW	surface water
SWEET	Surface Water Estimation and Evaluation Tool
TNC	The Nature Conservancy
USA	United States of America
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WMAC	Water Management Advisory Committee
WSCC	Delaware Water Supply Coordinating Council
WY	water year (1 October – 30 September)

1. INTRODUCTION

1.1 STUDY PURPOSE AND AUTHORITY

1.1.1 Study Objectives

The water resources of the Delaware River Basin (DRB or “Basin”) provide drinking water for more than 14 million people, 7.4 million of whom reside in a public water supply (PWS) service area within the Basin. Water withdrawals across the Basin to support PWS in calendar year (CY) 2024 totaled approximately 0.8 billion gallons per day (BGD). In addition, approximately 5.3 BGD was withdrawn to support other uses, including thermoelectric power generation, irrigation, industry, and out-of-Basin diversions. The purpose of this surface water availability study is to evaluate whether there would be enough water present in the Basin’s non-tidal tributaries to meet recent average withdrawal volumes from those tributaries during a repeat of dry periods that have occurred in the DRB over 1960–2010, with an emphasis on PWS and thermoelectric withdrawals. This study focuses on specific withdrawal locations (“points”) throughout the Basin where the Delaware River Basin Commission (DRBC or “Commission”) has allocated water. By improving understanding of potential in-stream surface water availability challenges during drought conditions, this project directly supports Basin-wide water resource management and planning efforts to ensure a resilient water supply. Specifically, this study has two primary objectives:

1. **Develop a method to evaluate surface water availability throughout the Delaware River Basin.** DRBC’s surface water availability model is called SWEET (Surface Water Estimation and Evaluation Tool). SWEET compares available streamflow with recent average withdrawal volumes at individual surface water withdrawal locations, utilizing local information including pass-by flow (PBF) requirements, groundwater withdrawals, and returns. Challenges, limitations, and uncertainties in conducting this type of analysis are highlighted. With SWEET’s capability to evaluate a range of scenarios, this study works toward quantifying what measures may be needed and where to supplement freshwater flows during drought conditions, supporting both aquatic habitat and water supply needs. SWEET is designed to evaluate water available for run-of-river intakes along tributaries to the Delaware River. Additional techniques would be required to assess withdrawals from impoundments, the main stem Delaware River, or tidal waters.
2. **Apply this methodology to screen for possible surface water availability issues in non-tidal portions of the Brodhead Creek, Brandywine-Christina River, Lehigh River, Neshaminy Creek, Chester-Ridley-Crum Creeks, and Schuylkill River watersheds.** These six watersheds contain all public water supply surface water intakes in the DRB that meet the following conditions: (1) Do not draw from the main stem Delaware River, (2) do not draw from a reservoir or impoundment, and (3) do not draw from tidal waters. Surface water availability is evaluated by considering how a repeat of past hydrologic conditions (e.g., rainfall) might affect these watersheds given recent observed and possible future water demands. SWEET models hydrologic conditions from

a 50-year period (water years 1960–2010), which includes the DRBC-recognized drought of record (Section 1.3.1). Any specific surface water withdrawal points that may not be able to support recent withdrawal volumes during a severe drought will be flagged for possible further study.

1.1.2 Sustainable Water Supply Plan

This work is being conducted in accordance with Article 3 Section 3.6.c of the Delaware River Basin Compact (PL 87-328, 75 Stat. 688). More specifically, this work is related to initiatives set forth in the *Water Resources Plan for the Delaware River Basin*, henceforth referred to as the “*Basin Plan*” (DRBC, 2004). The *Basin Plan* includes five interrelated Key Result Areas (KRAs) which outline desired results for the Basin. The first KRA is “Sustainable Use and Supply”, which calls for an adequate and reliable supply of suitable quality water to sustain human and ecological needs. Under KRA-1, Goal 1.3 is specifically focused on ensuring that there is an adequate and reliable supply of water given the current demands in each water use sector, as well as future demands based on projections of water use trends.

The Commission’s most recent Water Resources Program (fiscal year [FY] 2027–2029) section 2.2.1.1.1 calls for a “*detailed and comprehensive analysis of water demand, availability and sufficiency through 2060*” (DRBC, 2026b). Furthermore, the Commission’s 2060 Sustainable Water Supply workplan includes a task to evaluate non-tidal surface water demand and availability. This study will further the Commission’s mission of ensuring water security for the 14.2 million Americans who rely on the Basin’s waters.

1.1.3 Previous Studies Associated with 2060 Planning

The surface water availability tool presented in this report is part of a larger project broadly focused on water availability in the DRB through 2060, as noted in Section 1.1.2. Namely, there are two related DRBC publications that come before this one:

- 1. Water Withdrawal and Consumptive Use Estimates for the Delaware River Basin (1990–2017) with Projections Through 2060**

The purpose of this study was to analyze existing water withdrawal and consumptive use data for the Delaware River Basin and to provide projected water withdrawal trends through the year 2060 in support of water availability planning. Data were analyzed at a system level, resulting in over 600 projection summaries representing a continuation of current operational trends within the Basin.

- 2. Estimated Groundwater Availability in the Delaware River Basin 2020–2060**

The purpose of this study was to assess current and projected groundwater availability in the Delaware River Basin. This report included a detailed background of the screening methodology used and a thorough description of the Basin’s hydrologic setting through a hydrogeologic lens. The screening tool results were presented for two assessment scales: (1) the entire Basin, and (2) the Southeastern Pennsylvania Groundwater Protected Area.

Specific limitations of the methodology were addressed in a manner not previously undertaken by the Commission. The results were tied into discussions on trends in available natural resources over time (streamflow and groundwater levels), possible impacts of climate change, and the seasonal patterns of annual data.

1.2 WATERSHEDS INCLUDED IN THIS REPORT

Six watersheds of major tributaries to the Delaware River that are used for water supply were selected for this study: Brodhead Creek, Brandywine-Christina River, Lehigh River, Neshaminy Creek, Chester-Ridley-Crum Creeks, and Schuylkill River. These watersheds cover portions of Pennsylvania (PA) and Delaware (DE), two of the four Delaware River Basin states. These watersheds were identified in part based on their importance in providing public water supply. Public water supply (PWS) withdrawal volumes at surface water points evaluated within these six watersheds comprise approximately 75 percent of all non-main stem PWS surface water withdrawals in the DRB. This assessment includes 1,325 miles of stream habitat along these rivers and their major tributaries: Brodhead Creek (93 miles), Brandywine-Christina River (208 miles), Lehigh River (391 miles), Neshaminy Creek (70 miles), Chester-Ridley-Crum Creeks (57 miles), and Schuylkill River (563 miles).

New Jersey (NJ) has relatively few surface water intakes for public water supply in the DRB that are not on the main stem Delaware River. Much of New Jersey's surface water from the DRB is sourced from the Delaware and Raritan Canal (up to 100 MGD), New Jersey American Water's tidal Delaware River intake at Delran (up to 40 MGD), and other intakes along the main-stem Delaware River. In New York (NY), most surface water use is associated with three reservoirs in the Upper Basin (Pepacton, Neversink, and Cannonsville Reservoirs, combined supplying up to 800 MGD) owned and operated by the New York City Department of Environmental Protection. Additional surface water use for public water supply is limited in NY.

1.3 DROUGHTS

Two multi-year drought periods were selected as periods of focus for surface water availability analyses. Evaluating availability under drought conditions facilitates identification of areas where freshwater flows are potentially deficient. The first drought evaluated is DRBC's drought of record (1961–1967), the most severe drought on record in the Basin and defined in the DRBC Water Code to be the basis for determination and planning of dependable Basin water supply. The DRBC Water Code also outlines specific drought management plans. The second drought period comprises another series of dry years (1998, 1999, 2001, and 2002) that had great impacts on both surface and groundwater supplies throughout the Basin. This drought period is the third-worst drought on record. (The second-worst drought occurred in the 1930s, when less data was

available.) More information about droughts in the DRB is available on the DRBC website¹. By evaluating surface water availability against hydrologic conditions from these two droughts, the Commission gains insight into the resilience of the individual surface water withdrawals in this study.

1.3.1 Drought of Record (1961–1967)

In the years leading to the drought of record there was an abundance of rain and snow, which falsely left water suppliers believing they were drought proof. In May 1961, a United States Army Corps of Engineers (USACE) report predicted ample water supplies in the DRB until 2010 (USACE, 1961). However, in August 1961 a prolonged drought began impacting the Delaware River Basin that would last 7 years. As time went on, precipitation deficits increased as each year was drier than the last.

Between 1961 and 1965, it is estimated that the Northeastern United States lost a year's worth of rainfall. The drought became especially critical in spring 1965, when massive fish kills occurred due to very low dissolved oxygen in the Delaware River Estuary. In the tidal portion of the Basin, the salt front moved much farther upstream than expected, leading to the possibility of saltwater intrusion into the drinking water supplies of Philadelphia, PA, and Camden, NJ (DRBC, 2019). Furthermore, corrosion impacted industrial cooling systems. In the Upper Basin, New York City officials feared their reservoirs would empty by late November 1965, leading to a drinking water shortage (Hogarty, 1970).

On July 5, 1965, DRBC passed two resolutions: Resolution No. 1965-13 (also known as Emergency Order 1), which declared a water supply emergency within the Basin, and Resolution 1965-14, which modified the 1954 Supreme Court Decree to reduce New York City's out-of-basin diversion and reduce the flow objective at Montague, NJ (Resolution No. 65-13, 1965). In addition, the Commission passed two conservation orders. Conservation Order 1 stipulated that two hydroelectric generating companies in the Upper Basin release water downstream to push back the salt front (DRBC, 2019). Conservation Order 2 directed the USACE to store water in F.E. Walter and Prompton Reservoirs with releases to be made based on a schedule created by DRBC. In October 1965, Emergency Order 2 was passed to reduce the flow target at Trenton, NJ. In March 1967, Resolution No. 1967-3 was passed, ending the drought emergency after 20 months (Resolution No. 67-3, 1967).

The drought that occurred during 1961–1967 is expected to occur once in 200 to 1,000 years (Hogarty, 1970; McCabe & Wolock, 2020). In 1983, a resolution was passed to codify the 1961–1967 drought as the drought of record in the DRB (Resolution No. 83-12, 1983). The resolution states it shall be the “basis for determination of and planning of dependable Basin water supply.”

¹ <https://www.nj.gov/drbc/programs/flow/drbc-drought.html>

1.3.2 1998–2002 Drought

In the late 1990s, two droughts prompted the DRBC to implement drought emergencies. The first began in summer 1998, due to an annual rainfall deficit of almost 12 inches in parts of the DRB. That December, the Delaware River at Trenton, NJ, was so low that boats were unable to cross for the annual reenactment for Washington's Crossing for the first time since the tradition began in 1953 (DRBC, 2019). In November 1998, flow objectives were reduced at Montague, NJ, and Trenton, NJ. A conditional drought emergency was declared in January 1999 but never officially took effect because hydrologic conditions improved by February (Resolution No. 99-01, 1999).

The following summer, dry conditions returned to the DRB, impacting streams and crops. By mid-August 1999, the salt front had reached Philadelphia International Airport (River Mile 89). Drought operations were not triggered by storage in NYC reservoirs, but the flow target at Trenton, NJ, was reduced to conserve storage in Beltzville and Blue Marsh Reservoirs (DRBC, 2019). In August, a resolution was passed requesting for releases from Nockamixon Reservoir, Lake Wallenpaupack, and the Mongaup system (Resolution No. 99-01, 1999). In September 1999, Hurricane Floyd brought 6 to 10 inches of rain, ending the drought (DRBC, 2019).

Dry conditions returned in late 2001, lasting until November 2002. In October 2001, the Upper Basin experienced an annual deficit of about 8 inches causing storage in the New York City reservoirs to rapidly decline. By December 15, 2001, storage had declined to 25% of usable capacity and the salt front reached its farthest-upstream location for the year, River Mile 86. On December 18, 2001, a drought emergency was declared for the Basin (Resolution No. 01-32, 2001). Dry conditions persisted into 2002 with a little relief in the spring when snowmelt and rainfall allowed for storage in the NYC reservoirs to rise above the drought threshold. Summer brought dry conditions, and the salt front moved back upstream to River Mile 89. In August 2002, Delaware issued a drought emergency after a 13-month rainfall deficit of 20 inches (DRBC, 2019). By November, rainfall had returned and the drought emergency officially ended (Resolution No. 02-31, 2002). In Northern Newcastle County, DE, the year 2002 is used as its planning drought (Delaware Water Supply Coordinating Council, 2003). In this study, the droughts occurring in 1998, 1999, and 2001–2002 are evaluated together as one multi-year drought period.

2. A METHODOLOGY FOR EVALUATING SURFACE WATER AVAILABILITY

The objective of this approach is to understand what would happen if historical dry periods were repeated with current (or future) conditions. The methodology outlined in this section applies current withdrawal volumes, discharges, and operations to historical hydrologic conditions. No part of this work aims to “recreate” the past.

2.1 WATER WITHDRAWAL DATA

Water withdrawal data used by DRBC typically come from two sources: (1) data sharing with state environmental management agencies in respective Basin states, or (2) data submitted directly to DRBC as required by the surface water charging program (DRBC, 2023b). Data from all sources are synthesized into a central database that stores information on individual withdrawal points (sources) and the organizations which own and operate them. For this report, water withdrawal data includes the designation (groundwater or surface water) and water use sector (**Figure 2-1**).

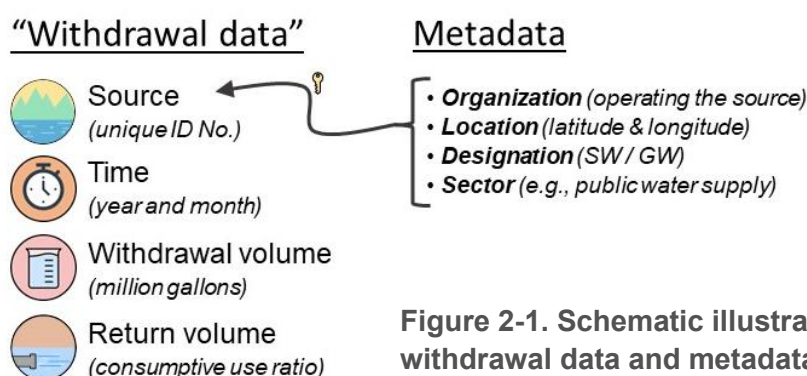


Figure 2-1. Schematic illustrating withdrawal data and metadata.

2.2 POINT SELECTION AND CATCHMENT DELINEATION

2.2.1 Surface Water Withdrawal Location Data

Based on geographical coordinates in withdrawal metadata, all mapped surface water withdrawal points located within the six study watersheds were screened for inclusion in SWEET. A withdrawal point was *not* included if it met any of the following criteria:

- There were no withdrawal data for the past ten years (since 2013), indicating that the withdrawal may no longer be in use and/or that it does not have sufficient data for analysis.
- The withdrawal is largely for pass-through flow (e.g., aquaculture or hydropower).
- It is known that the withdrawal point is no longer in use.

- The withdrawal data are sporadic and intermittent, with no discernable pattern, indicating that estimated withdrawal rates would be uncertain and imprecise (e.g., a rarely used back-up intake).
- The withdrawal intake is located in a tidally influenced surface water body.
- The surface water withdrawal intake draws from a body of water that is ultimately sourced from groundwater (e.g., a retention pond or spring). This withdrawal volume would already be accounted for in groundwater withdrawal data.

Surface water withdrawal points from reservoirs and impoundments, as well as more consistently used backup intakes, were included in the model, but availability was not assessed at these locations.

The selected surface water withdrawal points were loaded into ArcGIS Pro using geographical coordinates. In some cases, the location of the withdrawal point was adjusted based on knowledge of the system (e.g., moving a point from a river's tributary to the main stem). Additional points without an associated withdrawal were added for large reservoirs and for United States Geological Survey (USGS) gages. In total, SWEET models 148 points, including 54 "SW points" where surface water availability was analyzed. **Table 2-1** summarizes these points, and a complete list can be found in Appendix A.

2.2.2 Catchment Delineation Concept

SWEET estimates surface water availability at specified points throughout a watershed by performing a mass balance within the area draining to each point, considering the water withdrawn, water returned, and contributing surface water flow. To avoid double-counting contributing surface water flows, the analysis for an individual point needs to account for the area

Table 2-1. Number of points analyzed for each watershed.

Watershed	Total Number of Points	Surface Water Withdrawal Points (SW Points)	Reservoirs, Impoundments & Other Points	USGS Gage Points
Brodhead Creek	13	7	4	2
Brandywine-Christina River	22	8	10	4
Lehigh River	29	12	14	3
Neshaminy Creek	10	2	7	1
Chester-Ridley-Crum Creeks	12*	5	5	3
Schuylkill River	62	20	34	8
Total	148	54	74	21

**One of the USGS gages, Ridley Creek at Media, is located in the same location as the Aqua Pennsylvania intake on Ridley Creek. In SWEET, point R01 represents both the intake and the USGS gage.*

that (1) drains to that point and (2) does *not* drain to any upstream points. Thus, an amended catchment delineation process was applied, such that the catchments for all points in a watershed comprise discrete non-overlapping “pieces” of the watershed (**Figure 2-2**).

2.2.3 Processing in ArcGIS

Creating SWEET catchments required delineation of the area draining to each point. Ground elevation data were obtained from a 1/3 arc-second digital elevation model (DEM), resulting in an approximately 10x10 meter grid of elevation data (a “raster”) covering each of the six watersheds (USGS, 2019). Elevation data were analyzed using the Fill, Flow Direction, and Flow Accumulation tools (Hydrology toolset, Spatial Analyst toolbox) to generate flow accumulation rasters for each watershed. Each point location was then adjusted to be on the correct pixel representing a flow path in the flow accumulation raster. The total contributing drainage area for each point was calculated using the Watershed tool (Spatial Analyst toolbox, Hydrology toolset) and converted to a polygon (Conversion Tools toolbox, From Raster toolset). The Union tool (Analysis toolbox, Overlay toolset) was used to combine all drainage area polygons within a watershed to create non-overlapping catchments. **Figure 2-3** shows the final 157 catchments used in SWEET, colored by watershed.

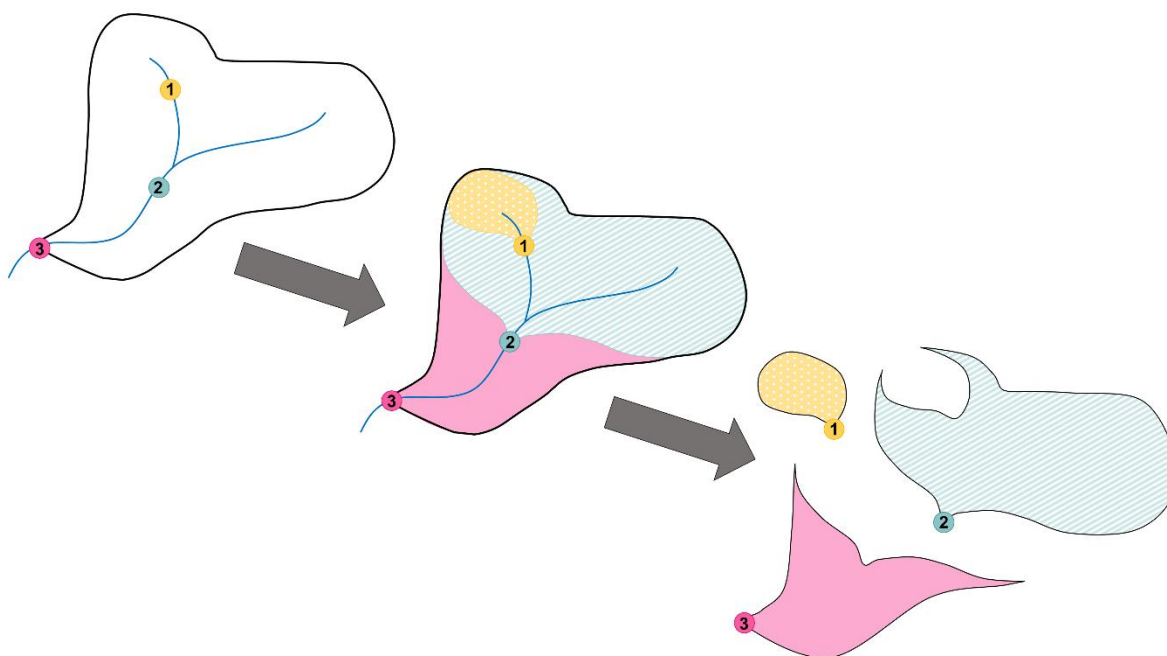


Figure 2-2. Schematic illustrating delineation of discrete, non-overlapping catchments for three surface water withdrawal points.

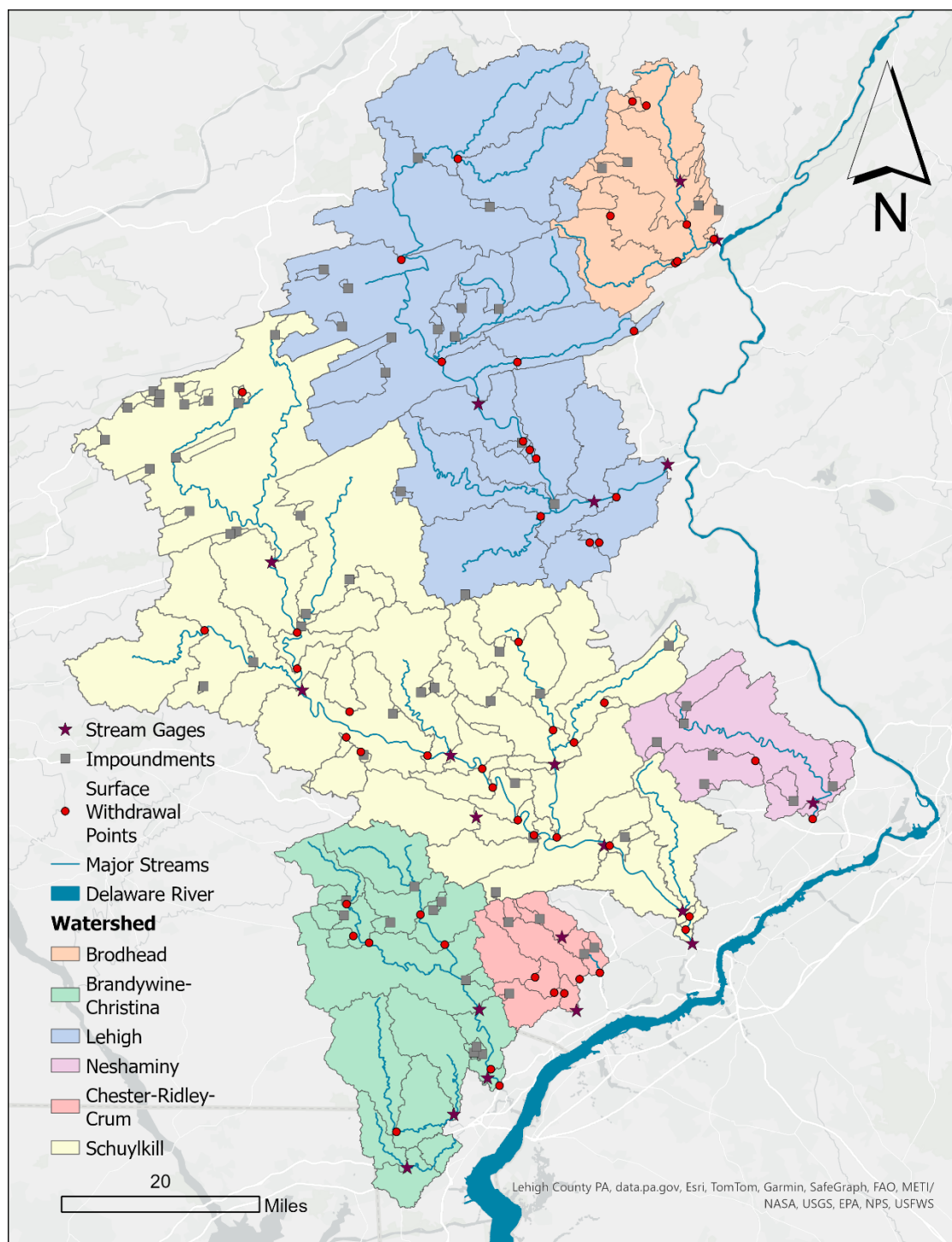


Figure 2-3. Map of 148 catchments used in SWEET.

Colors indicate the Brodhead Creek, Brandywine-Christina River, Lehigh River, Neshaminy Creek, Chester-Ridley-Crum Creek, and Schuylkill River watersheds. See Appendix A for a complete list of modeled points.

2.3 ESTIMATION OF “UNALTERED” STREAMFLOW

2.3.1 Delaware River Basin–Streamflow Estimator Tool

USGS developed the Delaware River Basin–Streamflow Estimator Tool (DRB–SET), which is software that can estimate minimally-altered daily streamflow for water years (WY; October 1–September 30) 1960–2010 at any point in the Basin (Stuckey, 2016; Stuckey & Ulrich, 2015). Notably, this time frame includes the drought of record (1961–1967). For a given point, DRB–SET automatically selects a nearby, hydrologically-similar “reference gage”. An expected flow-duration curve is developed based on soil properties, typical precipitation, and the area draining to that point. The QPPQ method is used to relate reference gage streamflow and the expected flow-duration curve to generate an estimated streamflow record at the point (e.g., Gazoorian, 2015). DRB–SET output is intended to represent streamflow that is minimally altered by regulation, diversion, mining, or other anthropogenic activities. Critically for the SWEET analysis, unlike stream gage data, DRB–SET output is intended to represent surface water flows (including storm flows and baseflow) *before* surface water or groundwater has been withdrawn.

2.3.2 Data Sources and Processing

DRB–SET requires several watershed characteristics as inputs (**Table 2-2**) that are typically calculated using the USGS tool StreamStats (Ries et al., 2008). StreamStats takes in a point as input; automatically delineates the area draining to that point and generates the area-weighted watershed characteristics needed for DRB–SET, based on the full drainage area. However, many SWEET catchments do not comprise the full drainage area to a point, so StreamStats output watershed characteristics could not be used. Therefore, the underlying geospatial data used by StreamStats was sought in order to calculate watershed characteristics for non-standard SWEET catchments.

Soils data (SSURGO)

Three soil parameters are required for DRB–SET: percent poorly drained soil, percent sand in soil, and saturated hydraulic conductivity (K_{sat}). StreamStats uses data from the Natural Resource Conservation Service’s (NRCS) Soil Survey Geographic Database (SSURGO) to estimate these parameters (Williamson et al., 2015). SSURGO data available by state includes (1) a geospatial layer with polygons representing soil groups, each with a unique identifier and (2) a Microsoft Access database with extensive soil data for each soil group (NRCS, 2023). Users can extract the desired information from the database and link with the geospatial data using the identifiers. StreamStats, released in 2008, employs a previous version of SSURGO data that currently is not publicly available (Marla Stuckey, personal communication, July 2023). For each soil group, SSURGO includes information for individual soil horizons, and StreamStats employs a depth-weighted average of the values across all horizons. This approach was implemented in Python

Table 2-2. Data inputs needed to run DRB–SET.

Watershed Characteristic	Units	Data Source
Outlet latitude and longitude	decimal degrees (°)	Calculate within ArcGIS Pro
X- and Y- location at the center of the watershed	Albers meters (m)	
Drainage area	square miles (mi ²)	
Poorly drained soil	percent (%)	Soil Survey Geographic Database (SSURGO) (NRCS, 2023)
Sand in soil	percent (%)	
Saturated hydraulic conductivity (K _{sat})	micrometers per second (µm/s)	
Mean annual precipitation	inches (in)	PRISM (Daly et al., 2008)
Mean winter monthly precipitation	inches (in)	

(v3.9) using SSURGO data accessed in July 2023; data for NJ, NY, PA, and DE were merged and clipped to the DRB. Based on a test analysis for six watersheds within the Lehigh River watershed (1.7 to 885 mi² in area), this approach yielded results similar to StreamStats soil parameter output, but they were not identical. The minor differences are attributed to the difference in SSURGO data versions.

After the soil parameter values from the database were linked with the polygon dataset in ArcGIS using the “Join Features” tool (GeoAnalytics Desktop toolbox, Summarize Data toolset), the data were converted into rasters for each soil parameter (**Figure 2-4**). For each parameter, the “Zonal Statistics as Table” (Spatial Analyst toolbox, Zonal toolset) tool was used to calculate a spatially-weighted value to represent each catchment as input to DRB–SET.

Precipitation data (PRISM)

In StreamStats, mean annual precipitation and mean winter precipitation are calculated using data from PRISM (Parameter-elevation Relationships on Independent Slopes Model) (Daly et al., 2008). Daily precipitation data for calendar years 1981–2022 are available at ~4 km resolution for the contiguous United States (NASCE, 2022); StreamStats makes use of data from 1981–2010. For this project, daily precipitation raster data from PRISM were downloaded and aggregated into mean annual and mean winter (December, January, and February) totals for the DRB during 1981–2010 (**Figure 2-5**). A test analysis for six watersheds within the Lehigh River watershed (1.7 to 885 mi² in area) demonstrated that the resulting datasets closely matched StreamStats output.

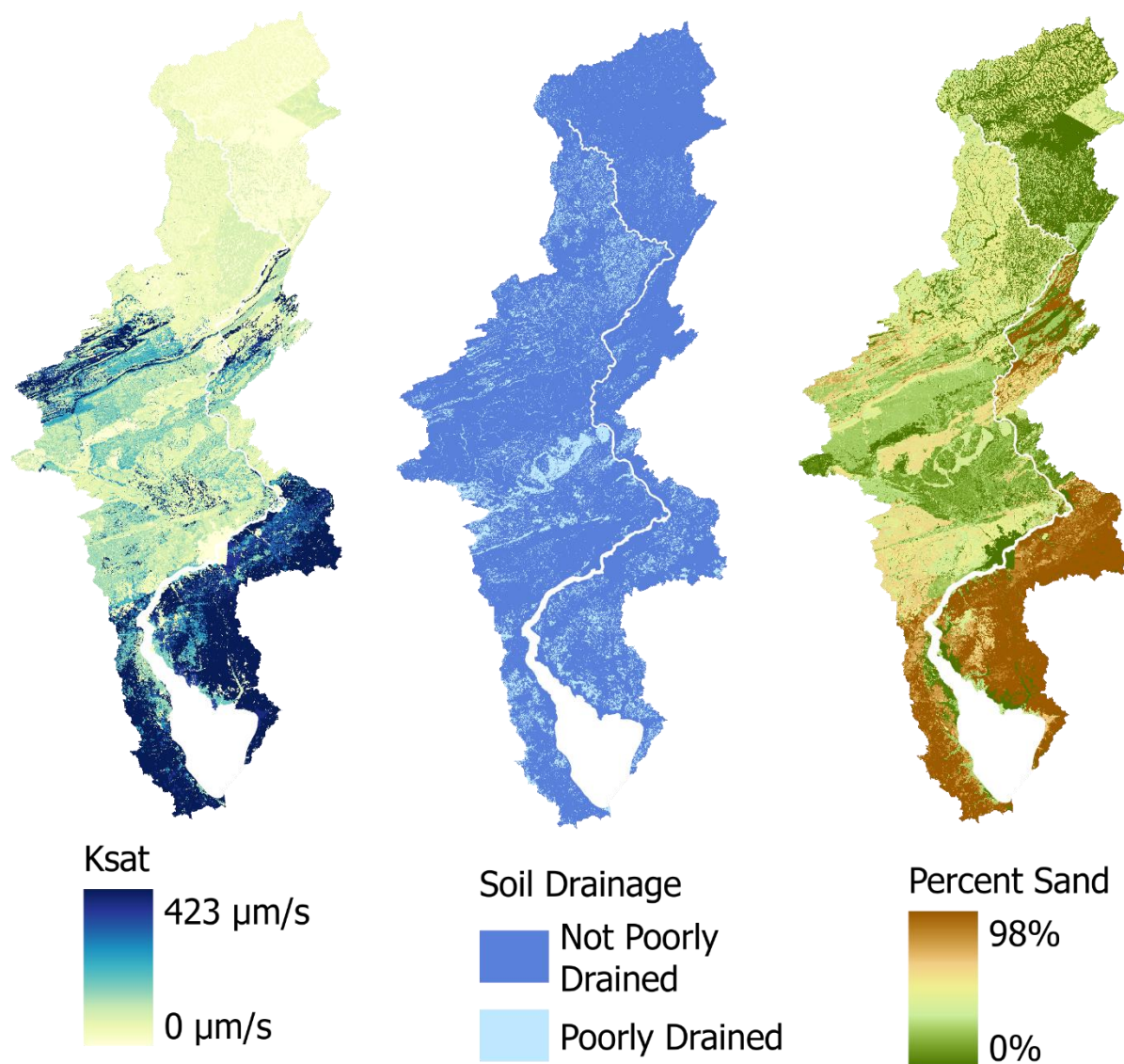


Figure 2-4. Rasters for saturated hydraulic conductivity (K_{sat}), soil drainage, and percent sand for the DRB.

Values from these rasters were used as input to DRB-SET.

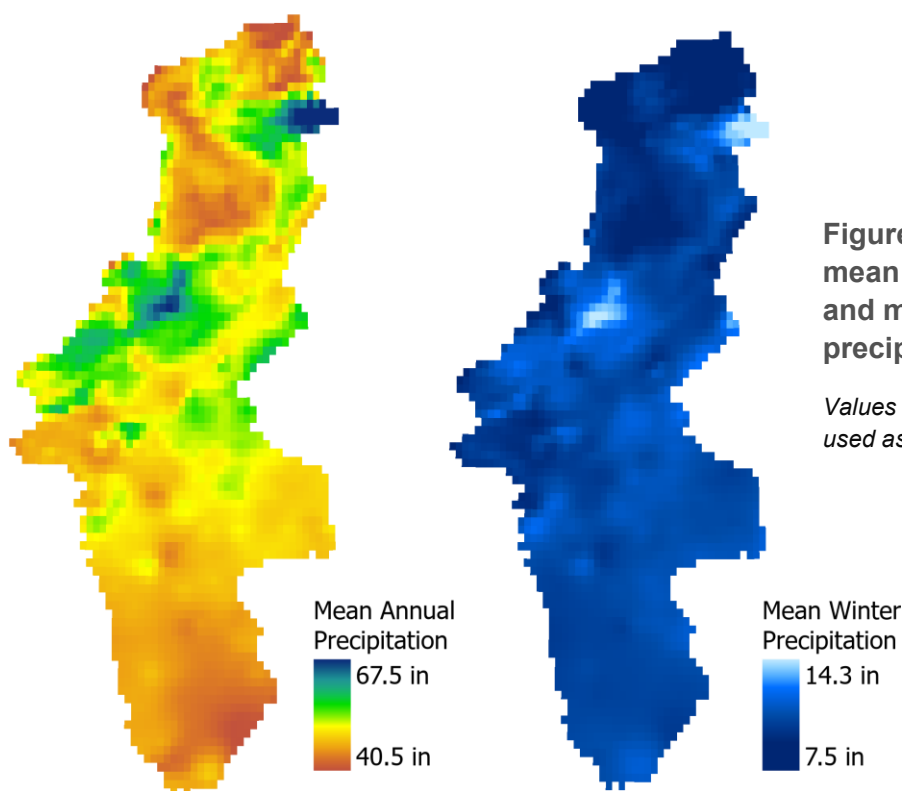


Figure 2-3. Rasters for mean annual precipitation and mean winter precipitation for the DRB.

Values from these rasters were used as input to DRB–SET.

ArcGIS calculations

Each catchment's area, outlet latitude and longitude coordinates, and X & Y central points were calculated in ArcGIS Pro. Using the "Calculate Geometry Attributes" tool (Data Management toolbox, Features toolset), each catchment's area and outlet coordinates were calculated. The X & Y central points were also calculated using the same "Calculate Geometry Attributes" tool, but the coordinate system of the map was changed to "USA Contiguous Albers Equal Area Conic USGS" to calculate the values in Albers meters.

2.4 WATER WITHDRAWALS AND RETURNS

2.4.1 Withdrawal data: Current conditions

Withdrawal data processing is discussed here using an example scenario from the Lehigh River watershed (**Figure 2-6A**). This example considers surface water withdrawal point L01. As described in Section 2.2.2, Catchment L01 is delineated as the drainage area between L01 and any point(s) upstream (in this case, L26). Catchment L01 contains 34 groundwater withdrawal points with data during 1990–2017 and many National Pollutant Discharge Elimination System (NPDES) returns. Withdrawal data were managed in two ways:

1. **Surface water:** As each point is modeled individually, the raw data is largely unaltered. Withdrawal data are a time series of monthly withdrawal volumes (**Figure 2-6B**).
2. **Groundwater:** Monthly groundwater withdrawal data must be aggregated such that all groundwater withdrawals within a catchment are represented by a single time series. The temporal scale of the time series is maintained (**Figure 2-6C**), yielding one groundwater withdrawal volume per month, per year.

For both surface and groundwater withdrawal volume time series, twelve monthly averages were calculated using all data available from 2018–2022. This time frame comprises the last five years for which data were processed and, in this analysis, is used to represent water demands under current conditions. The monthly withdrawal volumes (in MG) were divided by the number of days in each month to construct a daily time series (in MGD) for one year, which was repeated to cover WY1960–2010. The sector (e.g., public water supply, irrigation, etc.) was used to help determine how surface and groundwater are returned to the watershed, as described in Section 2.4.4.

Previously, surface and groundwater withdrawal data were compiled for years 2013–2017 in DRBC’s trend projection report (Thompson & Pindar, 2021). These results are also presented briefly in a comparison with the more recent data (Section 4.1).

2.4.2 Withdrawal data: Trend projections to 2060

This report focuses not only on water availability given current demands, but also considers how those demands may evolve in the future based on recent trends. A previous DRBC study projected annual average water withdrawal trends through 2060 (Thompson & Pindar, 2021); in that study, surface water points were treated individually and groundwater was projected at a sub-watershed scale. To estimate 2060 water use for SWEET, the trend projection methodology had to be updated in two ways:

1. As SWEET uses a daily time step, trend projections were performed on average monthly (rather than annual) surface and groundwater withdrawal volumes and converted to daily records for SWEET input.
2. SWEET requires that groundwater be aggregated and projected for specific catchments between surface water points (rather than for pre-defined sub-watersheds).

An example annual average trend projection for the Northampton Borough Municipal Authority (NBMA) system is provided in **Figure 2-7A** because point L01 is the system’s primary source (the projection also includes an average “constant value” projection of NBMA’s secondary withdrawal point). Annual data points are represented as dark circles; the trend projection extends as a blue line with grey 80% and 95% confidence limits. Alternatively, the same data for L01 are presented in **Figure 2-7B**, but on a monthly basis where each monthly withdrawal volume is an open circle. **Figure 2-7B** shows 12 trend projections for the data, each based on 29 data points for that month.

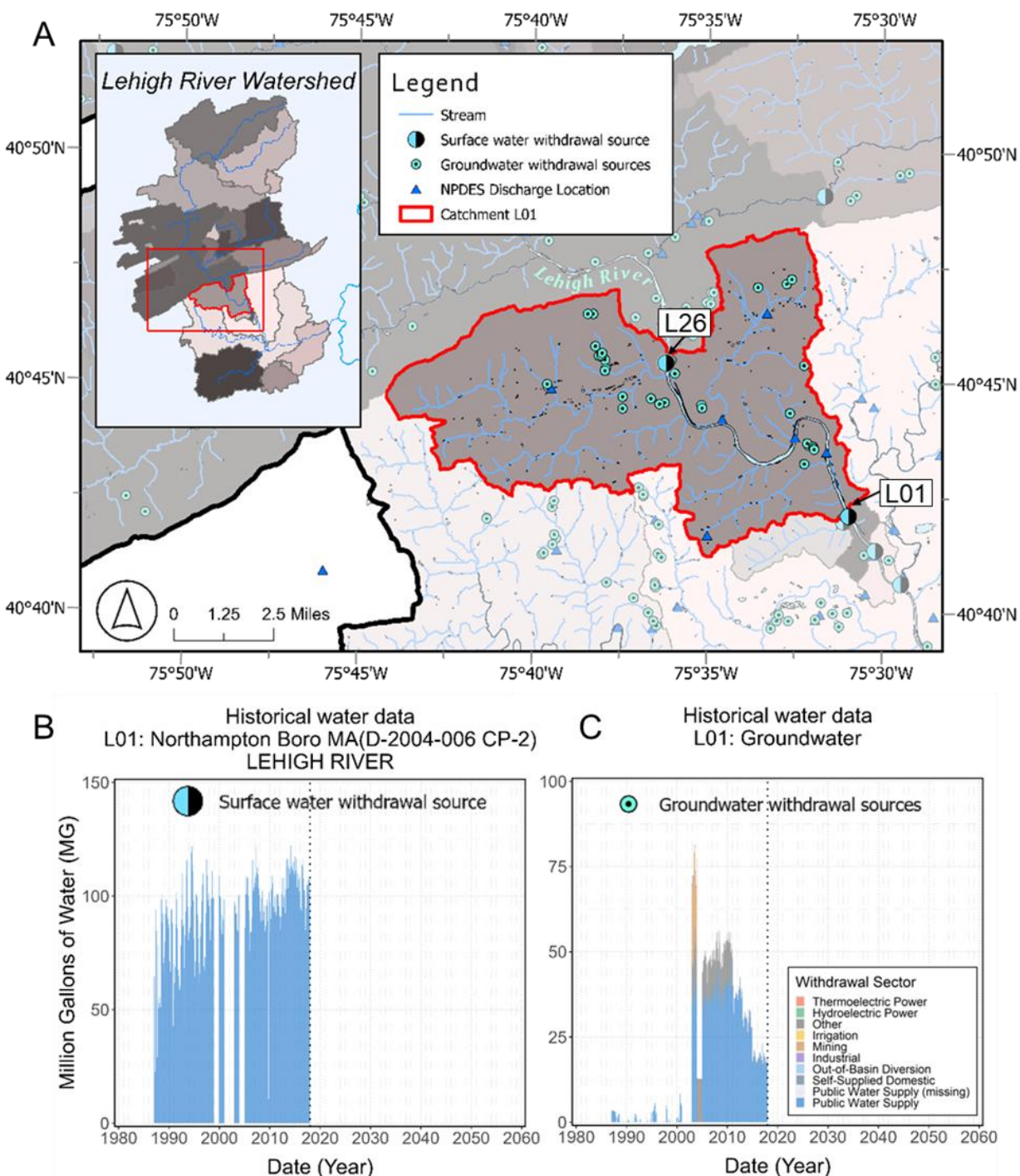


Figure 2-6. Surface and groundwater withdrawal data for point L01.

A. A map showing surface water withdrawal point L01 on the Lehigh River, the associated catchment, and all the groundwater withdrawals within the catchment. B. A monthly time series of withdrawals from point L01. C. The aggregated monthly withdrawal of water from all groundwater withdrawal points in catchment L01, colored by sector.



The monthly groundwater trend projection for Catchment L01 is provided as **Figure 2-8**. See Appendix C for surface water trends and projections to 2060 for all surface water withdrawal points (SW points).

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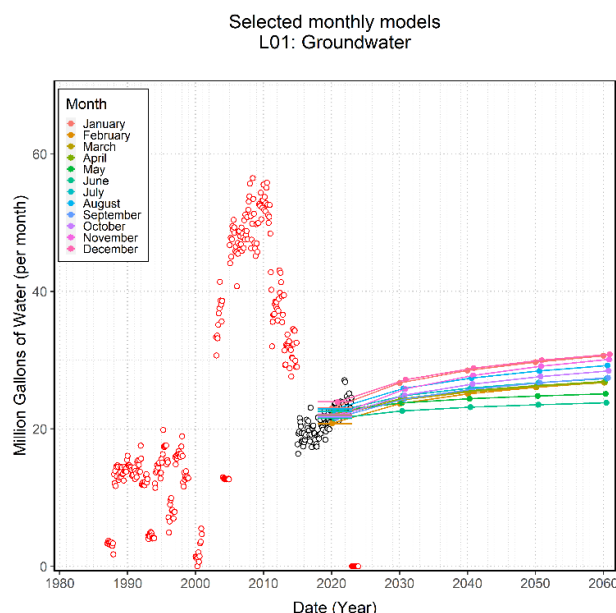


Figure 2-4. Groundwater projection for point L01.

*The same groundwater data provided in **Figure C**, instead represented as open circles. Note that data appearing as red were not considered in the trend projection in order to obtain the most representative dataset for current conditions. In this case, a recent five-year average value (2013–2017) was selected.*

More than half of the surface water (65 out of 114) and groundwater (60 out of 99) withdrawal points did not have a strong increasing or decreasing temporal trend, so the average withdrawal volumes from the most recent five years (2018–2022) were also used for to represent withdrawals in 2060. Among the withdrawal points that had a temporal trend, almost all had a logarithmic trend (43 out of 49 surface water trends and 37 out of 39 groundwater trends). Using the selected trends, monthly surface and groundwater withdrawal volumes were extrapolated to the year 2060; monthly totals in MG were divided by the number of days in each month to construct a daily time series for one year, which was repeated to cover WY1960–2010 for SWEET input.

As noted above, an earlier draft of this surface availability work utilized withdrawal data through 2017, before data from 2018–2022 were available. The withdrawal trend projections computed with data through 2022 were compared with withdrawal trend projections computed with data through 2017, using the same methodology. This comparison provides an opportunity to validate the methodology by evaluating how robust the trends are.

2.4.3 Withdrawal Data: Trend Projection Validation and Uncertainty

Before data for 2018–2022 were available, the same analysis was performed using monthly withdrawal data for 2013–2017. In that previous analysis, 110 surface water withdrawals were evaluated for (1) current conditions, represented by the average of monthly data in 2013–2017 and (2) future conditions, represented by extrapolating any current temporal trends to the year 2060. After five additional years of withdrawal data were obtained (2018–2022), current and future monthly withdrawal volumes were re-calculated and compared with the original estimates. This comparison evaluates how robust the estimations of current and future withdrawal volumes are, with a goal of providing some context for the level of uncertainty in these model inputs for the surface water availability analysis.

Major changes due to external factors

Four of the 110 points had no surface water withdrawals over the period 2018–2022 (two in the Brandywine–Christina watershed and two in the Schuylkill watershed). This outcome may reflect that a facility has closed; for example, the Christiana Country Club, formerly point C17, closed in 2020 and stopped withdrawing an annual average of 1 MGD (349 MGY) from the Christina River. Alternatively, the organization may have obtained water from a new source; for example, Cleveland Cliffs, formally point S25, switched to a new groundwater well in 2013 and stopped using a surface water intake on the Schuylkill River. In the original analysis, these four points in total withdrew approximately 19 MGD under current conditions and 17 MGD under future conditions. In the updated analysis through 2022, these four points withdrew 0 MGD under both current conditions and future conditions. This result represents one limitation of the trend projection methodology: it cannot account for existing withdrawal points ceasing operations or new withdrawal points coming online, though these changes could result in substantial increases or decreases in withdrawal volumes and/or locations.

Another example of a trend that could not be predicted by extrapolating past use is abandonment of a source due to water quality considerations. In recent years groundwater sources contaminated by per- and polyfluoroalkyl substances (PFAS) have caused utilities to shift source water from groundwater well networks to surface water withdrawals; specifically, two examples were observed in Bucks County, Pennsylvania. Warminster Municipal Authority discovered PFAS contamination impacting a well network that was allocated 125 MGM across 17 groundwater wells. While the full allocation has never been withdrawn, a typical month's demand for this system is regularly between 80 and 90 MG. Historically, when the full well network was online, it supplied 70 to 75 MGM. In the 2010s, the well network was reduced from 17 wells to 2 wells, reducing volume to 11 MG of the total monthly withdrawal with the rest supplemented by purchased water from the Forest Park water system, which utilizes surface water from the Neshaminy Creek via a transfer of surface water from the Delaware River. In Warrington Township, the water department operated on a well network that supplied 45 MGM across 9 groundwater wells. Since the discovery of PFAS contamination in 2016, Warrington has reduced their groundwater withdrawal from 45 to 0 MGM. After an acquisition by North Wales Water Authority in 2019, all of the water supplied to Warrington Township is now sourced from Forest Park surface water system.

Comparison of Withdrawal Volumes in 2013–2017 with Those from 2018–2022

The following comparisons focus on the 106 remaining surface water withdrawals that have complete data from 2013 to 2022. In terms of total annual withdrawals under current conditions, surface water withdrawals from these 106 points collectively decreased in 2018–2022 by approximately 3% relative to 2013–2017, from an average of 10.8 BGD to 10.5 BGD. This result validates one of the primary findings of Thompson & Pindar (2021) that overall water withdrawals in the Delaware River Basin have been, and are projected to continue, decreasing over time. However, there was a lot of variability in the comparisons at specific points. Almost half of the points, 47 out of 106, had a change of more than 20% (increase or decrease) in total annual

withdrawals when comparing 2018–2022 to 2013–2017, and 19 points had a change of more than 50%; the median change was 16%. These large swings in withdrawal volumes over a relatively short time indicate that “current conditions” are changing rapidly at specific withdrawal points in response to site-specific factors, and it is important to use up-to-date withdrawal data for any availability analyses.

Comparison of Projected Withdrawal Volumes in 2060

In total, the 106 points were originally projected to withdraw 10.6 BGD in 2060, approximately a 2% decrease from 2013–2017. According to updated projections, in 2060 a total of 10.2 BGD are projected to be withdrawn, a 3% decrease from 2018–2022. In aggregate, this result demonstrates that, according to more recent data, projected decreases are accelerating somewhat faster than anticipated based on 2013–2017 data.

At each specific point, withdrawal trend projections varied quite a bit when based on (1) all available data through 2017 or (2) all available data through 2022 (the same dataset as (1), with five additional years of data). After adding in the recent five years of data, more than half of the points, 60 out of 106, had a change of more than 20% (increase or decrease) in projected total annual withdrawals in 2060, and 32 points had a change of more than 50%; the median change was 28%. Furthermore, more than half of points (62 out of 106) had a change in the direction of projected trends. For 51 points, a decreasing or increasing trend was updated to a constant trend or vice versa; for the remaining 11 points, a decreasing trend was updated to an increasing trend, or vice versa.

As an illustrative example, **Figure 2-9** shows both sets of withdrawal trend projections for point S03. In the original dataset (on the lefthand plot), withdrawal volumes show a decrease beginning around 2010, and by 2017 appear to be trending upward again. The recent modest increasing trend was projected into the future. This analysis projected that 241 MGD would be withdrawn in 2060. However, with additional data from 2018–2022, withdrawal volumes began to decrease after 2017. In the updated analysis (on the righthand plot), the long-term record on average shows a modest decreasing trend, and results in a projection of 84 MGD in 2060.

These results highlight that future projections for individual points are subject to substantial uncertainty—the addition of five more years of data was enough to result in large changes to projected withdrawal volumes for 2060, and in some cases changed the direction of the trend projection. Selecting a best-fit trend for withdrawal data is a highly subjective process, such that two individuals may have different views on which data is reasonable to include or remove, and which trend has the best fit. Given the uncertainty and imprecision of point-specific withdrawal trend projections, this study draws stronger conclusions about surface water availability under current conditions than about availability under future conditions.

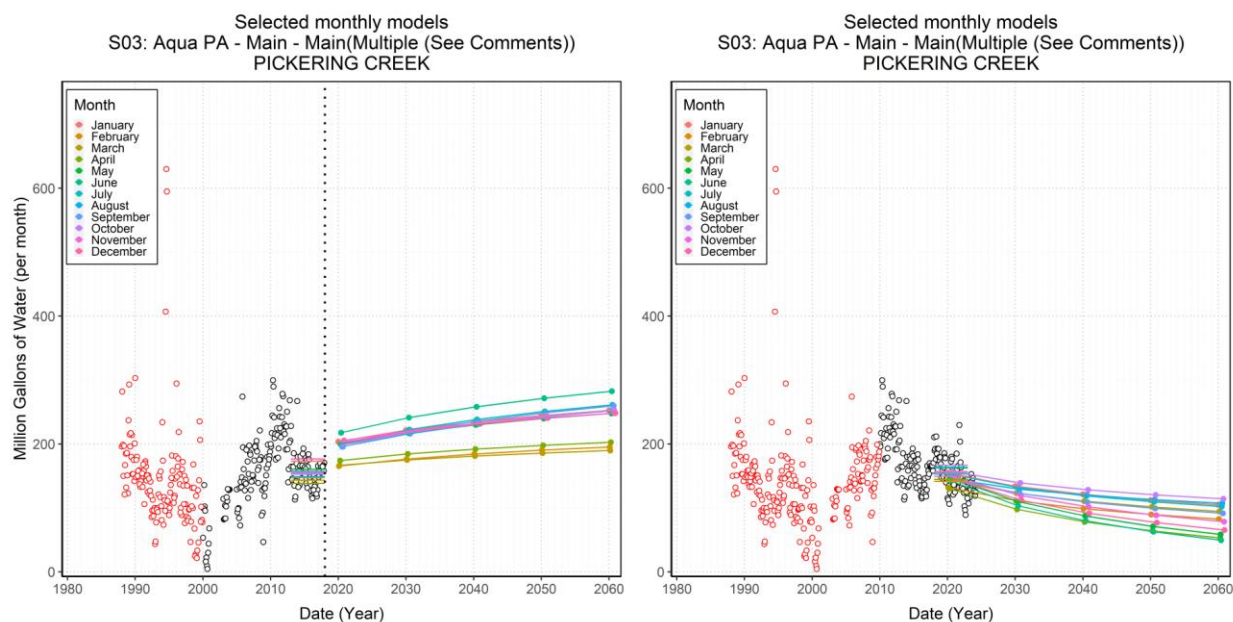


Figure 2-9. Comparison of withdrawal trend projections with five additional years of data.

Withdrawal trend projections based on data through 2017 and data through 2022 for point S03: Aqua Pennsylvania, Pickering Creek. Red data points were excluded from the trend calculations.

2.4.4 Return data: NPDES

Data processing

After water is withdrawn for various uses, much of that water (the non-consumptive portion) eventually returns to a waterway via a discharge or return, and these returns are an important component of water availability. For public water supply, non-consumptive use comprises approximately 90% of withdrawal volumes. Water return data (wastewater discharge) associated with facilities permitted under the NPDES program were downloaded from the United States Environmental Protection Agency (EPA) Enforcement and Compliance History Online (ECHO) website for FY2013–2022 (EPA, 2023b). Each NPDES data record represents a monthly volume of water returned to a stream that is associated with an NPDES Permit Number (a facility) and an NPDES Feature Number (e.g., an outfall); there may be multiple features assigned to a single facility. Outfall coordinate data were used to determine which features were located within the DRB. A summary of the number of data records for each year of NPDES data is provided for reference in **Table 2-3**. In FY2022, there were approximately 25 million data points across the United States, of which approximately 405,000 data points were within the DRB, attributed to 1,725 unique NPDES permit numbers in the DRB.

Table 2-3. A summary of return data records downloaded from the EPA ECHO database.

NPDES FY	Number of data points (USA)	Number of data points (DRB)	Unique NPDES permits (DRB)
2013	13,672,595	143,777	323
2014	16,377,508	148,444	330
2015	17,590,622	153,101	338
2016	20,348,587	159,456	385
2017	22,801,530	267,891	938
2018	23,728,591	347,248	1,315
2019	24,357,354	374,640	1,584
2020	24,900,999	392,464	1,647
2021	25,243,047	401,708	1,707
2022	25,544,824	405,412	1,725

FY2018–2022 was determined to be the most complete and representative timeframe regarding NPDES data within the Basin and was therefore used to define “current” return conditions.

There is a clear shift in the amount of data reported annually starting in FY2017 (**Table 2-3**). This shift is likely due to Phase 1 timing of the NPDES Electronic Reporting rule (“eRule”), transitioning paper reports to electronic data, with a compliance deadline effective December 21, 2016 (USEPA, 2023a). Therefore, the 5-year period with the most complete and accurate data is FY2018–2022. An added benefit to the SWEET model is that this date range aligns with the updated water withdrawal data date range; therefore, both datasets are a reasonable and consistent representation of current water use.

Before defining average FY2018–2022 return volumes for each NPDES Feature Number, the DRB data required additional pre-filtering. The following are parameter requirements for a data point to be included:

- STATISTICAL_BASE_CODE = “MK” (monthly average)
- MONITORING_LOCATION_CODE = 1 (effluent gross)

For months without a return volume, the monthly value is left blank and the data receives a “No Data Indicator” of “C”. These records were amended to replace blank values with zeroes. Data were subject to a standard quality assurance and quality control (QA/QC) process, described in the next section. Finally, 12 average values were computed for each NPDES Feature Number representing the average return for each month in FY2018–2022. Similar to the withdrawal data,

average monthly values were converted to a daily record for WY1960–2010. (Monthly totals in MG were divided by the number of days in each month to construct a daily time series for one year, which was repeated to cover WY1960–2010.)

Quality assurance / quality control

In total, 630 returns were identified from the NPDES dataset as located within the six study watersheds and therefore were included in SWEET. Several approaches were used to confirm the validity of the NPDES data, including:

- Comparing return volumes with internal DRBC water quality models in Qual2K for the Lehigh River and Brodhead Creek watersheds.
- Comparing return volumes with a Philadelphia Water Department (PWD) report on the Schuylkill River watershed (PWD, 2010).
- Comparing large return volumes with Annual Effluent Monitoring Report data. The Annual Effluent Monitoring Report has been an annual reporting requirement for most DRBC wastewater approvals since circa 2010.
- Best professional judgement: For example, some return values were in error by several orders of magnitude (e.g., reporting in gal/day or billion gallons per day [BGD] instead of million gallons per day [MGD]), or some may have reported quarterly data on a monthly basis (with data only reported in January, April, July, and October).

As a result of the QA/QC process, one return in the NPDES dataset was found to have incorrect latitude and longitude coordinates that placed it outside the Schuylkill River watershed; these coordinates were corrected according to the organization's DRBC docket. Otherwise, no major discrepancies were identified.

2.5 RESERVOIRS AND INTRABASIN TRANSFER

2.5.1 Reservoirs and Conservation Releases

Throughout the DRB, many reservoirs and surface water impoundments are owned and operated by varying entities. These reservoirs are crucial to ensuring continuous water supply, especially under dry conditions. Within the six watersheds studied here (Brodhead Creek, Brandywine-Christina River, Lehigh River, Neshaminy Creek, Chester-Ridley-Crum Creeks, and Schuylkill River), approximately 2%, 12%, 29%, 15%, 15%, and 28% of each watershed's total area, respectively, is controlled by a reservoir (**Figure 2-10**). It is important to consider the impact that reservoirs may have on surface water availability at downstream locations, particularly during low flow conditions.

It is beyond the scope of this project to model reservoir operations in detail because most of the factors affecting reservoir releases are not simulated in SWEET. However, the minimum release from a reservoir has the greatest impact on water availability and was thus used as a conservative

substitute for reservoir operations in this analysis. For many reservoirs, a minimum conservation release is required by regulatory agencies to maintain some downstream flow during dry conditions – with various goals to support. These goals can include the support of aquatic life/habitat, water quality, downstream intakes and recreation. In SWEET, 33 of 71 impoundments have a documented conservation release required by an environmental regulatory agency.

Most conservation release requirements were identified from the associated DRBC docket, state permit, or available water control manual (e.g., Beltzville Reservoir). When running the daily surface water availability model, it was assumed that these 33 reservoirs released their conservation release every day. This assumption is conservative, underestimating likely reservoir releases during all but the driest times, and can be considered a “worst-case” scenario. Future surface water availability work may consider a wider range of reservoir release scenarios.

For impoundment points without an identified conservation release requirement, a minimum release was not explicitly defined in the model. Instead, the point was represented within SWEET as if the impoundment storage did not exist. In these circumstances, we approximated the effect of a minimum release during dry conditions by subtracting groundwater and surface water withdrawals from the DRB-SET baseflow. Without directly modeling impoundments, SWEET output represents a rough approximation of water availability at these locations (and thus these results are not presented as part of the surface water availability analysis). However, the results at these points affect how much surface water is available for downstream withdrawal points, assuming a “worst-case” scenario in which these impoundments’ storage does not offset any withdrawals during dry times.

2.5.2 Intrabasin Transfer (Point Pleasant Pump)

One large intrabasin transfer, the Point Pleasant Pump, was included in SWEET. Via the Point Pleasant Pump, Delaware River water is conveyed to Bradshaw Reservoir and then to (1) the East Branch Transmission Main to East Branch Perkiomen Creek, a tributary of the Schuylkill River, for use by Limerick Generating Station, and (2) the North Branch Transmission Main to the North Branch Neshaminy Creek, for use by Forest Park Water. Forest Park Water then wholesales the water to North Wales Water Authority and North Penn Water Authority.

To model the East Branch Transmission Main’s inflow to the Schuylkill River watershed, a similar approach to that which we used for modeling reservoirs was taken—focusing on the impact during low-flow conditions. As a result of a DRBC approval, the minimum flow in the East Branch Perkiomen Creek is required to be at least 10 cubic feet per second (cfs) (DRBC Docket D-1969-210 CP-15). Within SWEET streamflow at this point (S68) was adjusted so that any modeled values below 10 cfs (6.46 MGD) were increased to 10 cfs. Additional inflow from the North Branch Transmission Main to the Neshaminy Creek watershed was not explicitly included in the model, as this water fills a reservoir (Lake Galena).

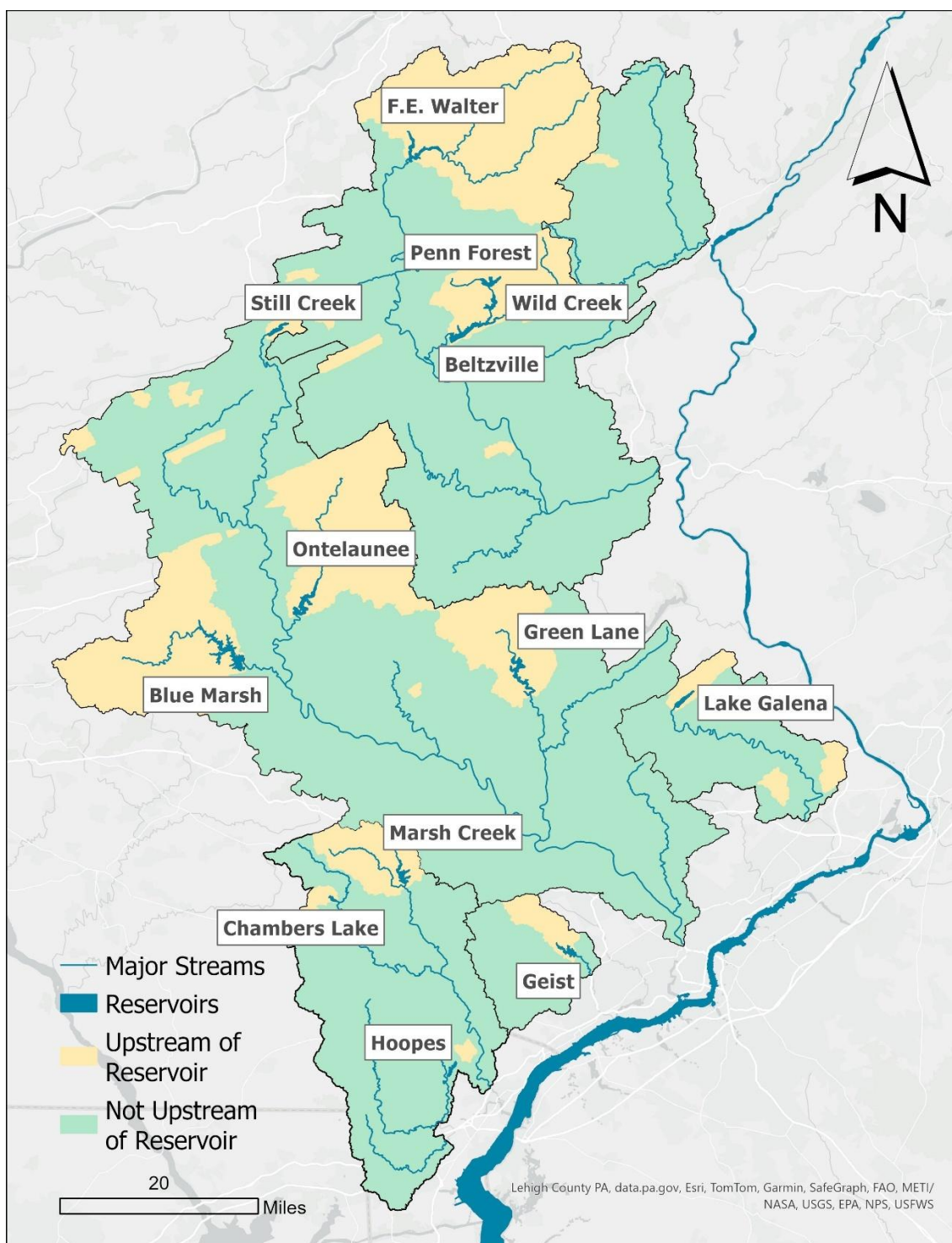


Figure 2-10. Map of the study area showing which areas drain to reservoirs.

The six watersheds in this report (black outlines), with the yellow areas draining to reservoirs with conservation releases and the green areas not draining to reservoirs without conservation releases.

Table 2-4. Conservation releases for reservoirs in SWEET.

Watershed	Point ID: Reservoir Name (Organization)	Conservation Release (MGD)
Brodhead Creek	B14: Mount Airy Lake (Mount Airy Lodge)	0.243
Brandywine-Christina River	C03: Rock Run Reservoir (Pennsylvania American Water Company) C09: Chambers Lake (Chester County Water Resources Authority) C11: Marsh Creek Reservoir (PA Dept. of Conservation and Natural Res.) C12: Adams Dam (Wilmington Country Club)	0.6 0.646 1.94 0.582
Lehigh River	L10: Spring Mill Pond (Northampton Borough Municipal Authority) L21: Fourth Hollow Reservoir (Nesquehoning Borough Authority) L07: Dreck Creek Reservoir (Hazleton City Authority) L04: Wild Creek Reservoir (City of Bethlehem) L25: F.E. Walter Reservoir (United States Army Corps of Engineers) L24: Beltzville Reservoir (United States Army Corps of Engineers) L20: Mauch Chunk Lake Dam (PA Fish & Boat Commission)	0.101 0.169 0.275 2.5 27.8 / 32.3 * 9.70 / 22.6 * 0.746
Neshaminy Creek	N08: Lake Galena (Bucks County Water and Sewer Authority) N09: Lake Luxembourg (Bucks County Parks Department) N10: Churchville Reservoir (Springfield)	1.532 0.969 0.646
Chester-Ridley-Crum Creeks	R10: Springton Reservoir/Geist (Aqua Pennsylvania)	19.389
Schuylkill River	S05: Reservoir 2 (Auburn Municipal Authority) S04: Reservoir 1 (Auburn Municipal Authority) S43: Mt Laurel Reservoir (Schuylkill County Municipal Authority) S42: Pine Run Reservoir (Schuylkill County Municipal Authority) S44: Kauffman Reservoir (Schuylkill County Municipal Authority) S11: Trout Run Reservoir (Boyertown Muni Waterworks) S64: Furnace Creek Reservoir (Hamburg Municipal Authority) S09: Silver Creek Reservoir (Blythe Township Municipal Authority) S08: Crystal Reservoir (Blythe Township Municipal Authority) S41: Broad Mountain Eisenhuth Reservoir (Schuylkill Co. Municipal Auth.) S40: Indian Run Reservoir (Schuylkill County Municipal Authority) S63: Still Creek Reservoir (Tamaqua Borough Authority) S52: Wolf Creek Reservoir (Schuylkill County Municipal Authority) S67: Tumbling Run Reservoir (Schuylkill Haven Borough Water Dept.) S48: Green Lane Reservoir (Aqua Pennsylvania) S32: Lake Ontelaunee (City of Reading) S29: Blue Marsh Reservoir (U.S. Army Corps of Engineers)	0.023 0.07 0.07 0.10 0.10 0.112 0.145 0.151 0.162 0.25 0.32 0.414 0.53 0.533 0.646 30 16.2 / 29.1 *

* Drought / normal

2.6 PASS-BY FLOW (PBF) REQUIREMENTS

Many surface water intakes are subject to pass-by flow (PBF) requirements. These requirements generally state that the withdrawal must not cause streamflow at the intake point to be less than a specified value. If streamflow upstream of the intake is above the specified value, the full allocation may be withdrawn only if doing so also allows streamflow downstream of the intake to remain at or above the pass-by flow value. If the streamflow upstream of the intake falls below that value, no withdrawals may be taken from that intake until streamflow exceeds the PBF value again (or some similar value identified by the requiring agency). Of the 54 surface water points analyzed in SWEET, 21 have PBF requirements in respective DRBC dockets or state water allocation permits that are incorporated in SWEET (**Table 2-5**). Most existing PBF requirements are a single value, often the 7Q10 (10-day low flow that occurs once every 10 years), that applies year-round. For a few SW points, the PBF varies with the season or with the onset of drought conditions. The details of these exceptions are noted on **Table 2-5**.

Additionally, of the 38 impoundments without a conservation release plan available, 11 have a PBF requirement; typically, these are ponds to which surface water is diverted from a stream for storage. PBF requirements at these points indicate when water cannot be diverted from the stream to fill the pond, but they do not preclude withdrawal of surface water from the ponds. In SWEET, withdrawals from streams used to fill ponds are modeled, but withdrawals from the ponds themselves are not modeled. PBF requirements were implemented at these points such that withdrawals ceased when streamflow dropped below the specified PBF value.

2.6.1 Ecological Pass-by Flows

An additional, hypothetical set of pass-by flows was developed to further evaluate supporting ecological needs. The Nature Conservancy (TNC) indicated that a single minimum flow requirement based on the 7Q10 flow may not be fully protective (TNC, 2013) of the full spectrum of ecological needs. TNC outlined an approach for developing protective flow recommendations for the Delaware River Basin that consider monthly low (10th percentile), median, and high (90th percentile) flows, as well as seasonal flow ranges and flood frequency (TNC, 2013, 2017). Based on a similar set of recommendations for the Susquehanna River, the Susquehanna River Basin Commission (SRBC) adopted a revised Low Flow Protection Policy in 2012 (SRBC, 2012). For this study, an approach modeled on the SRBC policy was applied.

According to SRBC's approach, each prospective withdrawal point is classified into an Aquatic Resource Class (ARC) depending on the drainage area to that point, as indicated in **Table 2-6**. Flow data from that point, or a nearby gage, is used to determine monthly flow percentiles, such that the P_{95} flow is exceeded 95% of the time (5th percentile), the P_{90} flow is exceeded 90% of the time (10th percentile), and so on. If the expected monthly withdrawal volume exceeds 5% (for ARC 2, 3, or 4) or 10% (for ARC 5 or 6) of the monthly P_{95} , a PBF requirement must be met during that month. Any withdrawal from ARC1 (headwaters) requires a PBF requirement during every month, regardless of the withdrawal volume. The PBF value also depends on the ARC, and ranges from

Table 2-5. Pass-by flow requirements for SW points in SWEET

Watershed	Point ID: Organization (Surface Water Body)	Pass-by Flow (MGD)
Brodhead Creek	B03: Camelback Mountain Resort (Pocono Creek)	1.15 / 2.7 ***
Brandywine-Christina River	C05: City of Newark (White Clay Creek)	14
	C07: Pennsylvania American Water Co. (W. Br. Brandywine Cr.)	35
	C14: DuPont Country Club (Brandywine Creek)	90.48 **
Lehigh River	L02: Lehigh County Authority (Little Lehigh Creek)	10.34
	L08: Hazleton City Authority (Lehigh River)	53.4
	L11: Palmerton Borough Municipal Authority (Pohopoco Creek)	25.6 / 11 *
	L12: Tuthill Corp. / Blue Mountain Ski Area (Aquashicola Creek)	2.67
	L14: Pennsylvania American Water Co. (Ross Common Creek)	0.342
	L15: Northampton Generating Company (Lehigh River)	124.74 **
	L18: Calpine Corporation (Lehigh River)	209.9 / 191.5 *
	L22: JFBB Ski Areas, Inc. (Tobyhanna Creek)	14.5
	L29 & L30: Saucon Valley Country Club (Saucon Creek)	6.38
Chester-Ridley-Crum Creeks	R01: Aqua Pennsylvania – Main Plant (Ridley Creek)	2.91
	R03: Aqua Pennsylvania – Media Plant (Chester Creek)	8.12
Schuylkill River	S06: Berkshire Country Club (Schuylkill River)	55 **
	S14: Cambridge-Lee Industries, LLC (Schuylkill River)	100.2
	S18: Constellation Energy Limerick Gen. Station (Schuylkill R.)	202.3
	S14: Cambridge-Lee Industries, LLC (Schuylkill River)	100.2
	S33 and S34: Philadelphia Water Department (Schuylkill River)	64.6 **

* Normal / drought

** Measured at alternate location, not intake

*** Seasonally variable: Apr–Sep / Oct–Mar

Table 2-6. Low flow protection policy implementation details as adopted by SRBC (2012).

ARC	Description	Drainage area (mi ²)	De minimis withdrawal threshold	Pass-by flow requirement
1	Headwaters	≤10	None	monthly P ₇₀
2	Creeks	>10 and <50	5% monthly P ₉₅	monthly P ₇₅
3	Small Rivers	≥50 and <200	5% monthly P ₉₅	monthly P ₈₀
4	Medium Tributary Rivers	≥200 and <1,000	5% monthly P ₉₅	monthly P ₈₅
5	Medium Main-stem Rivers	≥1,000 and <5,000	10% monthly P ₉₅	monthly P ₉₀
6	Large Rivers	≥5,000	10% monthly P ₉₅	monthly P ₉₅

monthly P₇₀ for ARC1 to monthly P₉₅ for ARC6 (**Table 2-6**). Note that this means that, on average, a withdrawal from a headwater stream (ARC1) will be expected to not take any water approximately 30% of the time, while withdrawals from larger rivers (ARC5 and 6) are subject to less stringent de minimis thresholds and PBF requirements.

In this study, all non-headwaters, non-impoundment surface water withdrawals were assigned an ecological PBF requirement according to SRBC's method. Headwaters withdrawals in the DRB were not subject to a PBF requirement in this hypothetical scenario. As each of the headwaters points would receive a stringent PBF requirement that would severely limit withdrawals taken under current conditions, we could not learn much from including them in this scenario. In the Susquehanna River Basin, most withdrawals from headwaters are related to natural gas extraction. In comparison, withdrawals from the eight headwaters SW points in the SWEET model include sectors with more consistent water needs, such as public water supply. Thus, it would not be realistic to expect them to stop withdrawing water 30% of the time. Surface water withdrawals from impoundments were also not assigned an ecological PBF requirement. While SRBC's Low Flow Protection Policy outlines guidance for setting conservation releases that protect aquatic life, detailed analysis of reservoir operations is beyond the scope of this study (Section 2.5). The monthly ecological PBF values were compared with existing PBF values for that withdrawal, if applicable. For each month, the more stringent (highest) of the two PBF values were selected.

Figure 2-11 shows examples of ecological PBF calculations for three surface water withdrawal points. The top left plot shows that monthly withdrawals at point C02 exceed the de minimis withdrawal threshold (5% of monthly P₉₅) in all months. The top right plot shows that the existing PBF at this point is equivalent to 7Q10, and in all months the ecological PBF (monthly P₈₀ for ARC3) is greater than the existing PBF. Thus, for the ecological flows scenario, the monthly P₈₀ is applied as the PBF for every month.

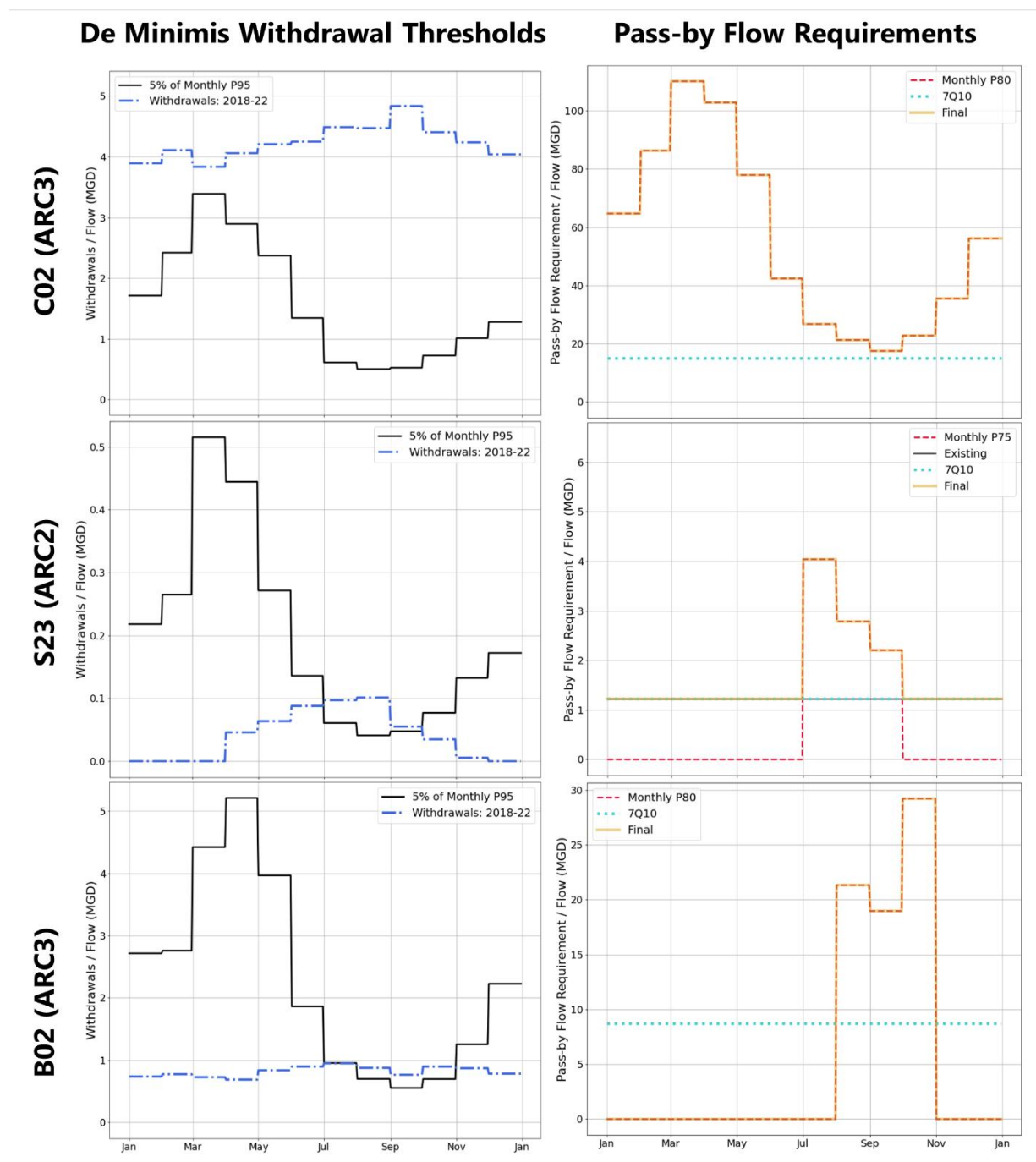


Figure 2-11. Example of ecological pass-by flow results for C02, S23, and B02.

Left column: Monthly withdrawal rates (purple dash-dot line) and de minimis withdrawal thresholds (equivalent to 5% of monthly P_{95}). Right column: Existing PBF (black line), ecological PBF (red dashed line), 7Q10 flow (green dotted line), and final PBF selected for the ecological flows scenario (the monthly maximum of ecological PBF and existing PBF). Examples are shown for C02 (top), S23 (middle), and B02 (bottom). Analogous plots for all other SW points can be found in Appendix G.

In the middle row, withdrawals from point S23 only exceed the de minimis withdrawal threshold in three months: July, August, and September. The ecological PBF would be equivalent to monthly P_{75} (for ARC2) during these three months, and no PBF would be set for the other nine months of the year. However, there is an existing PBF at this point, set to 7Q10. Thus, in the ecological flows scenario, point S23 will have a PBF of monthly P_{75} during July, August, and September, and a PBF equivalent to 7Q10 during the other months of the year.

Similarly, withdrawals from point B02 (bottom row) only exceed the de minimis withdrawal threshold during the months of July, August, and September. Unlike S23, this point does not currently have a PBF requirement. So, in the ecological flows scenario, it will have a PBF equivalent to monthly P_{80} during July, August, and September, and no PBF during other months.

Presently, 21 out of 54 surface water withdrawal points analyzed in this report have an existing PBF in place. For 10 of these SW points, in at least one month the ecological PBF is greater than the existing PBF, meaning that the ecological flows scenario places a more-stringent requirement on these points (**Table 2-7**). For 8 of the 24 SW points with an existing PBF, an ecological PBF would not be assigned because withdrawals in 2018–2022 were always below the de minimis threshold; however, in the ecological flows scenario, the existing PBFs are kept as-is for these points.

An ecological PBF was also set for at least one month for an additional 10 SW points that do not currently have one (see Appendix G). There are 18 SW points that do not have an existing PBF and would not have an ecological PBF, because their withdrawals are always below the de minimis threshold. An additional 6 SW points that do not have an existing PBF are classified as ARC1; as described above, these points would be assigned an ecological PBF equivalent to monthly P_{70} under the methodology applied by SRBC, but in this study, they were not assigned a PBF. The remaining two ARC1 points already have a PBF in place.

Table 2-7. For all SW points that qualify for an ecological PBF, a comparison with existing PBF requirements.

SW Point	Existing PBF (MGD)	Monthly Ecological PBF (MGD)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
B02	None	None	None	None	None	None	None	None	None	None	21.3	19.0	29.2
C02	None	64.7	86.3	110.1	102.8	78.0	42.4	26.8	21.3	17.5	22.8	35.5	56.2
C04	None	189.4	247.7	304.1	288.2	228.5	138.5	91.7	79.8	66.4	82.0	117.2	162.7
C05	14	49.4	61.1	None	None	57.1	40.6	29.7	25.2	21.2	25.2	33.8	41.5
C06	None	None	None	None	None	None	None	16.7	13.0	10.5	14.0	None	None
C07	35	12.9	None	None	None	None	7.0	4.0	2.8	2.0	3.0	5.7	10.3
C08	None	None	None	None	None	None	None	8.9	6.8	5.4	None	None	None
L02	10.34	31.1	47.8	68.7	69.6	56.2	47.7	39.0	35.0	27.6	28.2	28.7	31.4
L12	2.67	42.9	None	None	None	None	None	None	None	None	None	None	46.7
L29	6.38	None	None	None	None	None	None	5.8	4.7	4.1	None	None	None
L30	6.38	None	None	None	None	None	10.0	6.3	None	4.4	None	None	None
N01	None	136.3	165.4	208.8	194.2	149.8	90.2	60.6	52.3	42.9	54.8	80.9	120.4
R01	2.91	21.6	28.0	30.5	29.9	23.8	16.0	11.5	9.4	7.5	9.2	13.0	17.2
R02	None	20.1	25.6	28.8	28.8	22.6	15.1	10.3	8.4	7.1	8.6	12.1	15.3
R03	8.12	34.7	45.5	50.9	None	38.0	25.1	18.0	14.3	12.2	14.7	20.7	26.8
S01	None	None	None	None	None	None	None	None	216.4	207.3	None	None	None
S02	None	176.8	191.9	None	240.7	161.7	87.2	52.9	41.0	36.8	52.6	92.6	152.0
S07	None	7.2	None	None	None	None	None	3.6	2.4	1.8	2.2	4.1	5.9
S18	202.3	None	None	None	None	None	405.8	261.7	200.3	186.8	231.8	281.9	471.2
S33	64.6	None	None	None	None	None	618.5	398.2	305.2	284.0	348.4	462.7	728.9
S34	64.6	None	None	None	None	None	None	399.0	305.6	284.5	349.3	463.5	None

2.7 SURFACE WATER AVAILABILITY CALCULATION

The above sections outline how daily records of streamflow, surface and groundwater withdrawal volumes, wastewater returns, conservation releases, and PBF requirements were generated for each catchment. These records are all data inputs to the SWEET calculation (**Figure 2-12**), which was performed in the programming language R version 4.1.2 (R Core Team, 2023).

The SWEET calculation function is recursive, such that the results at one location depend on the results from all upstream points. For every surface water withdrawal point, the daily withdrawal volume is compared to the daily streamflow available at that point, which is calculated as:

$$Q_w = Q_{in} + Q_{set} + Q_{ret} - Q_{gw}$$

- Q_w = daily streamflow available at the withdrawal point
- Q_{in} = flow into the catchment from upstream catchment(s)
- Q_{set} = streamflow contributions from the catchment area (calculated by DRB-SET)
- Q_{ret} = total return flows entering the stream within the catchment
- Q_{gw} = consumptive groundwater withdrawal from the catchment

All values are in units of million gallons per day (MGD). Note that Q_{in} is dependent on the presence of upstream catchments. If there are no upstream catchments, the term $Q_{in} = 0$. If there are one or more upstream catchments, Q_{in} is the sum of all flows exiting upstream catchments (Q_{out}):

$$Q_{in} = \sum_{i=1}^n Q_{out(i)}$$

- $Q_{out(i)}$ = the flow leaving catchment i
- i = an upstream catchment
- n = the number of upstream catchments

In terms of calculating the flow leaving a particular catchment and, if applicable, the volume of surface water withdrawn, the specific calculation applied depends on the type of point being analyzed and follows one of four scenarios:

1. **An impoundment with a conservation release:** the flow out of the catchment is always equal to the conservation release:

$$Q_{out} = Q_{res}$$

- Q_{out} = the flow leaving the catchment
- Q_{res} = the conservation release

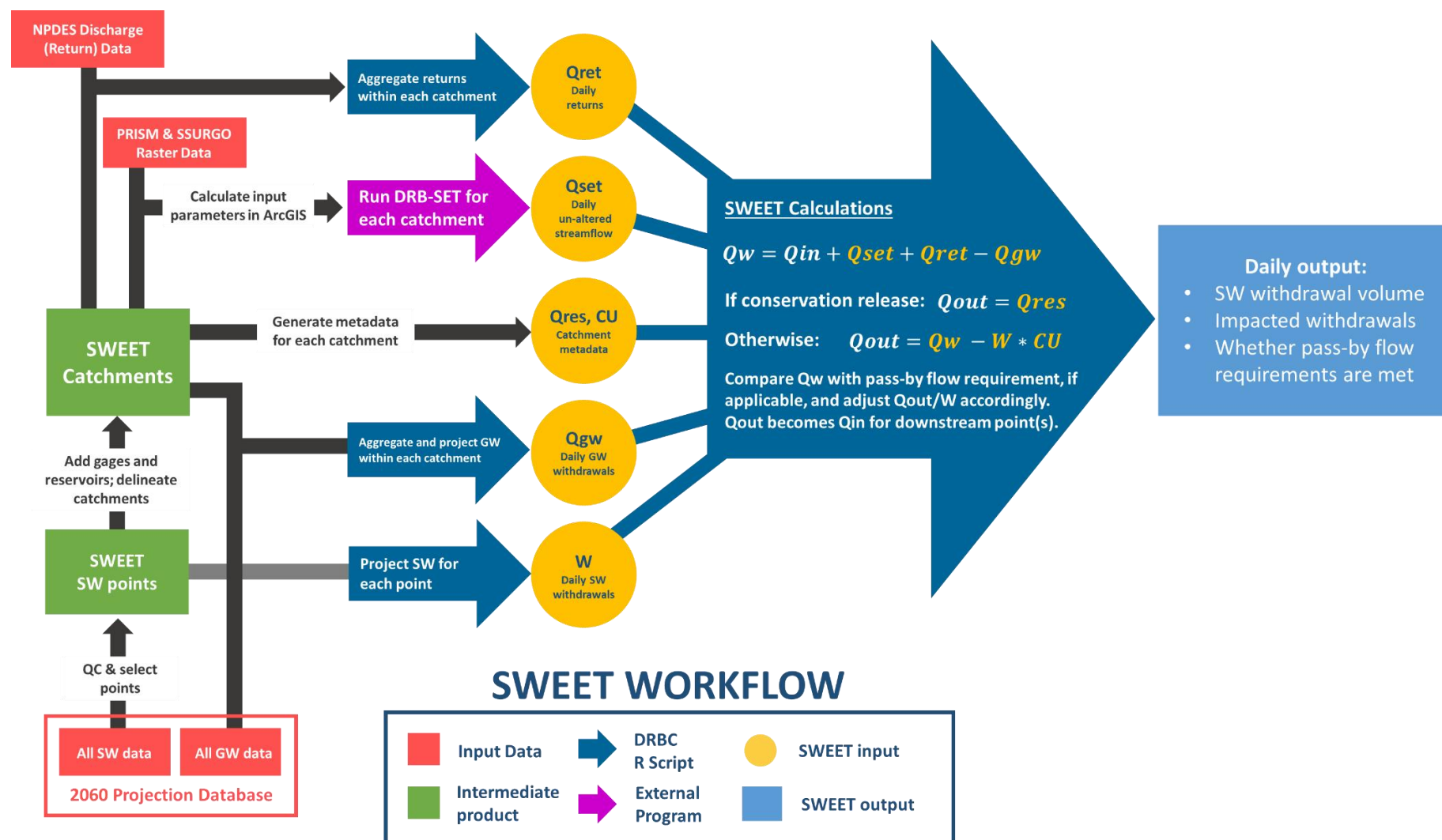


Figure 2-12. Workflow for SWEET, including data inputs and calculations.

2. **A surface water withdrawal *not* subject to a pass-by flow requirement:** The flow out of the catchment and the actual withdrawal volume are dependent upon the daily streamflow available at the withdrawal point, specifically:

$$\text{if } W > Q_w \dots\dots\dots Q_{out} = 0 \quad \text{and} \quad W_{actual} = Q_w$$

$$\text{otherwise} \dots\dots\dots Q_{out} = Q_w - (W * CU) \text{ and } W_{actual} = W$$

W = intended withdrawal volume

W_{actual} = actual withdrawal volume

CU = consumptive use ratio applied to that volume (if applicable)

If W is greater than Q_w , the full withdrawal volume cannot be taken. Otherwise, if the full volume can be taken, the remaining water is sent downstream as Q_{out} . Consumptive use ratios were applied to surface water withdrawals that were not likely to be accounted for in returns, i.e., irrigation for golf ($CU = 0.9$) and ski resorts ($CU = 0.22$). (Non-consumptive use from public water supply, industrial, and thermoelectric power generation were assumed to be reflected in NPDES returns data.) For all other withdrawals, $CU = 1$, as the non-consumptive portion is assumed to return to the stream elsewhere (Q_{ret}).

3. **A surface water withdrawal subject to a pass-by flow requirement:** Withdrawal volumes are limited if needed to meet the requirement. If the full volume can be taken and the PBF met, Q_{out} and W_{actual} are determined using the equations above. Alternately, if the flow reaching the intake (Q_w) is less than the sum of the intended withdrawal volume (W) and what needs to pass by the intake according to the PBF requirement (Q_{pbf}), then W_{actual} is reduced accordingly to meet the PBF:

$$\text{if } Q_w < Q_{pbf} \dots\dots\dots Q_{out} = Q_w \quad \text{and} \quad W_{actual} = 0$$

$$\text{otherwise} \dots\dots\dots Q_{out} = Q_{pbf} \quad \text{and} \quad W_{actual} = Q_w - Q_{pbf}$$

If the flow reaching the intake is less than Q_{pbf} , then no water can be withdrawn. Otherwise, water may be withdrawn such that the remaining flow is equal to Q_{pbf} .

4. **A USGS gage:** the flow through this point (Q_{out}) is always $Q_{out} = Q_w$.

When withdrawal volumes are limited by available water or PBF requirements (i.e., when W_{actual} is less than W), the daily difference between intended (W) and actual (W_{actual}) withdrawal volumes represents the magnitude of impact to that withdrawal point. In other words, “impacted withdrawals” represent the volume of water that could not be withdrawn due to limited availability. The total impacted withdrawals (in MG) over monthly, annual, and multi-year time frames were recorded as a primary output. For annual and multi-year time frames, impacted withdrawals are presented in units of million gallons per year (MGY) or billion gallons per year (BGY). The aggregated impacted withdrawals represent the volume of water that would need to be made up for by another source or foregone by conserving use.

When PBF requirements cannot be met (i.e., when $Q_w \leq Q_{pbf}$), no water can be withdrawn. The total number of days on which this occurs is also a primary output that was aggregated on monthly or annual timescales (in units of days/year).

2.8 SCENARIOS

Four scenarios were run using SWEET:

- The **baseline scenario** represents present-day water withdrawal volumes, returns, and management under “normal” conditions. This scenario is designed to evaluate how a repeat of the drought of record would affect present-day surface water availability.
- The **2060 withdrawal** scenario updates surface and groundwater withdrawal volumes for the year 2060 following recent water-use trends. Returns, conservation releases, and PBF requirements were not adjusted from the baseline scenario.
- The **drought management** scenario applies drought-specific conservation releases at F.E. Walter, Beltzville, and Blue Marsh Reservoirs (**Table 2-4**) and drought-specific PBF requirements for Palmerton Borough Municipal Authority and Calpine Corporation (**Table 2-5**). These changes were applied to the baseline scenario. All other model inputs remained the same as the baseline withdrawal scenario.
- The **ecological flows** scenario applies hypothetical pass-by flow requirements that are generally considered more protective of aquatic life. As described in Section 2.6.1, the approach applied here was guided by previous work by TNC and SRBC.

2.9 LIMITATIONS AND ASSUMPTIONS

This analysis relies on work from two prior studies, and their limitations and assumptions carry through to this study.

- Streamflow data from the USGS model DRB-SET (Stuckey, 2016) are a primary input to SWEET. Notably, the development of DRB-SET was a continuation of work developing a similar model for the entire Commonwealth of Pennsylvania (Stuckey et al., 2014). Consequently, some of the primary assumptions made in these studies are worth re-iterating here as they carry through to SWEET:
 - Missing data at one gage can be estimated using long-term streamflow records from hydrologically similar gages.
 - The most appropriate reference gage for a given location is the geographically closest, as similarity in the conditions determining streamflow increases with decreasing distance between two locations.
 - Transferring streamflow exceedance probabilities from a reference gage to an ungaged location (using the QPPQ method) carries the assumption that both locations will experience identical exceedance probabilities at identical times.

- The accuracy of DRB-SET output is limited by the availability of a reference gage with long-term data near the location of interest. A gage could only be a reference gage if up to 10% of the contributing area was controlled by reservoirs *and* if impervious surfaces comprised up to 10% of the contributing area. However, in some circumstances, these rules were exceeded to allow for more complete spatial coverage of reference gages. For example, in more heavily-urbanized southeastern Pennsylvania, reference gages with up to 29% impervious coverage were allowed (Stuckey et al., 2014).
- Surface and groundwater withdrawal volumes were aggregated and projected using data and methodology from DRBC’s water use trend projection report (Thompson & Pindar, 2021).
 - i. Withdrawal data from 2018–2022 are assumed to represent current conditions.
 - ii. Estimations of future water withdrawal volumes in 2060 are an extrapolation of recent trends in water use. These trends implicitly incorporate changes in climate, population, land use, and other factors over the period of record. However, using these trends to represent future conditions presumes that all of these trends will continue at the same rate, which may not be the case.
 - iii. This water use analysis does not attempt to forecast the discontinued operation of facilities, nor the construction of new facilities.
 - iv. To generate daily withdrawal time-series, we assume that monthly withdrawal volumes are evenly distributed over every day in the month.

In addition, SWEET itself has some assumptions and limitations:

1. DRB-SET was initially designed to produce output for complete watersheds, rather than for the SWEET catchments applied in this study. This methodological difference, and the need to re-create input datasets, introduces some additional uncertainty. As discussed in Section 2.3, more recently downloaded SSURGO soils data in particular did not match exactly with previously downloaded soil results that were originally used to develop DRB-SET.
2. SWEET assumes that DRB-SET outputs represent streamflow that is unaltered by anthropogenic activity. The DRB-SET model is built on reference gages that are “minimally altered”; for most reference gages, this means that <10% of their contributing area controlled by reservoirs and <10% of their contributing area is impervious. Inevitably, streamflow at these locations may have been modestly affected by anthropogenic activities.
3. SWEET conservatively assumes that any withdrawn groundwater has a one-to-one impact on streamflow, meaning that a specific groundwater withdrawal within a catchment has a volumetric impact on that catchment’s surface water flows equal to the consumptive portion of groundwater extracted. We know that this is not always true in the DRB, especially where surface water divides and groundwater divides do not align (Sloto et al.,

1991). However, this assumption supports SWEET's conservative nature, as groundwater withdrawals may in reality reduce surface water flows by no more than the total volume of groundwater withdrawn.

4. SWEET also conservatively assumes that there is no lag time between groundwater extraction and impacts on stream baseflow. In a time of limited water availability, groundwater demand in the model is always met before surface water demand. (In SWEET, the order of operations is such that all groundwater withdrawn from within a catchment is supplied before any surface water can be withdrawn.)
5. As discussed above, SWEET is not suitable for evaluating surface water availability at points that withdraw water from reservoirs (or those that are heavily dependent on upstream reservoir releases). Availability is not assessed for 73 points that have a surface water withdrawal but are dependent on reservoirs or impoundments.
6. Impoundments and reservoirs are very simply represented in SWEET using conservation releases and PBF requirements that constrain their operations. Many smaller impoundments do not have a documented conservation release or PBF requirement, and thus these impoundments were not included in the model (i.e., SWEET recreates streamflow as if these impoundments did not exist). It is understood that these impoundments may have the ability to influence downstream surface water availability due to human operation (if any). However, the average size of these impoundments is small; therefore, possible impacts on availability are thought to be small.

3. SURFACE WATER AVAILABILITY MODEL RESULTS

3.1 FLOW COMPARISON WITH OBSERVED DATA

SWEET includes 21 USGS gage points (**Table 3-1**), allowing model output to be compared to historical flow data. Eight of these USGS gages are also used as reference gages in DRB-SET; comparison is less useful for these gages because their data was incorporated into calculations that form the basis of streamflow in SWEET. Therefore, 12 non-reference USGS gages are the focus of this comparison. The Schuylkill River at Norristown gage was not included, as it began collecting data in 2007 and thus only has three years of overlap with the SWEET model. SWEET generates daily streamflow for WY1960–2010, but many USGS gages do not have a complete

Table 3-1. USGS streamflow gages included in the SWEET model.

Watershed	USGS Gage Name	USGS Gage ID	SWEET Point	Ref. gage in DRB-SET?
Brodhead Creek	Brodhead Creek near Analomink, PA	01440400	B04	Yes
	Brodhead Creek at Minisink Hills, PA	01442500	B10	Yes
Brandywine-Christina River	Brandywine Creek at Chadds Ford, PA	01481000	C23	No
	Brandywine Creek at Wilmington, DE	01481500	C24	No
	Red Clay Creek near Stanton, DE	01480015	C25	Yes
	Christina River at Coochs Bridge, DE	01478000	C26	Yes
Lehigh River	Lehigh River at Walnutport, PA	01451000	L26	No
	Lehigh River at Glendon, PA	01454700	L27	No
	Lehigh River at Bethlehem, PA	01453000	L31	No
Neshaminy Creek	Neshaminy Creek at Langhorne, PA	01465500	N07	No
Chester-Ridley-Crum Creeks	Crum Creek near Newtown Square, PA	01475850	R11	Yes
	Chester Creek near Chester, PA	01477000	R12	No
	Ridley Creek at Media, PA	01476480	R01	No
Schuylkill River	Schuylkill River at Norristown, PA	01473500	S20	No
	Schuylkill River at Reading, PA	01471510	S22	No
	Schuylkill River at Philadelphia, PA	01474500	S49	No
	Schuylkill River at Berne, PA	01470500	S53	Yes
	Schuylkill River at Pottstown, PA	01472000	S56	Yes
	French Creek near Phoenixville, PA	01472157	S60	Yes
	Perkiomen Creek at Graterford, PA	01473000	S50	No
	Wissahickon Creek at Mouth Philadelphia, PA	01474000	S51	No

Stations appearing in **bold text** are not reference gages for DRB-SET.

data record over this period. Flow comparisons were conducted only at times when both USGS and SWEET flow data exist.

These comparisons do not represent true model validation, because SWEET applies present-day water use and operations to past hydrologic conditions, rather than fully recreating past conditions. For example, when SWEET models hydrologic conditions from the 1960s, it includes reservoirs that were not yet built (e.g., Lake Galena, Beltzville Reservoir, and Blue Marsh Reservoir were all constructed in the 1970s) as well as major withdrawal points that did not yet exist (e.g., Limerick Generating Station Units 1&2 were built in the late 1980s). However, in recent years, SWEET streamflow is not expected to be very different from observed streamflow. This analysis provides confidence that SWEET streamflow results are reasonable.

As SWEET results are primarily used to evaluate surface water availability during dry periods, low flow conditions are particularly important. It is less consequential for SWEET to match streamflow peaks during high-flow events. SWEET is a screening tool that aims to conservatively estimate streamflow available during dry conditions. Therefore, when SWEET shows that a withdrawal point has adequate supply through a repeat drought of record, this result is robust. However, when SWEET shows that a point is impacted during a repeat drought of record, it indicates that this point *might* face limited supply during a future severe drought. More in-depth study will be needed to evaluate surface water supply and alternative sources at these impacted locations.

At 10 out of the 12 selected USGS gage points, SWEET low flows were generally equal to or lower than observed low flows, especially in recent years, supporting a conservative surface water availability analysis (**Figure 3-1**, Appendices F and G). SWEET low flows often exceeded observed low flows at two gage points: Wissahickon Creek at Mouth and Neshaminy Creek at Langhorne. Additionally, USGS gage data for the Schuylkill River at Philadelphia during the drought of record were lower than SWEET representations of these drought years. There are two reasons that SWEET may overestimate low flows:

1. Surface water and/or groundwater withdrawals upstream of the point decreased over time, such that their impact on past (observed) streamflow was greater than it was in 2018–2022 (as represented in the baseline scenario).
2. Reservoir and/or intrabasin transfer operations changed over time such that conservation releases were lower (or non-existent) in the past. Due to these operational changes, low flows are likely to be higher today than in the past. This factor may have particularly influenced Neshaminy Creek at Langhorne, which is downstream from two reservoirs and receives wastewater returns from areas served by a diversion of water from the main stem Delaware River via the Point Pleasant Pump (Section 2.5.2). For the Schuylkill River at Philadelphia during the drought of record, SWEET includes conservation releases from several reservoirs that did not exist in the 1960s.

Ultimately, SWEET was determined to represent streamflow reasonably well throughout the six watersheds, enough to support a conservative surface water availability analysis.

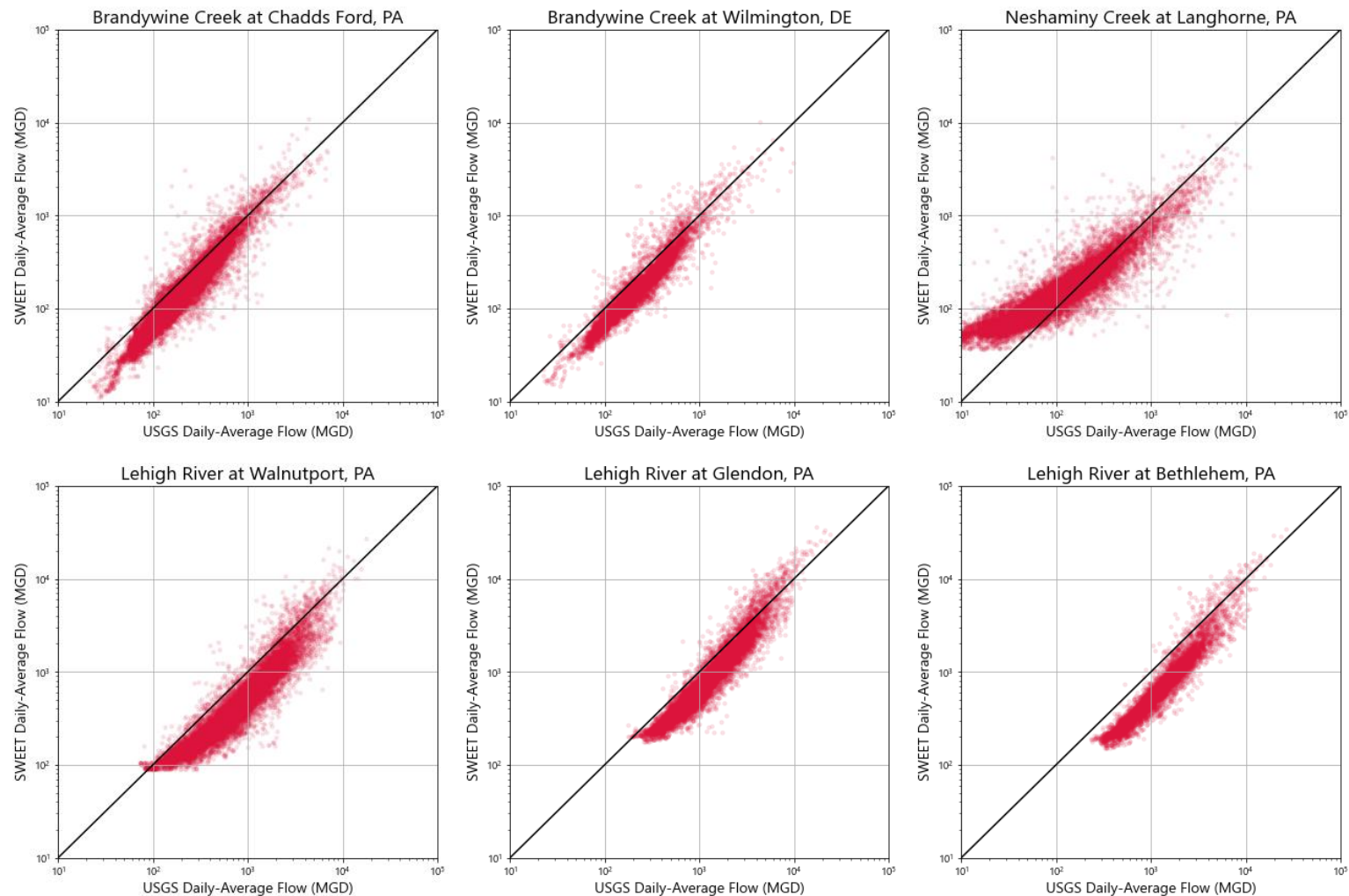


Figure 3-1. One-to-one plots comparing observed daily-average flow at USGS gages to SWEET modeled streamflow during the baseline scenario.

Note that these one-to-one plots are on a logarithmic scale.

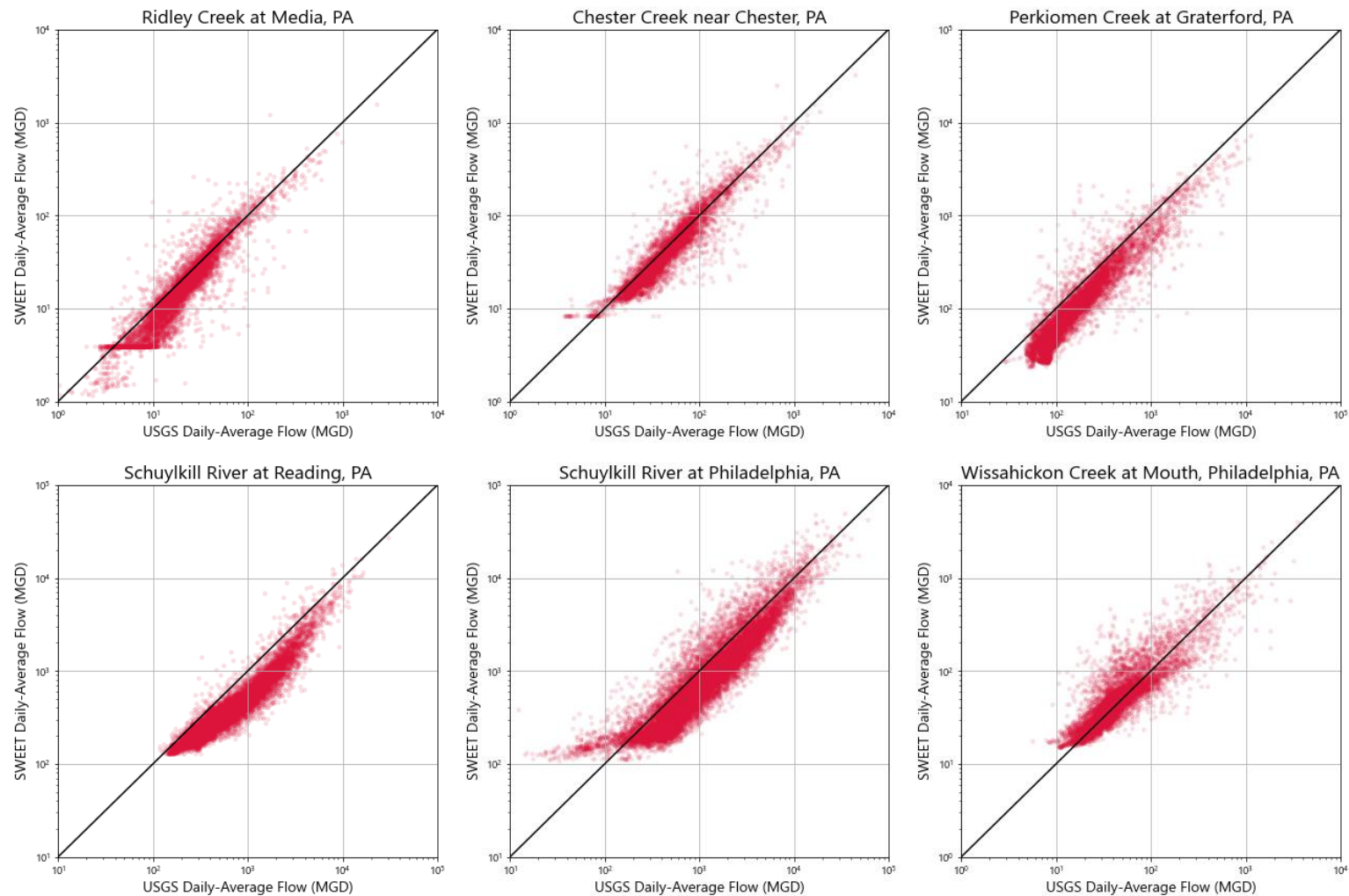


Figure 3-1 (continued). One-to-one plots comparing observed daily-average flow at USGS gages to SWEET modeled streamflow during the baseline scenario.

Note that these one-to-one plots are on a logarithmic scale.

3.2 BASELINE SCENARIO RESULTS: OVERVIEW

3.2.1 Screening Results: Points with No Impacted Withdrawals

In the baseline scenario, many surface water withdrawal points did not present supply issues during a repeat drought of record. Of the 54 points where surface water availability was evaluated, nearly two-thirds (32) met their current withdrawal volumes on every modeled day under repeated hydrologic conditions from 1960 to 2010. These points are shown as green circles on the maps in **Figure 3-2** and include 17 public water supply (PWS) withdrawals. In other words, SWEET results suggest that many PWS intakes across the six watersheds would be fully supported in terms of water quantity through a repeat drought of record, including those listed in **Table 3-2**.

Table 3-2. PWS points with no impacted withdrawals in the baseline scenario.

Point ID	Organization Name	Water Source	Annual SW Withdrawal (BG)
B02	Brodhead Creek Regional Authority	Brodhead Creek	0.30
C02	Aqua Pennsylvania (West Chester)	E. Br. Brandywine Creek	1.5
C04	Wilmington Department of Public Works	Brandywine Creek	5.2
C06	Downingtown Municipal Water Authority	E. Br. Brandywine Creek	0.23
L01	Northampton Borough Municipal Authority	Lehigh River	1.3
N01	Aqua Pennsylvania	Neshaminy Creek	3.8
R02	Aqua Pennsylvania	Crum Creek	6.0
S01	Aqua Pennsylvania	Schuylkill River	6.4
S02	Aqua Pennsylvania	Perkiomen Creek	3.7
S17	East Greenville Borough	Schuylkill River	0.01
S30	PA American Water Co. (Royersford)	Schuylkill River	0.74
S31	PA American Water Co. (Norristown)	Schuylkill River	4.1
S33	Philadelphia Water Dept. (Queen Lane)	Schuylkill River	21.6
S34	Philadelphia Water Dept. (Belmont)	Schuylkill River	17.2
S35	Borough of Phoenixville	Schuylkill River	0.8
S36	Pottstown Borough Authority	Schuylkill River	1.4
S59	Mary D Community Association	Swift Creek	0.01

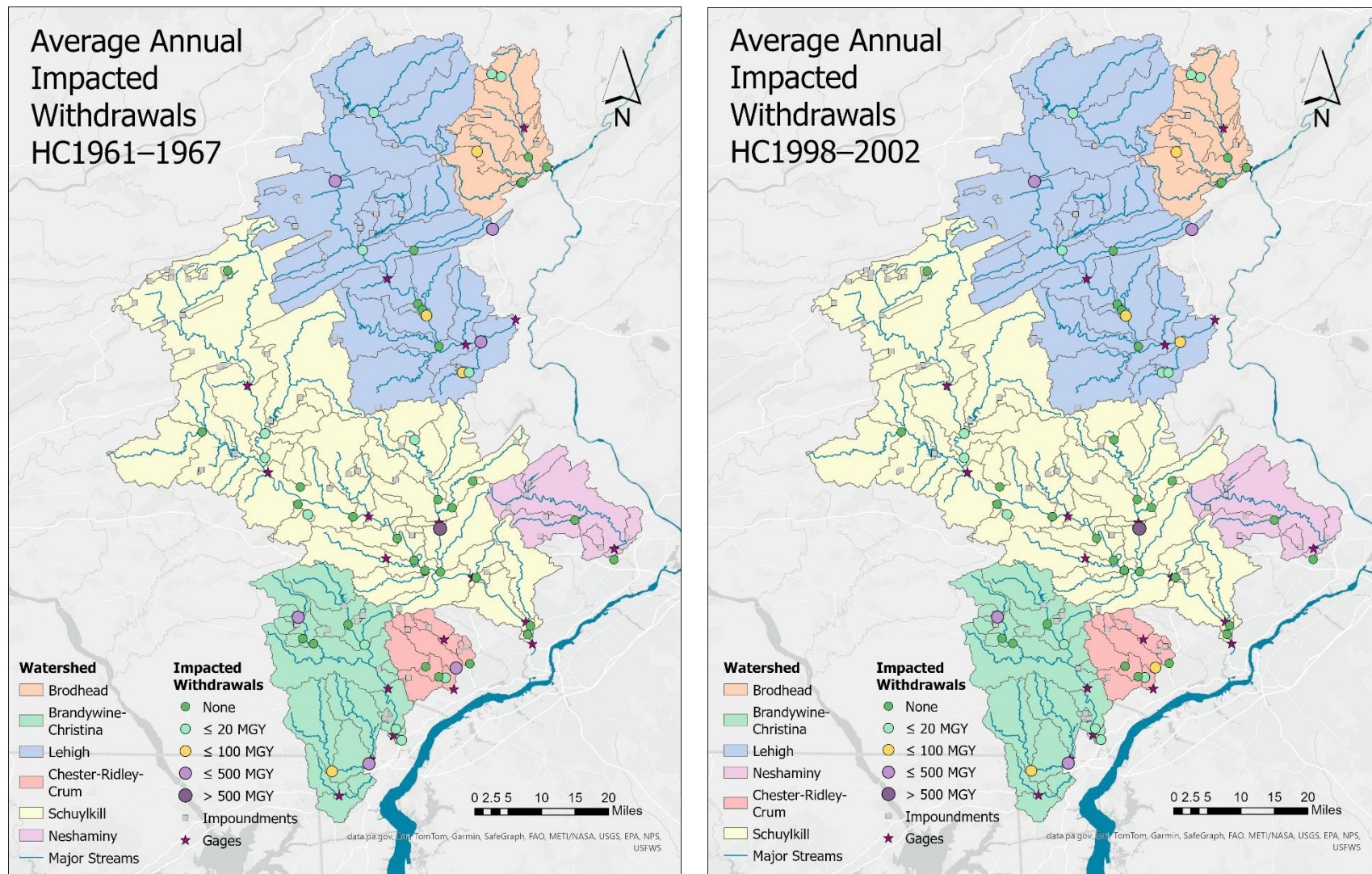


Figure 3-2. Maps of impacted withdrawals for two drought periods.

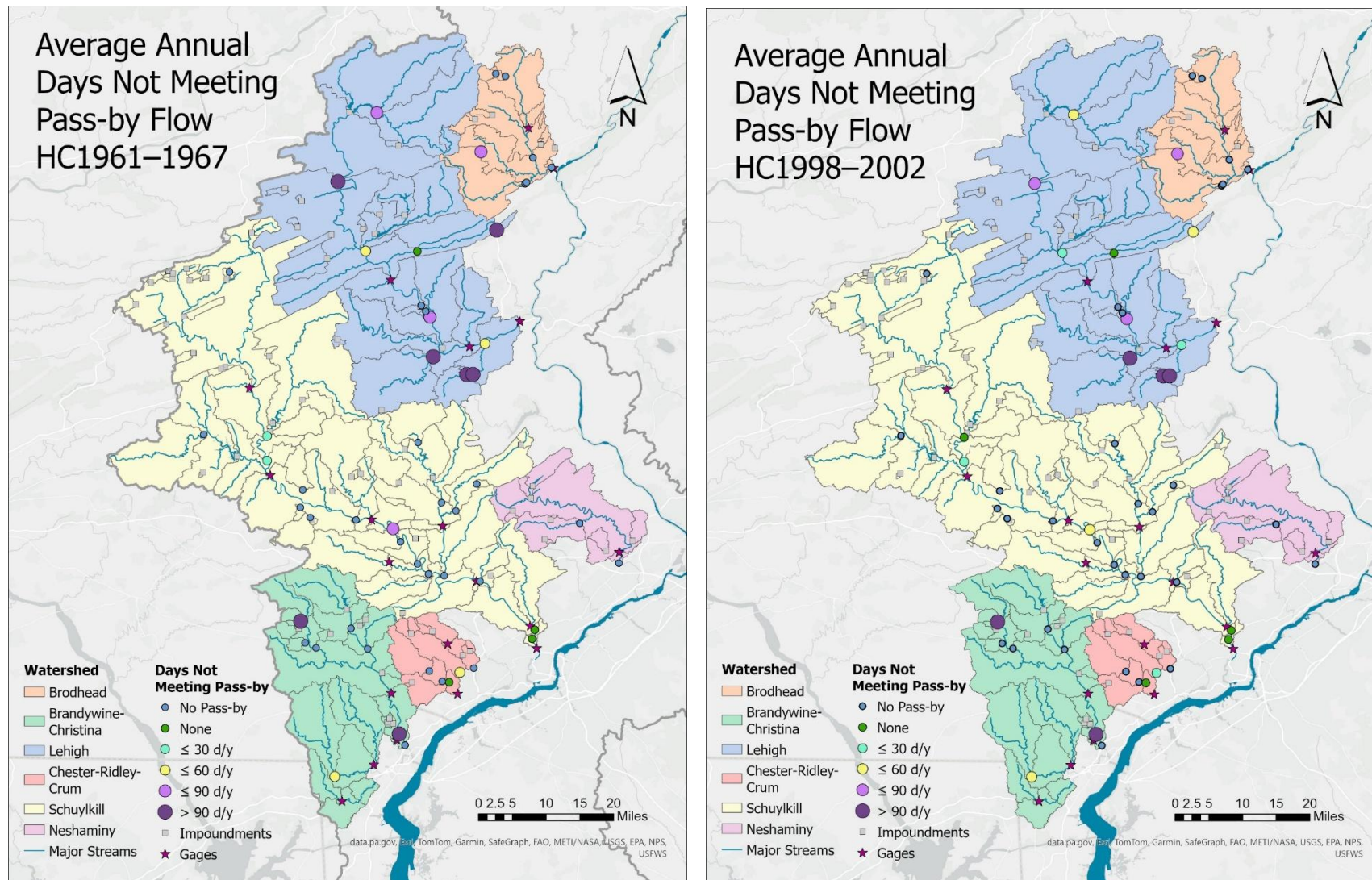


Figure 3-3. Maps of days not meeting pass-by flow requirements for two drought periods.

Of the 32 unimpacted points, only two (the Philadelphia Water Department's two Schuylkill River intakes) have a PBF requirement. As currently configured in SWEET, points without a PBF requirement are theoretically allowed to withdraw the entire streamflow and are shown as small blue circles on the maps in **Figure 3-3**. However, most of the unimpacted points did not come close to withdrawing the full stream volume in SWEET during hydrologic conditions from the drought of record. **Figure 3-4** shows the percentage of streamflow withdrawn at each SW intake for each modeled day. R02, Aqua Pennsylvania's Crum Creek intake, is immediately downstream of a reservoir with a modeled conservation release. While it is modeled as withdrawing a relatively large portion of the streamflow, this point is always able to take its intended withdrawal volume, indicating that the conservation release fully supports this intake's supply needs.

It is important to consider SWEET's limitations when interpreting these "null results". SWEET includes conservative assumptions that err on the side of limiting water availability, yet other factors may still lead SWEET to underestimate surface water vulnerability in some cases. At some USGS gage points, including Neshaminy Creek (near N01), Perkiomen Creek (upstream of S02), and urban portions of the Schuylkill River (near S33 and S34), SWEET low flows under repeated hydrologic conditions were often higher than observed historical low flows. Surface water availability results at these locations may be less conservative than elsewhere (Section 3.1).

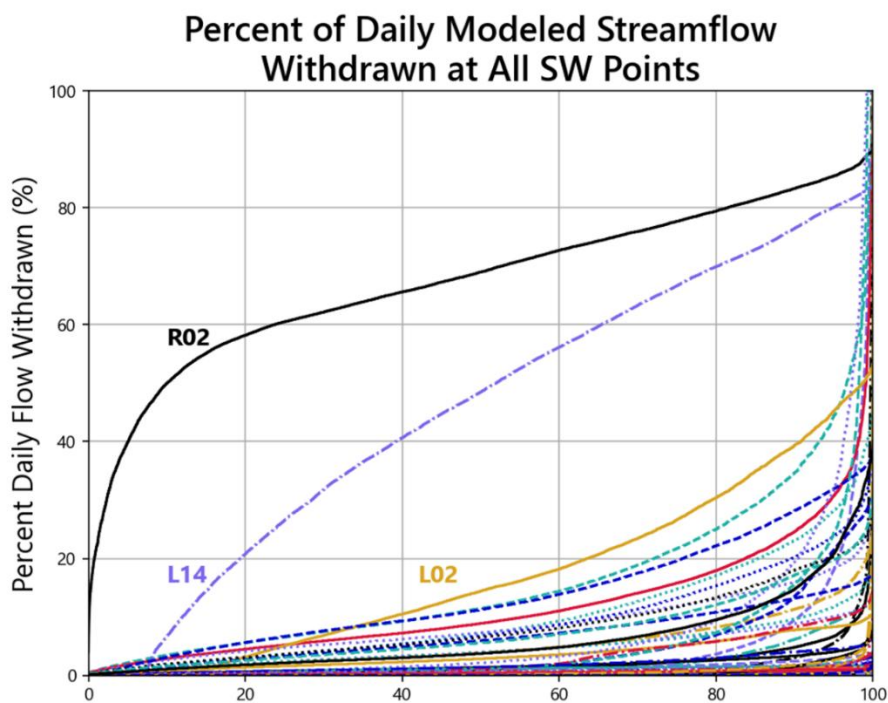


Figure 3-4. Cumulative density function showing the percent of daily modeled streamflow that was withdrawn at each SW point.

Three points with relatively high percent withdrawal of the stream are highlighted. R02 is discussed in this section. L14 and L02 are discussed in Section 3.3.1.

3.2.2 Screening Results: Points with Impacted Withdrawals

The remaining 22 points are unable to take the intended daily withdrawal volume on at least some days during HC1960–2010. These points include 9 PWS intakes, 3 thermoelectric power generation intakes, 5 golf intakes, 3 ski intakes, and 2 industrial intakes. The Lehigh River watershed had 10 impacted SW points (out of 12), while the Schuylkill River watershed had 4 impacted SW points (out of 20). For Neshaminy Creek, neither of the 2 SW points were impacted, while 3 (out of 7), 3 (out of 8), and 2 (out of 5) SW points in the Brodhead Creek, Brandywine-Christina River and Chester-Ridley-Crum Creek watersheds, respectively, were impacted.

The maps in **Figure 3-2** highlight the magnitude of average annual impacted withdrawals² for repeat hydrologic conditions (HC) from two drought periods: HC1961–1967 (Section 1.3.1) and HC1998–2002 (Section 1.3.2). Most impacted points were flagged in a repeat of both drought periods, though generally at a lower magnitude and/or less often during HC1998–2002, indicating consistency in model output and suggesting that these withdrawal points may be impacted during droughts which are less intense than the drought of record.

The average annual number of days on which PBFs were not met are mapped in **Figure 3-3** for the same drought periods. Eighteen of the 20 impacted points have PBF requirements, which may limit withdrawal volumes during low-flow periods (Section 2.6). (When PBF requirements are not met on a given day, this indicates that the associated intake could not withdraw any water on that day. Withdrawal volumes may also have been limited on some days when the PBF was met, as described in Section 2.6.) Seven points, including L02, L11, and C07, did not meet their PBF requirements on average more than 100 days per year during a repeat of hydrologic conditions from both droughts, indicating conditions under which these intakes could not be operated at least a quarter of the time for many years in a row.

Figure 3-5 shows an annual raster time series for each flagged SW point, indicating the percentage of total withdrawals for each HC year that were impacted by limited surface water availability and the number of days that flow was below the PBF requirements. For most of these impacted points, the most intense impacts occur during hydrologic conditions from the two most severe Basin-wide droughts, HC1961–1967 and HC1998–2002. Within these multi-year drought periods, different parts of the Delaware River Basin were impacted to varying degrees. For example, in the Brandywine-Christina River watershed, HC1963 was the most-supply-limited year, but farther north in the Lehigh River and Brodhead Creek watersheds, HC1964 and HC1965 had more limited water supply than HC1963. Many of these points were impacted during other dry years, notably HC1980–1981.

² This study defines impacted withdrawals as the difference between intended daily withdrawal volume and the modeled water available for withdrawal; see Section **Error! Reference source not found.**.

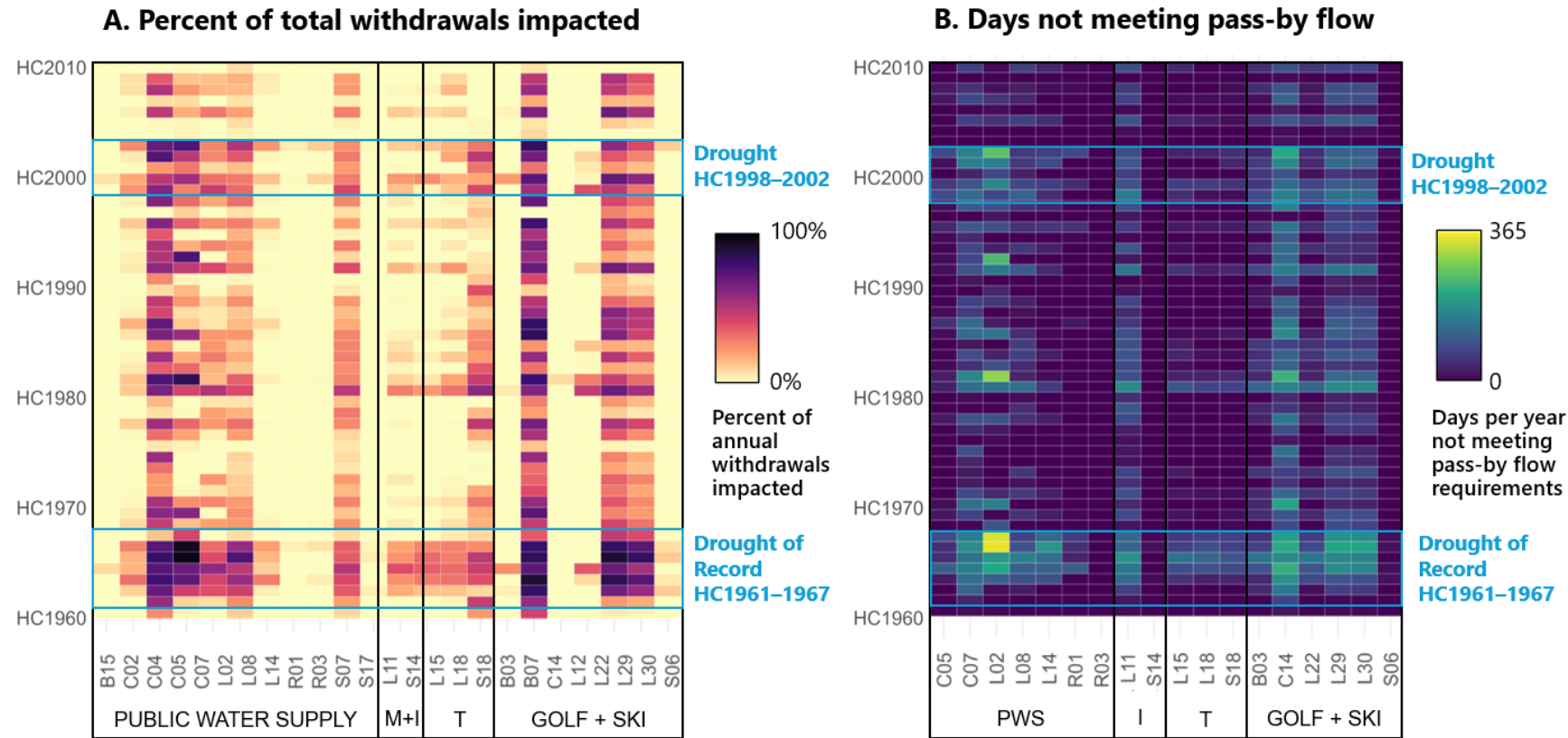


Figure 3-5. Annual results for impacted SW points.

These raster time-series plots show flagged SW points on the x-axis and years on the y-axis. Black boxes divide the SW points by sector: PWS = Public water supply, I = Industrial, and T = Thermoelectric power generation. On the left plot, darker colors indicate that a higher percentage of withdrawals from that intake were impacted. On the right plot, darker colors indicate more days each year that did not meet the PBF requirements. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

Not all withdrawal points that have been flagged in this analysis will necessarily have water supply issues. For example, many of these withdrawal points are part of larger systems that include reservoir storage, additional surface water intake(s), water supply interconnections, and/or groundwater well(s) that supplement water supplies and are not included in the SWEET model. Additionally, SWEET does not model directed releases from reservoir storage, which may also alleviate water supply limitations. Nine flagged points had impacted withdrawals and days that did not meet their PBF requirements (if applicable) during more than half of the years HC1960–2010: L02, L11, L14, C07, S19, B03, L29, L30, and C14 (**Figure 3-5B**). Given that these intakes have, in recent years, operated at similar withdrawal volumes to those in the model, these results are likely due to conservative model assumptions. Section 3.3 presents a more detailed evaluation of individual PWS and thermoelectric power generation withdrawal points' results within their specific water supply context. Impacted withdrawal points that serve the ski, golf, and industrial sectors are not addressed further in this report.

3.3 BASELINE SCENARIO RESULTS: POINT DETAILS

3.3.1 Public Water Supply

Nine public water supply withdrawal points were identified during the screening process as impacted in the baseline scenario. Although SWEET evaluates availability at individual withdrawal points, most PWS systems rely on several sources, such that if one source is unavailable due to limited supply, malfunction, etc., other sources may help make up the difference. Below is a brief review of alternative sources, other considerations, and detailed results for these nine impacted points. As stated above (Section 2.9), SWEET was not designed to recreate past conditions—rather, it applies current water use to past hydrology. The farther back in time, the more likely it is that past “real” withdrawal patterns and impacts did not match what SWEET modeled for the same time period. However, for recent years, it is reasonable to ground-truth the results by evaluating what really happened during these years. We reached out to the listed public water supply organizations to obtain ground-truthing data and observations and to ensure the accuracy of the interpretations presented here.

L02: Lehigh County Authority, Little Lehigh Creek

Lehigh County Authority's (LCA) Little Lehigh Creek intake (L02, DRBC Docket D-1984-016 CP) withdraws 3.9 BGY (~10.6 MGD). LCA serves approximately 270,000 people in the Lehigh Valley, PA, including the City of Allentown and 13 other municipalities. LCA operates a secondary (emergency backup) intake on the Lehigh River, which was modeled in SWEET (L03) as withdrawing 24 MGY and did not have any modeled impacted withdrawals. LCA also draws water from Schantz and Crystal Springs as well as groundwater wells.

The carbonate bedrock in this region makes it challenging to model surface or groundwater accurately. Karst geology is associated with rapid, variable groundwater flow such that the baseflow of Little Lehigh Creek is not always a consistent water supply. LCA shared gage data

from its intake for 2007 through 2010 for comparison with SWEET output. Streamflow estimates from SWEET severely under-represented observed flows at this location, especially at low flows. The median observed gage flow during 2007–2010 was 207 MGD, while the median SWEET streamflow value over the same period was 45 MGD. It is important to keep these point-specific limitations in mind when interpreting SWEET model results for L02.

In the baseline scenario, the Little Lehigh Creek intake had modeled impacted withdrawals in all but 4 HC years and did not meet modeled pass-by requirements on some days in more than half of HC years (36 out of 50) (**Figure 3-6**). With HC1965 and HC1966, more than 95% of modeled surface water withdrawal volumes were impacted (**Figure 3-5**). These severe modeled surface water shortages are due to relatively high groundwater consumptive use compared to streamflow; the order of operations in SWEET is such that all groundwater is supplied before surface water can be withdrawn. On more than 1,500 days, mostly during the HC1961–1967 and HC1998–2002 drought periods, daily groundwater consumptive use within Catchment L02 exceeded the sum total streamflow estimates from DRB-SET, flow out from the upstream Catchment L19, and NPDES discharges. In DRBC’s recent groundwater availability analysis, this catchment (subbasin DB-067 in that study) was flagged as the subbasin with the highest percentage of groundwater use relative to available groundwater (Thompson et al., 2022). A USGS study of karst aquifers in this region noted that surface water divides and groundwater divides do not align in this region, and that there is not a one-to-one relationship between surface water and groundwater, as assumed in the SWEET model (Sloto et al., 1991).

Given the limitations of the SWEET model in representing karst geology and the alternate sources available to LCA, additional study is recommended. However, knowledge about the challenges of water supply in this karst region and consistent flagging in DRBC’s surface and groundwater availability analyses indicate a moderate concern about water availability in this region. In awareness of instances of water supply stress in the Lehigh County Authority service area, studies are underway to better understand the carbonate geology–related challenges to local water supplies.

In early 2026, LCA approached DRBC to discuss the impacts of shifting water withdrawals from the Little Lehigh Creek intake to the main-stem Lehigh River intake when flows were restricted on the Little Lehigh Creek. Those discussions centered on what operational restrictions are applicable to the Lehigh River withdrawal during low flow conditions. A re-evaluation of the LCA system in SWEET with a shift in demand from the Little Lehigh intake to the Lehigh River intake could provide additional insight.

L08: Hazleton City Authority, Lehigh River

Hazleton City Authority (HCA)’s Lehigh River intake (L08; DRBC Docket D-1991-065 CP-4) withdraws 310 MGY (~0.85 MGD). HCA provides water for 13,650 domestic, 1,000 commercial, and 160 industrial service connections in Luzerne and Carbon Counties, PA. The service area includes parts of both the DRB and the Susquehanna River Basin. In addition to the Lehigh River

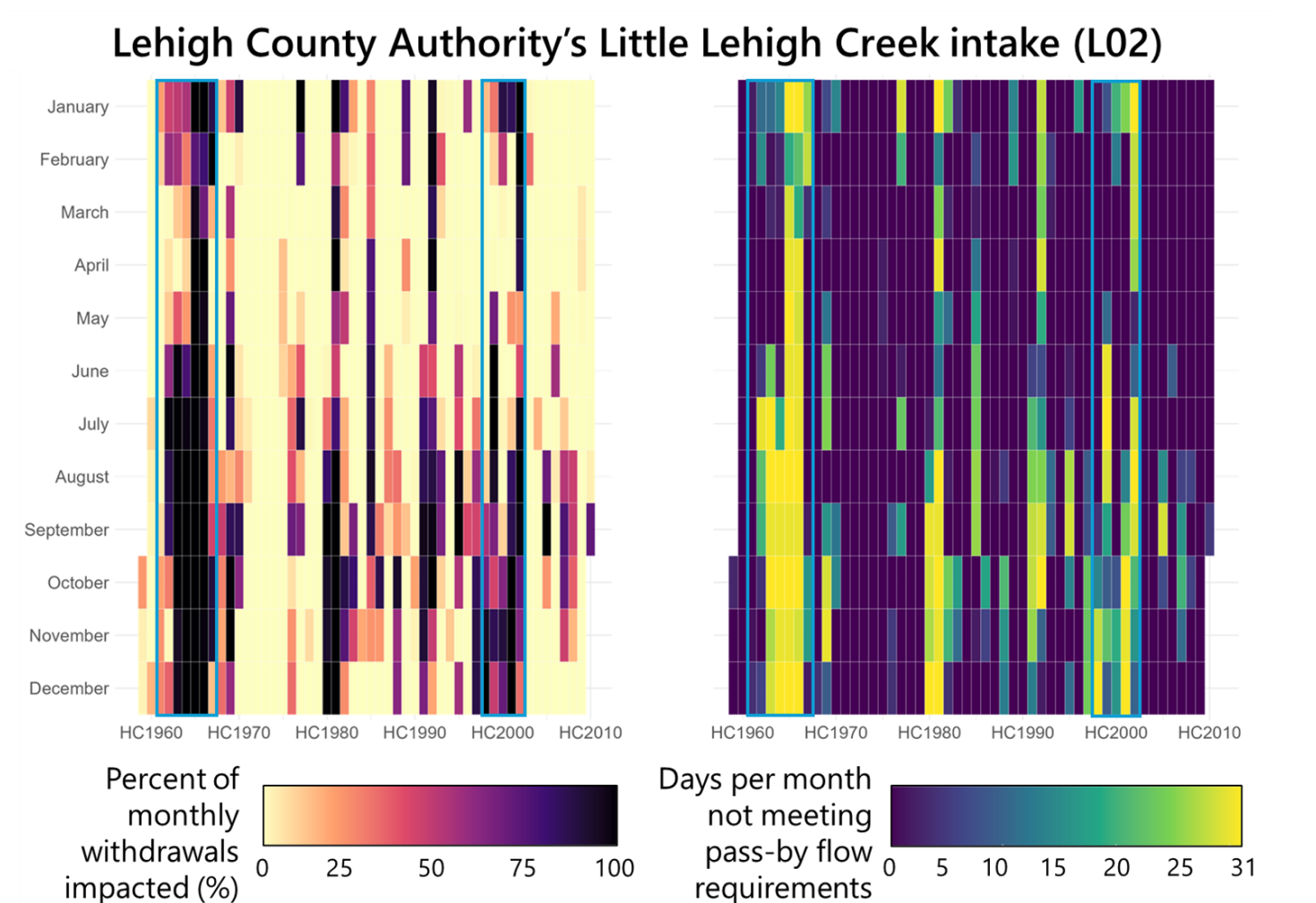


Figure 3-6. Raster monthly time-series plots for point L02, Lehigh County Authority's Little Lehigh Creek intake.

These raster time-series plots show years on the x-axis and months on the y-axis. On the left plot, darker colors indicate that a higher percentage of withdrawals from this intake were impacted. On the right plot, darker colors indicate more days each year that did not meet PBF requirements. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

intake, HCA operates additional intakes on Quakake Creek, Beisel's Run, Dreck Creek, and two reservoirs (Dreck Creek Reservoir and Quakake Creek Reservoir). The Dreck Creek intake is used to fill Dreck Creek Reservoir and is represented in SWEET as point L07. The Quakake Creek and Beisel's Run intakes are used to fill Quakake Creek Reservoir and are represented in SWEET as point L06. Because these intakes are directly linked to reservoirs, they are considered impoundments in SWEET and surface water availability was not evaluated at these points.

In 33 of 51 modeled years, the Lehigh River intake in the SWEET model could not withdraw at least 5% of its annual total intended volume, and in 21 years it could not withdraw at least 20% (**Figure 3-7**). The years with the greatest impacts were HC 1964 (59%), HC1980 (51%), HC1998 (46%), HC1963 (43%), HC1991 (41%), and HC1965 (40%). These impacts occur almost exclusively in late summer and fall. In reality, HCA's two reservoirs would help compensate for times when there is less water available at their Lehigh River intake.

In a unique location, HCA straddles the boundary between the Susquehanna and Delaware River Basins and has allocations for withdrawal in both. As it relates to the DRB side, HCA only takes a portion of its 5 MGD allocation due to pumphouse capacity limitations. HCA is currently seeking to upgrade their pumphouse to handle an increased volume to withdraw more of their allocation to meet growing demand and reduce system stress. Given the modeled impacts to this intake during a range of hydrologic conditions and the likelihood of increased withdrawal capacity at this intake, this intake presents moderate surface water availability concerns. A more thorough analysis of the HCA system that includes reservoir operations and expanded withdrawal capacity would be needed to more completely assess availability.

C05: The City of Newark, White Clay Creek

The City of Newark's White Clay Creek intake (C05, DRBC Docket D-2002-002 CP) withdraws 690 MGY (~1.9 MGD), serving a northwestern portion of New Castle County, DE. The City of Newark also operates 13 groundwater wells with a combined allocation of 5.35 MGD and, when flows are high, stores surface water from White Clay Creek in a 317 MG reservoir with a usable capacity to supply about 79 days³. Their water supply system is interconnected to Veolia Water Delaware. In the baseline scenario, modeled withdrawals were impacted during HC1962–1966, with a maximum for HC1963 of 216 MGY, 31% of the annual withdrawal volume (**Figure 3-5**). For HC1963–1966, between 24 and 110 model days did not meet the PBF requirements, indicating that the modeled intake could not withdraw any water (**Figure 3-8**). This intake also had modeled impacted withdrawals and days that did not meet the PBF requirements in approximately half of years with hydrologic conditions outside of the two focused drought periods. Given the diversity of alternate sources available, this intake does not present significant water availability concerns.

³ The Delaware Water Supply Coordinating Council (WSCC) estimates that Newark Reservoir's usable capacity is 300 MG over 75 days, or 4 MGD (Delaware Water Supply Coordinating Council, 2018).

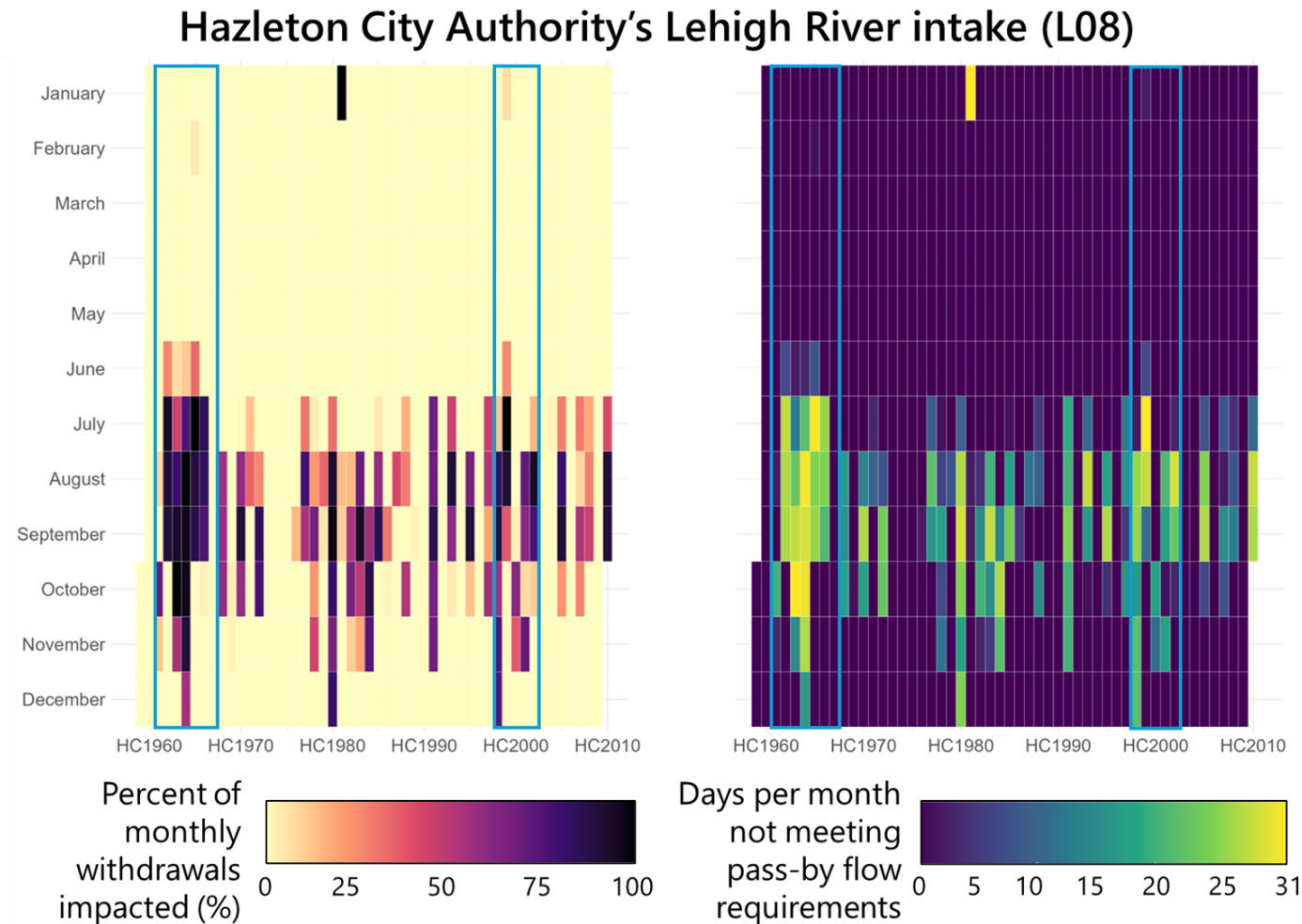


Figure 3-7. Raster monthly time-series plots for point L08, Hazleton City Authority's Lehigh River intake.

These raster time-series plots show years on the x-axis and months on the y-axis. On the left plot, darker colors indicate that a higher percentage of withdrawals from this intake were impacted. On the right plot, darker colors indicate more days each year that did not meet PBF requirements. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

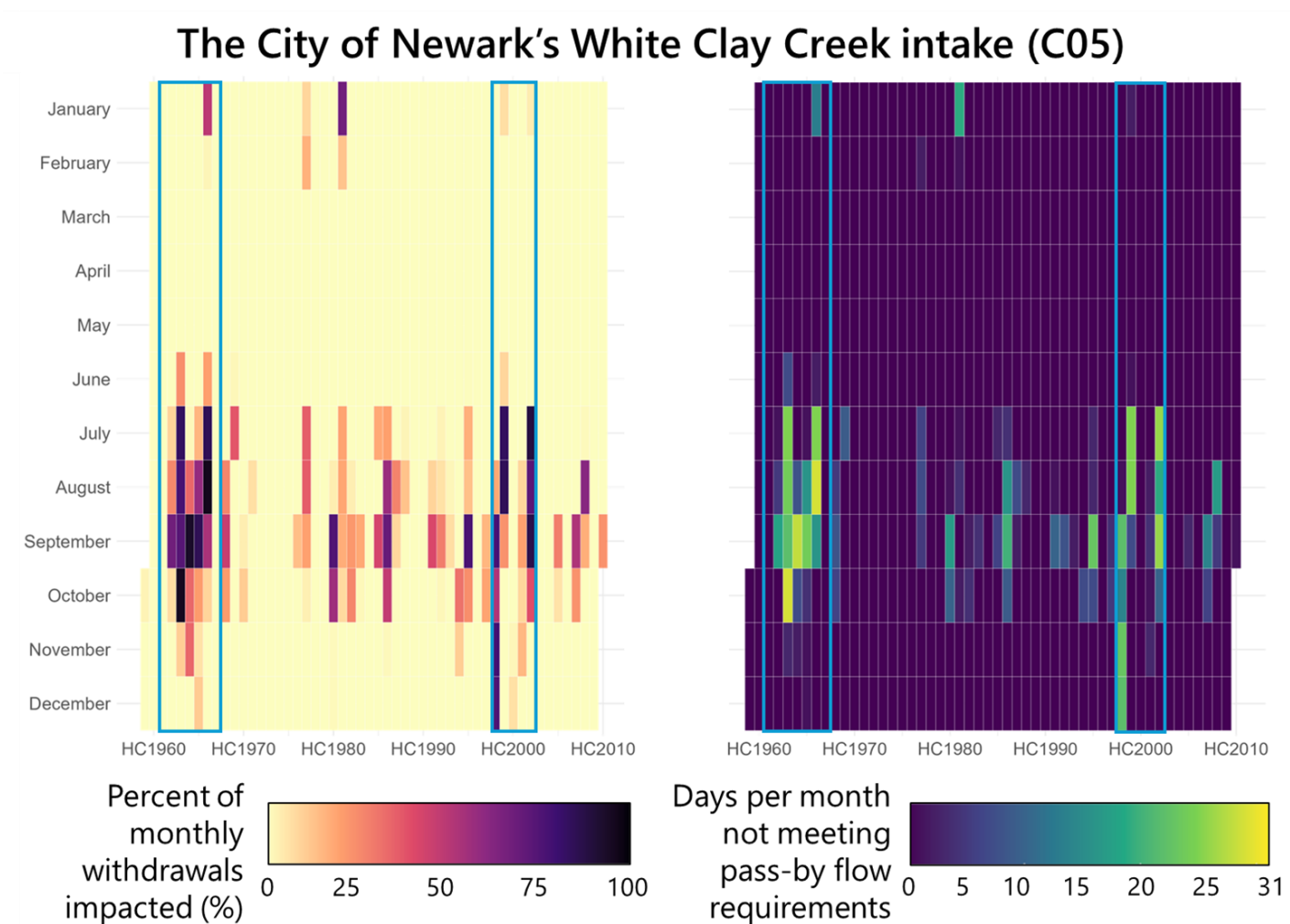


Figure 3-8. Raster monthly time-series plots for point C05, The City of Newark's White Clay Creek intake.

These raster time-series plots show years on the x-axis and months on the y-axis. On the left plot, darker colors indicate that a higher percentage of withdrawals from this intake were impacted. On the right plot, darker colors indicate more days each year that did not meet PBF requirements. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

R01 & R03: Aqua Pennsylvania, Ridley Creek (R01) and Chester Creek (R03)

Aqua Pennsylvania's Ridley Creek intake (R01, DRBC Docket D-1985-029 CP-2) withdraws 790 MGY (~2.2 MGD). During a repeat drought of record, this intake had modeled impacted withdrawals from HC1961 to HC1966, with a peak of 280 MG (35% of intended withdrawals by volume) in HC1963 (**Figure 3-9**). During HC1998–2002, this intake had impacted withdrawals in all years but HC2000, with a peak of 205 MG (26%) in HC2002. This intake also had impacted withdrawals (up to 20%) in approximately half of years outside of these droughts.

Aqua Pennsylvania's Chester Creek intake (R03, DRBC Docket D-1985-029 CP-2) withdraws 566 MGY (~1.6 MGD). During a repeat of the 1960s drought, this intake had minor impacts, with 15.4 MG (2.7%) of impacted withdrawals in HC1966 and 19 MG (3.3%) in HC2002 (**Figure 3-10**).

The Aqua Main system has multiple interconnections with other systems, providing supplementary water during times of impacted withdrawals at the Ridley and/or Chester Creek intakes. Alternate intakes include those at Crum Creek (R02), Schuylkill River (S01), Perkiomen Creek (S02), Neshaminy Creek (N01), East Branch Brandywine Creek (C02), and Pickering Creek (S03). These alternate sources and interconnection network supplement water supply during low-flow conditions where either adequate water quantity is not available or the quality of available water is compromised due to lack of flow. Given the diversity of alternate sources available, these intakes do not present significant water availability concerns.

L14: Pennsylvania American Water Company (PAWC), Ross Common Creek

Pennsylvania American Water Company (PAWC)–Nazareth District's Ross Common Creek intake (L14, DRBC Docket D-1977-047 CP) withdraws 500 MGY (~1.4 MGD). This intake is one of several sources supplying in-district customers within portions of Monroe and Northampton Counties, PA. Two reservoirs (Pen Argyl and Stony Garden), three springs (Frantz, Road, and Brewer), and eight groundwater wells also provide water supply to portions of these service areas.

The DRBC docket states that prior to a PBF requirement being implemented, this intake had often withdrawn the entire flow of Ross Common Creek, and that a specific well is in place to supplement surface water from this intake during times of low flow. Thus, it may not be surprising that L14 had modeled impacted withdrawals in all 50 HC years modeled in SWEET (**Figure 3-11**). Presumably, PAWC's other sources are able to supplement this intake when needed. Anecdotally, PAWC reported water quality concerns at the Ross Common intake during low flow periods in fall 2024. The present study cannot establish the robustness of alternate sources available to the Nazareth District.

C07: PAWC, West Branch Brandywine Creek

PAWC–Coatesville District's West Branch Brandywine Creek intake (C07, DRBC Docket D-1996-016 CP-3), withdraws 243 MGY and is primarily used to supply water to Rock Run Reservoir

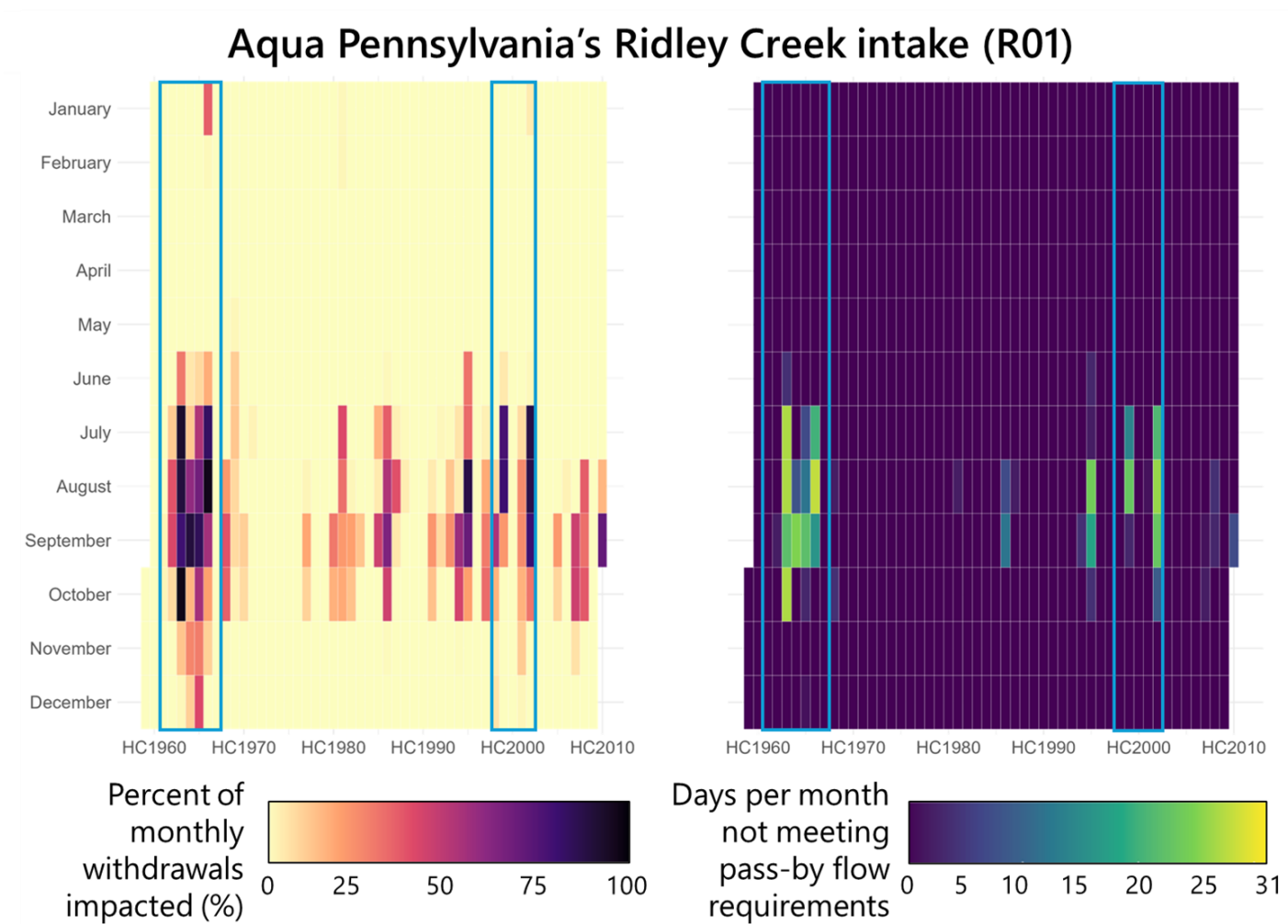


Figure 3-9. Raster monthly time-series plots for point R01, Aqua Pennsylvania's Ridley Creek intake.

These raster time-series plots show years on the x-axis and months on the y-axis. On the left plot, darker colors indicate that a higher percentage of withdrawals from this intake were impacted. On the right plot, darker colors indicate more days each year that did not meet PBF requirements. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

Aqua Pennsylvania's Chester Creek intake (R03)

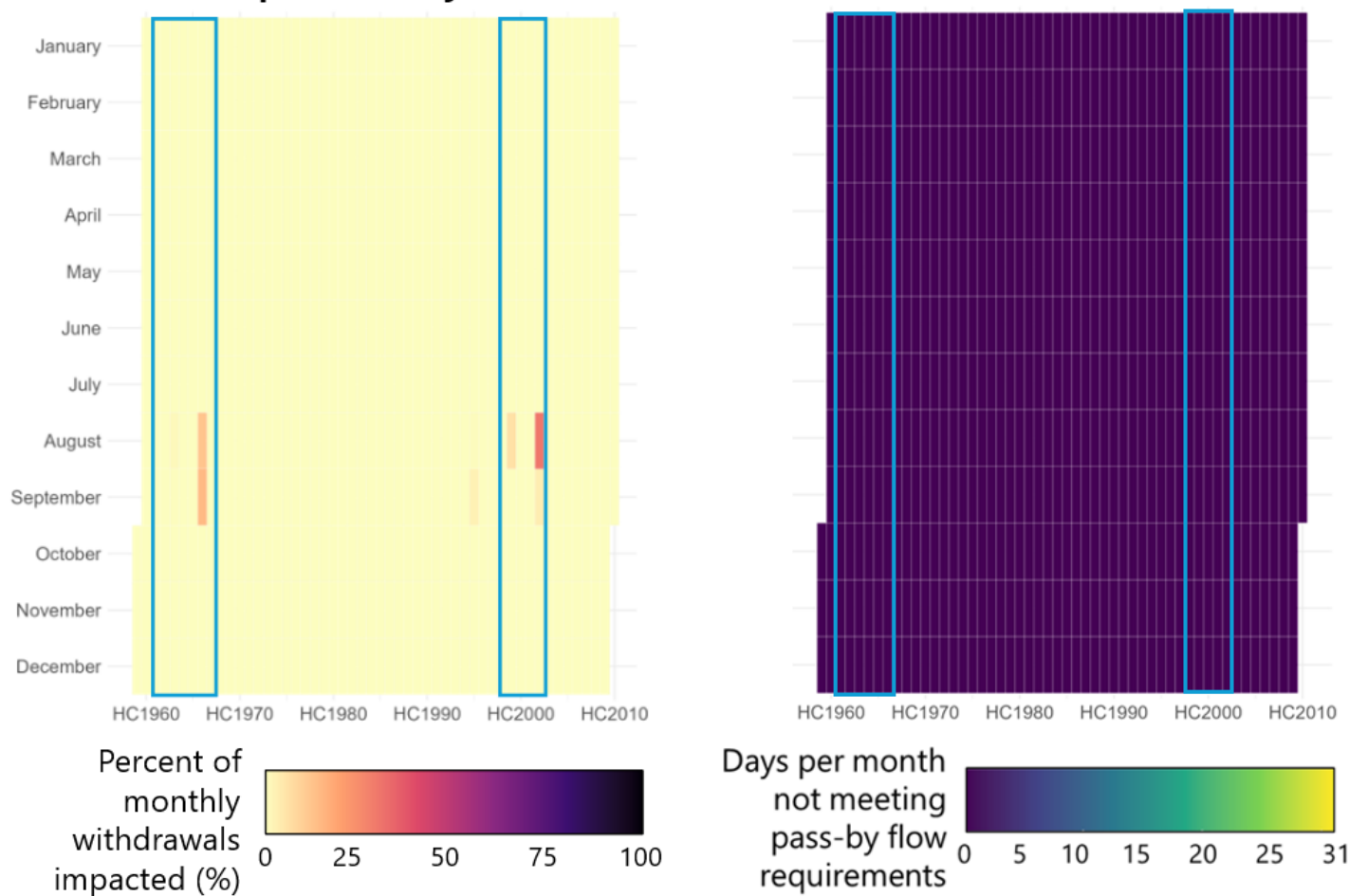


Figure 3-10. Raster monthly time-series plots for point R03, Aqua Pennsylvania's Chester Creek intake.

These raster time-series plots show years on the x-axis and months on the y-axis. On the left plot, darker colors indicate that a higher percentage of withdrawals from this intake were impacted. On the right plot, darker colors indicate more days each year that did not meet PBF requirements. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

PA American Water Company's Ross Common Creek intake (L14)

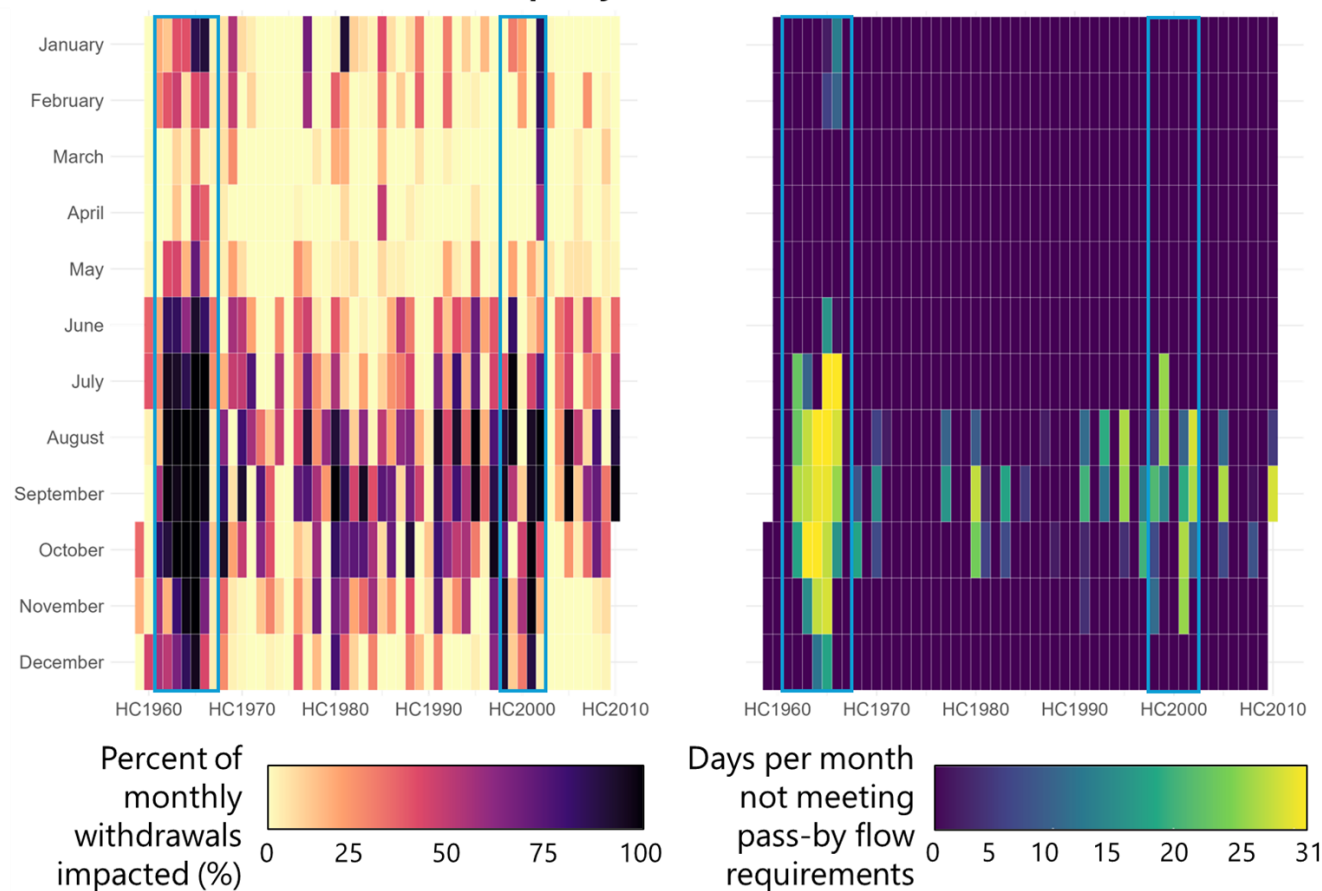


Figure 3-11. Raster monthly time-series plots for point L14, Pennsylvania American Water Company's Ross Common Creek intake.

These raster time-series plots show years on the x-axis and months on the y-axis. On the left plot, darker colors indicate that a higher percentage of withdrawals from this intake were impacted. On the right plot, darker colors indicate more days each year that did not meet PBF requirements. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

(C03), rather than to directly meet water demand. Presumably, the reservoir helps buffer water supply during dry times when the C07 intake has less availability. Nearby Chambers Lake serves as an additional reservoir source for PAWC–Coatesville. As SWEET does not actively model these reservoir operations, it will likely underestimate the water available at this combined source. It is notable that this point had modeled impacted withdrawals during nearly every simulated year (**Figure 3-12**). However, further work would be needed to comprehensively evaluate surface water availability points that are closely dependent on reservoir operations. Given SWEET's limitations in modeling reservoir operations, these results do not suggest surface water availability concerns.

S07: Birdsboro Municipal Authority, Hay Creek

Birdsboro Municipal Authority's (BMA's) Hay Creek intake (S07) is one of two surface water sources that serve Birdsboro Borough (population ~5,100) and a portion of Union Township, PA. The other source is an impoundment on nearby Indian Run, which is included in SWEET as point S62. The Hay Creek intake withdraws 44 MGY (~0.12 MGD). In the SWEET model, this intake had impacted withdrawals during 7 years: HC1963 (3.7% of withdrawals impacted by volume), HC1966 (5.3%), HC1968 (1.1%), HC1969 (0.2%), HC1981 (0.6%), HC1999 (8.9%), and HC2002 (9.8%). These impacts were confined to summer months (**Figure 3-13**). Overall, this intake had much more modest impacts than the other impacted points discussed in this section (**Figure 3-5**). In addition to Indian Run Dam, BMA has access to Dyer Quarry as a possible supplemental source. Given the conservative assumptions in the SWEET model, existing supplemental sources, and relatively modest impacts during select drought years, this intake does not pose water availability concerns.

B15: Buck Hill Falls Company, Buck Hill Creek

Buck Hill Falls Company's (BHFC's) Buck Hill Creek intake (B15) withdraws 2.87 MGY. This intake, a groundwater well, and a spring source collectively provide water for 309 homes and 5 businesses in Monroe County, PA. BHFC operates a second intake on Buck Hill Creek (B07) to support its golf club, located downstream of the public water supply intake, that withdraws 11.0 MGY, largely between May and September. BHFC's public water supply intake had impacted withdrawals during just two HC years: 0.2 MG (7.4% of withdrawals impacted by volume) in HC1964 and 0.16 MG (5.7%) in HC 1999 (**Figure 3-13**). Given the conservative assumptions in the SWEET model, existing alternative sources, and relatively modest impacts during only select drought years, this intake does not pose public water availability concerns.

PA American Water Company's W. Br. Brandywine Creek intake (C07)

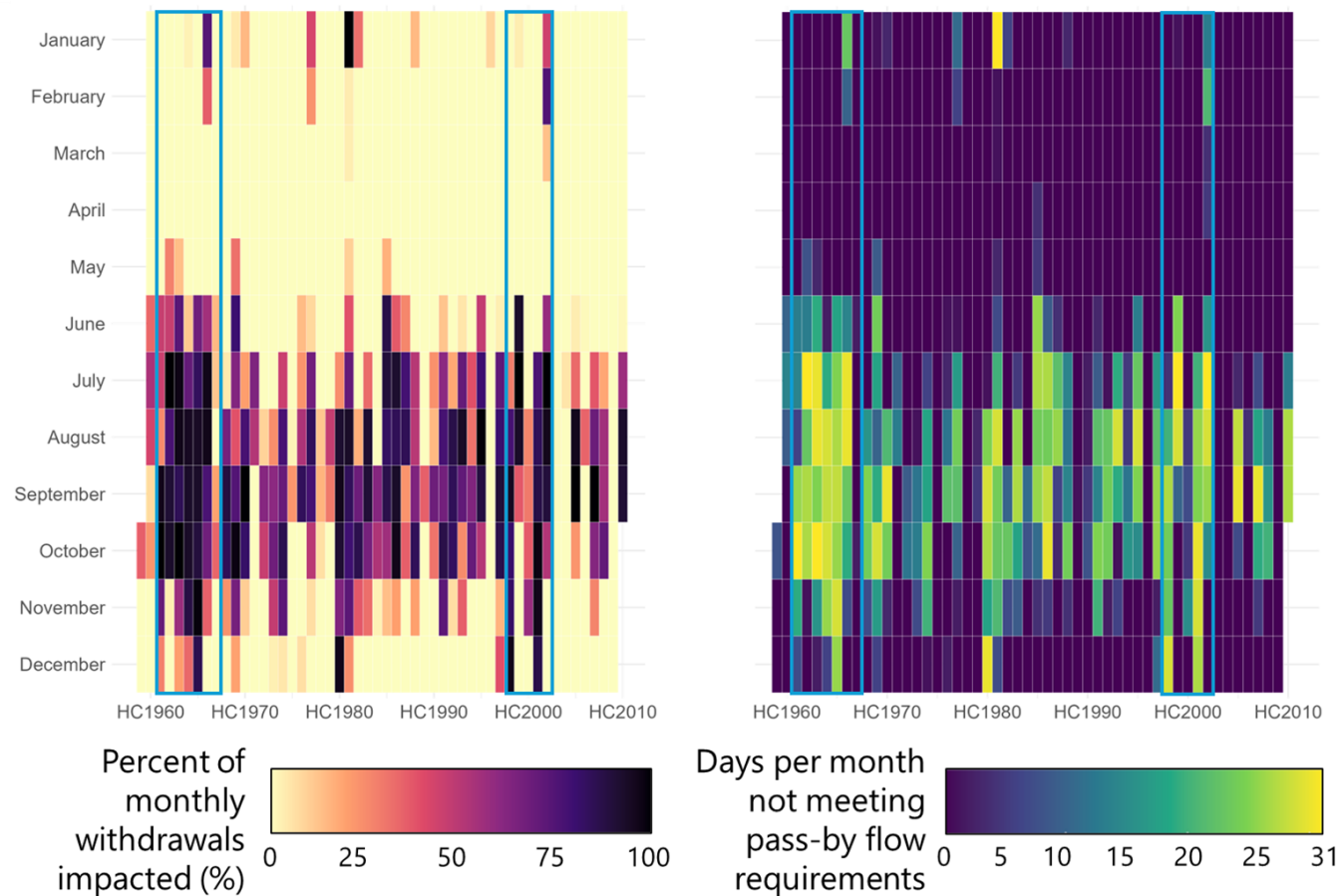


Figure 3-12. Raster monthly time-series plots for point C07, Pennsylvania American Water Company's West Branch Brandywine Creek intake.

These raster time-series plots show years on the x-axis and months on the y-axis. On the left plot, darker colors indicate that a higher percentage of withdrawals from this intake were impacted. On the right plot, darker colors indicate more days each year that did not meet PBF requirements. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

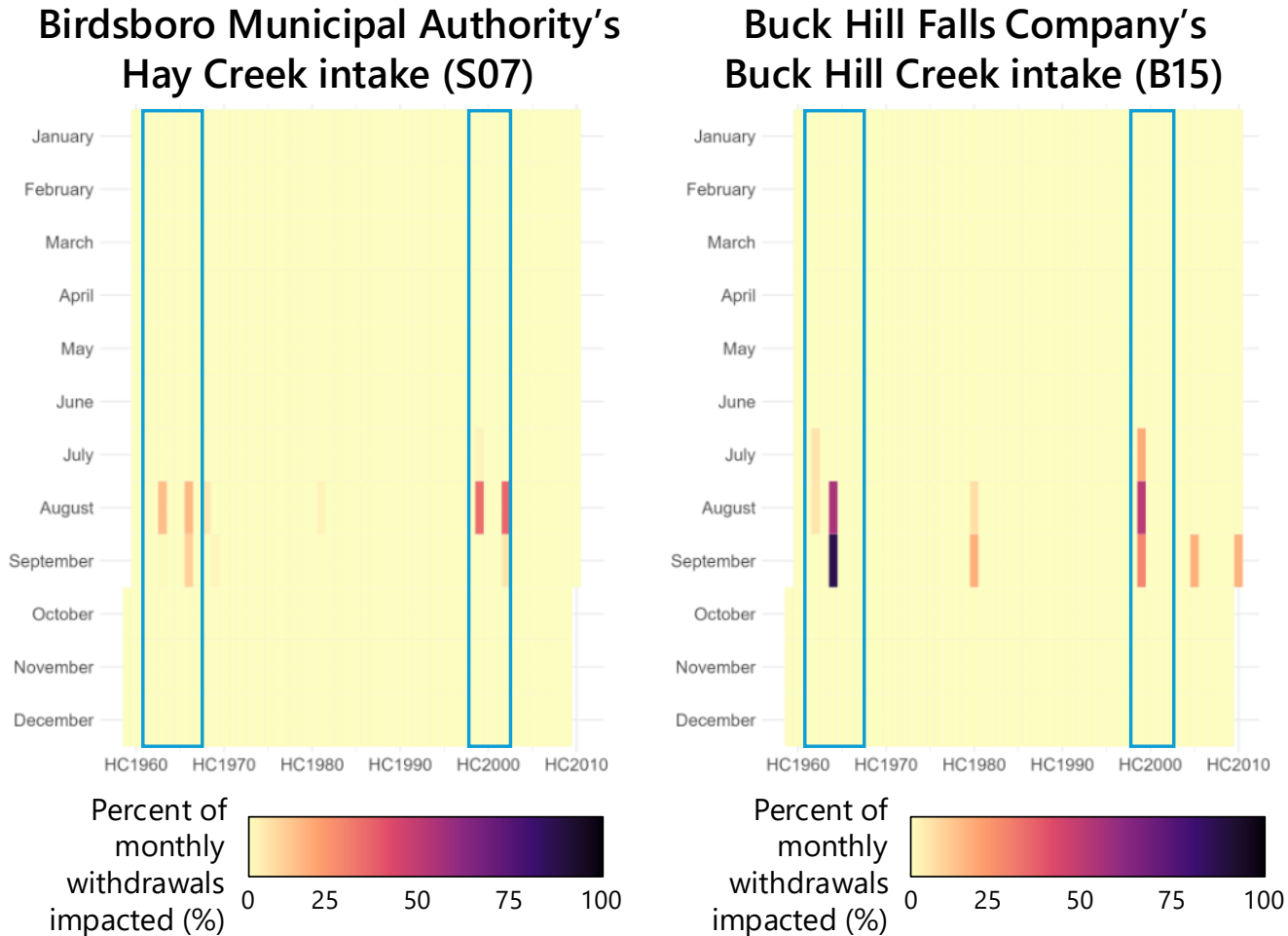


Figure 3-13. Raster monthly time-series plot for points S07 and B15.

These raster time-series plots show years on the x-axis and months on the y-axis. On these plots, darker colors indicate that a higher percentage of withdrawals from this intake were impacted. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

3.3.2 Thermoelectric Power Generation

Three thermoelectric power generation withdrawal points, all of which provide power to the PJM power grid, had impacted withdrawals in the baseline scenario. All three points have a PBF requirement and have alternative water sources available. Most thermoelectric power generation facilities within the Basin, including these, are required to adhere to the Commission's consumptive use make-up requirement during critical hydrologic conditions. These three facilities have secured consumptive make-up water that enables them to continue operations during critical hydrologic conditions (Resolution No. 2018-05, 2018). DRBC's consumptive use make up policy recommends that electric generating and cogenerating facilities in the Basin secure approximately 120 days' worth of consumptive use make up water. Below is a brief review of model results and context for these points.

L15: Northampton Generating Company, Lehigh River

Northampton Generating Company (L15, DRBC Docket D-1998-040-2) withdraws 305 MGY (~0.66 MGD) from the Lehigh River to support a cogeneration facility. Notably, L15 is located upstream of another thermoelectric power generation withdrawal point impacted in the baseline scenario, L18 (Calpine Corporation, Lehigh River). This point is also located downstream of F.E. Walter, Beltzville, Wild Creek, and Penn Forest Reservoirs. During low flow conditions, when the PBF requirement would otherwise preclude withdrawals from the Lehigh River, withdrawals may continue if Lehigh River flow is supplemented with supply from Horwith Quarry for a maximum of 12 days and 30 million gallons annually.

In the baseline scenario, L15 had at least 5% impacted withdrawals in 16 out of 51 modeled years. During a repeat drought of record, modeled impacted withdrawals peaked in HC1964 (121 MGY, 39% of annual withdrawal volume) (**Figure 3-14**). Model PBF requirements were not met, indicating that the intake could not withdraw water without an alternate source, for 136 days in HC1964. Northampton Generating Company's supplemental source would be able to meet some, but not all, of the possible shortfalls indicated by the SWEET model.

L18: Calpine Corporation, Lehigh River

Calpine Corporation (L18, DRBC Docket D-2001-031) withdraws 1.2 BGY (~3.4 MGD) from the Lehigh River to support electricity generation. When low flows (below the PBF) would otherwise prevent water from being withdrawn, Calpine Corporation can continue to withdraw water provided that they supplement flow in the Lehigh River with water from an upstream source, LaFarge Dragon Quarry. Releases from Merrill Creek Reservoir may be used to offset consumptive use during critical hydrologic conditions. Some water may also be received from the City of Bethlehem (L04 and L05). These supplemental sources are not represented in the SWEET model.

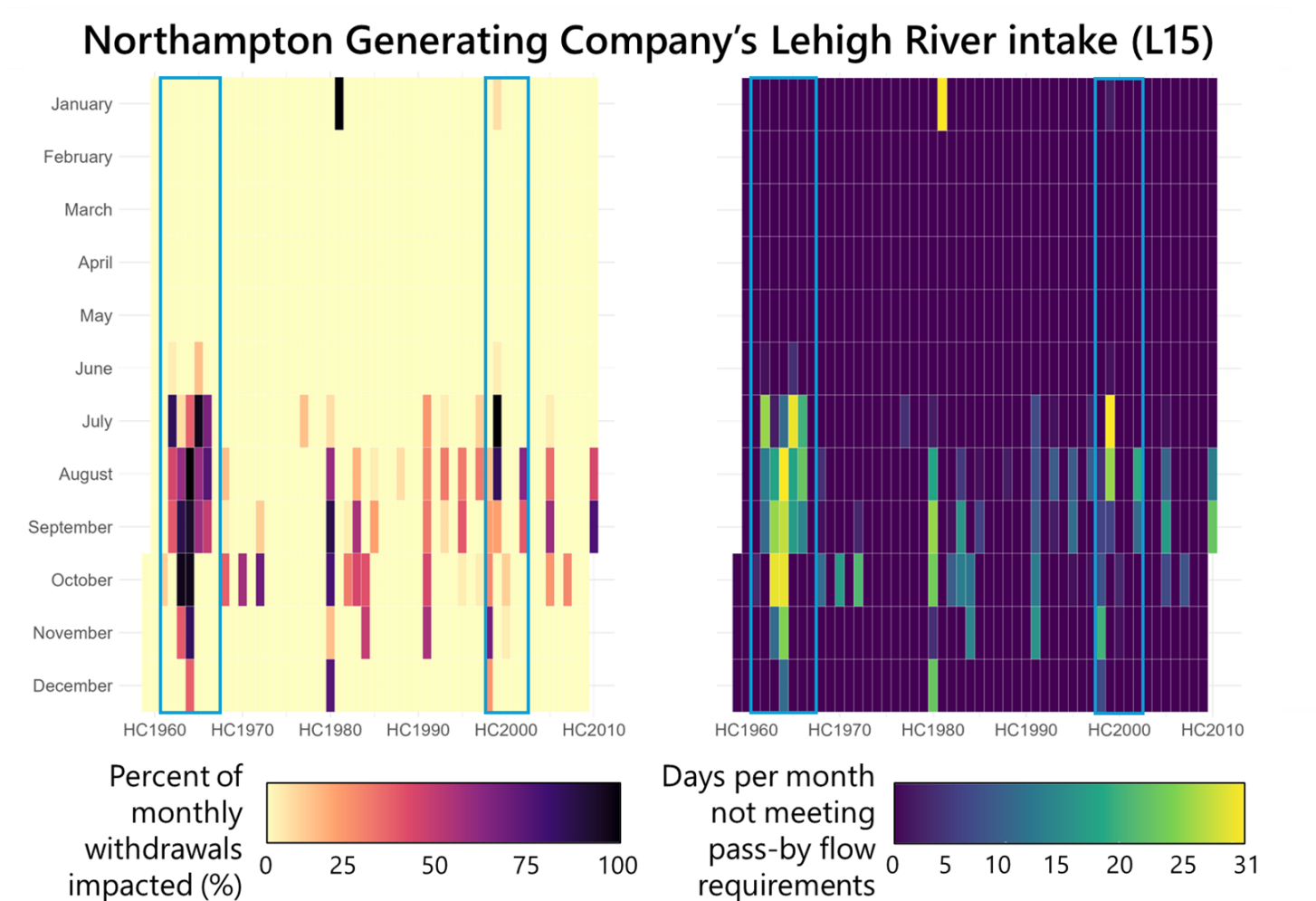


Figure 3-14. Raster monthly time-series plots for point L15, Northampton Generating Company's Lehigh River intake.

These raster time-series plots show years on the x-axis and months on the y-axis. On the left plot, darker colors indicate that a higher percentage of withdrawals from this intake were impacted. On the right plot, darker colors indicate more days each year that did not meet PBF requirements. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

In the baseline scenario, this point had modeled impacted withdrawals and model days not meeting PBF requirements during HC1963–1966, with a maximum of 443 MGY (36% of annual withdrawal volume) and 121 days not meeting the PBF in HC1964 (**Figure 3-15**). This point also had more than 5% annual modeled impacted withdrawals with HC1980 (273 MGY), HC1981 (265 MGY), HC1991 (111 MGY), HC1995 (91 MGY), HC1999 (303 MGY), HC2002 (151 MGY), and HC 2005 (92 MGY). Calpine Corporation’s supplemental sources would likely be able to meet the possible shortfalls indicated by the SWEET model.

S18: Constellation Energy Limerick Generating Station, Schuylkill River

Constellation Energy’s Limerick Generating Station (LGS) Schuylkill River and Perkiomen Creek intakes (S18 and S19, respectively; DRBC Docket D-1969-210 CP-15) withdraw water (13.9 BGY [38 MGD] and 1.5 BGY [4.1 MGD], respectively) to support nuclear power generation. To support operations during lower flow conditions, LGS is subject to stringent consumptive use makeup requirements that apply whenever flows in the Schuylkill River at the Pottstown USGS gage are below 530 cfs (one unit in operation) or 560 cfs (two units in operation). The consumptive use of LGS is required to be mitigated on a 1:1 gallon per day basis when flows are below those values. To meet these requirements, in addition to the intrabasin transfer (Point Pleasant Pump), LGS has secured water from additional upstream sources (Wadesville Mine Pool and the City of Tamaqua) that would provide releases which would then be available for withdrawal by LGS during low flow periods. Other than a minimum flow from the Point Pleasant Pump (Section 2.5.2), these supplemental sources are not modeled in SWEET.

In the SWEET model, from HC1963–1966 and in HC1980, S18 was unable to take approximately 30% of its intended withdrawal in the SWEET model (**Figure 3-16**). The HC1998–2002 drought was less severe for S18, with 12–18% of withdrawals impacted. These results demonstrate notable water availability concerns during dry years in a scenario without the consumptive use makeup requirements in place, reaffirming the value of these requirements to support water availability for LGS during lower flow conditions in the Schuylkill watershed.

Surface water availability was not assessed at point S19 because of the SWEET model’s inability to accurately represent (1) the daily volume of water that the East Branch Perkiomen Creek receives from the Delaware River via an intrabasin transfer (Section 2.5.2), and (2) how many units are operating at LGS, which affects the PBF requirement for point S19.

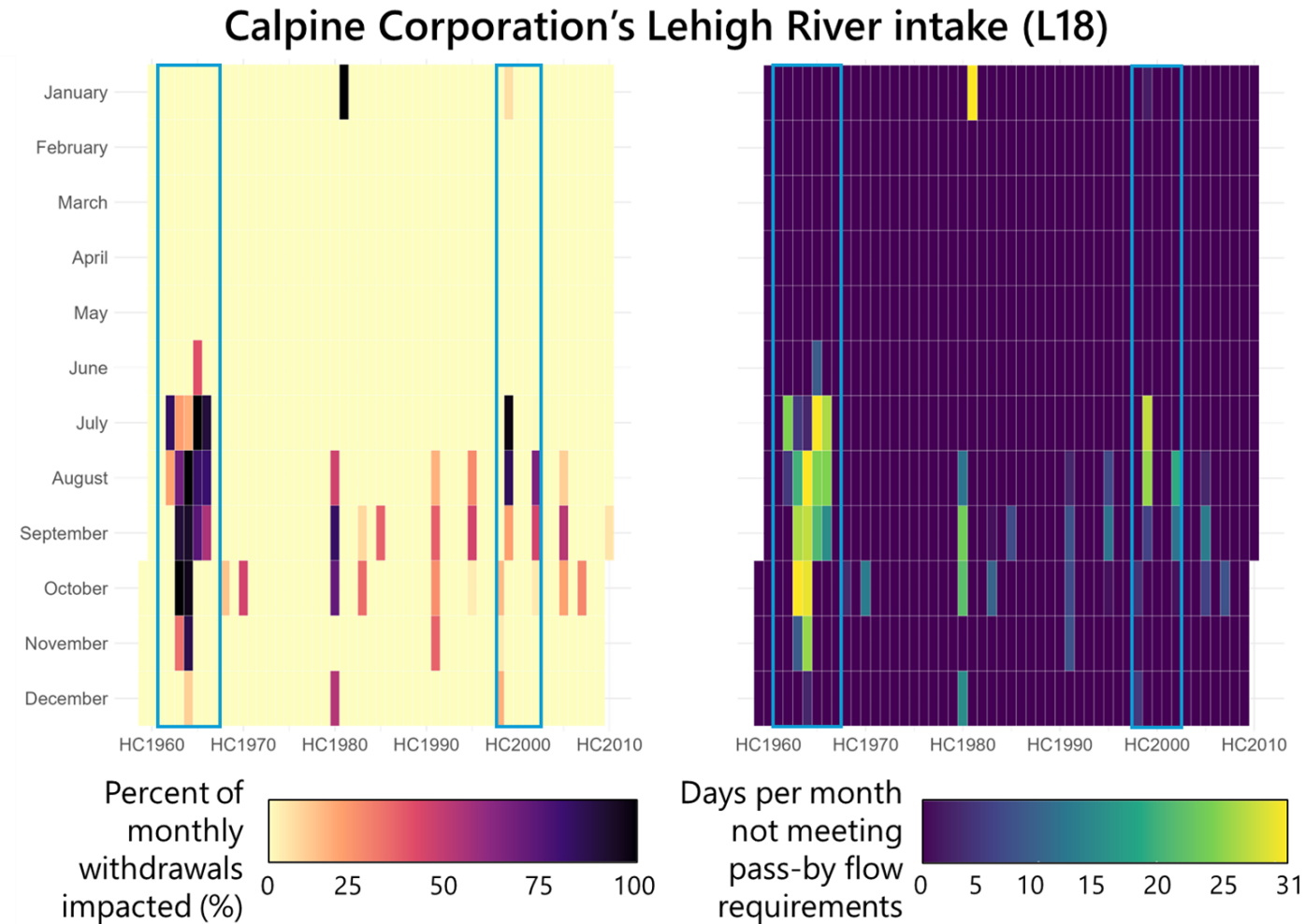


Figure 3-15. Raster monthly time-series plots for point L18, Calpine Corporation's Lehigh River intake.

These raster time-series plots show years on the x-axis and months on the y-axis. On the left plot, darker colors indicate that a higher percentage of withdrawals from this intake were impacted. On the right plot, darker colors indicate more days each year that did not meet PBF requirements. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

Limerick Generating Station's Schuylkill River intake (S18)

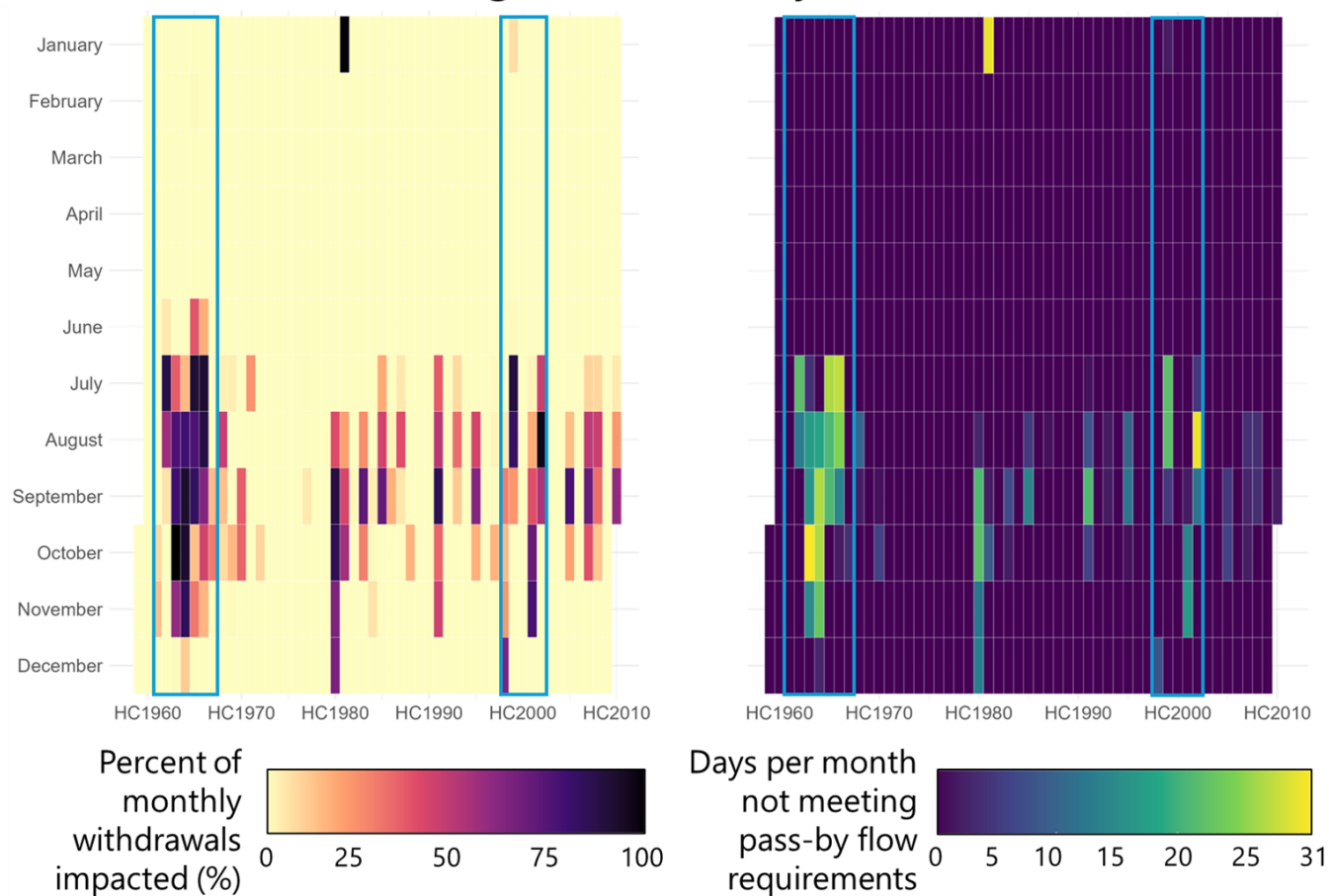


Figure 3-16. Raster monthly time-series plots for point S18, Constellation Energy's Limerick Generating Station Schuylkill River intake.

These raster time-series plots show years on the x-axis and months on the y-axis. On the left plot, darker colors indicate that a higher percentage of withdrawals from this intake were impacted. On the right plot, darker colors indicate more days each year that did not meet PBF requirements. The years representing a repeat of hydrologic conditions during the 1961–1967 and 1998–2002 droughts are highlighted in blue boxes.

3.4 2060 WITHDRAWAL SCENARIO

In the 2060 withdrawal scenario, SW and GW withdrawal volumes were adjusted to represent projected trends through the year 2060 (Section 2.4.2). (Returns, conservation releases, and PBFs were not adjusted from the baseline scenario.) At the watershed scale, recent water use trends are such that total surface water withdrawal volumes are projected to increase in the Brodhead Creek, Lehigh River, and Neshaminy Creek watersheds, by 0.052, 2.9, and 1.6 BGY, respectively. Groundwater consumptive use is also projected to increase in the Brodhead Creek and Lehigh River watersheds, and thus, flow out of these two watersheds decreased in the 2060 withdrawal scenario relative to the baseline scenario by 0.44 MGD (Brodhead) and 4.7 MGD (Lehigh). Flow out of the Neshaminy Creek watershed was unchanged, as a large decrease in groundwater consumptive use helped offset the increasing surface water withdrawals. In the Brodhead Creek watershed, public water supply withdrawal volumes are not projected to change, while public water supply withdrawals are projected to increase in the Lehigh River and Neshaminy Creek watersheds.

By 2060, total surface water withdrawal volumes are projected to decrease in the Brandywine-Christina River, Chester-Ridley-Crum Creek, and Schuylkill River watersheds by 1.7, 0.37, and 6.6 BGY, respectively. Changes in groundwater consumptive use were small relative to changes in surface water withdrawals in these three watersheds. The declining surface water withdrawal trends are driven by decreasing public water supply withdrawal volumes in these three watersheds. In fact, in the Chester-Ridley-Crum Creek and Schuylkill River watersheds, decreases in public water supply withdrawals offset increases in withdrawal volumes from other sectors. As a result, streamflow at the watershed outlets in the 2060 withdrawal scenario increased by 20.7 MGD (Schuylkill), 1 MGD (Chester-Ridley-Crum), and 5.4 MGD (Brandywine-Christina) relative to the baseline scenario.

Eight of the 20 points flagged in the baseline scenario had modeled withdrawal volume trends that changed in the 2060 scenario; a summary of results for these points is shown in **Table 3-5**. Similar results for all SW points are shown in Appendix B, and withdrawal trend projections for all SW points are shown in Appendix C. Three withdrawal points had higher withdrawal volumes in the 2060 withdrawals scenario relative to the baseline scenario and had no modeled impacted withdrawals in either scenario: Northampton Borough's Lehigh River intake (L01) as well as Aqua Pennsylvania's Neshaminy Creek (N01) and Schuylkill River (S01) intakes. These withdrawal points may be particularly resilient to increased future water demand.

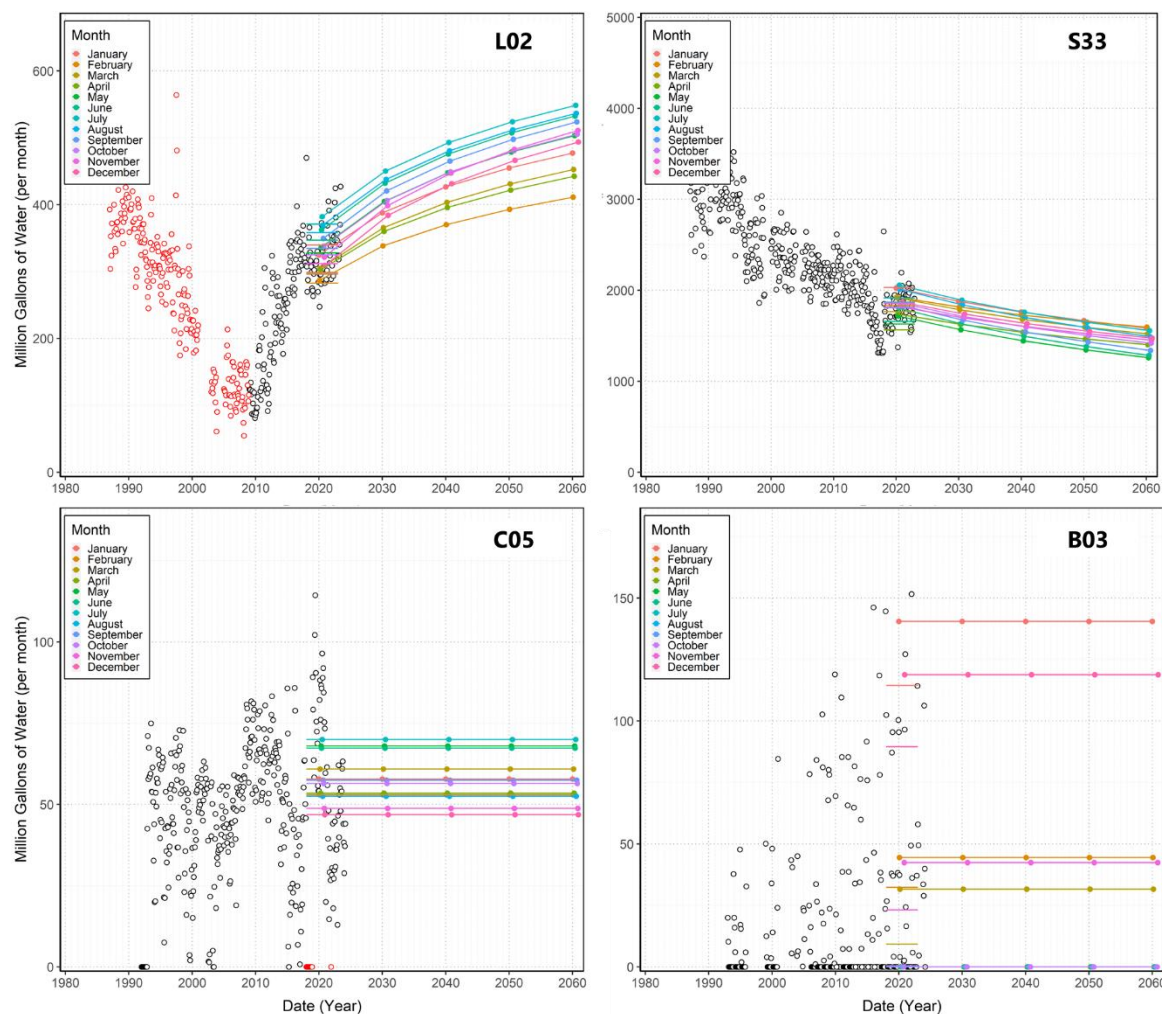


Figure 3-17. Example water use trends projected through 2060.

Top left: Increasing trend example, Lehigh County Authority's Little Lehigh Creek intake (L02). Top right: Decreasing trend example, Philadelphia Water Department's Queens Lane Schuylkill River intake (S33). Bottom left: No clear trend example, use average of past five years, City of Newark's White Clay Creek intake. Bottom right: Highly variable example, use maximum monthly value, Camelback Mountain Resort (B03). See trends for all 54 SW points in Appendix C.

Table 3-4. Watershed-wide trends in surface water withdrawals and groundwater consumptive use.

	Total Surface Water Withdrawals: All Sectors				Total Surface Water Withdrawals: Public Water Supply				Total Groundwater Consumptive Use			
	Baseline (MGY)	Future (MGY)	Diff. (MGY)	Diff. (%)	Baseline (MGY)	Future (MGY)	Diff. (MGY)	Diff. (%)	Baseline (MGY)	Future (MGY)	Diff. (MGY)	Diff. (%)
Brodhead Creek	1118	1170	+52	+5%	301	301	0	0%	1447	1626	+179	+12%
Brandywine- Christina River	14584	12890	-1694	-12%	7895	6899	-996	-13%	3837	3792	-45	-1%
Lehigh River	16812	19753	+2941	+17%	6019	8643	+2625	+44%	12337	12387	+50	+0.4%
Neshaminy Creek	14963	16588	+1625	+11%	3788	4105	+318	+8%	2236	1276	-960	-43%
Chester- Ridley-Crum Creek	7497	7127	-371	-5%	7369	6976	-394	-5%	174	212	+38	+22%
Schuylkill River	78748	72107	-6641	-8%	55971	47785	-8185	-15%	17602	16627	-974	-6%

Baseline = Average of data from 2018 through 2022. Future = Projection of recent trends through the year 2060.

Table 3-5. Impacted withdrawal results for the SW points that were impacted in the baseline scenario and had a change in withdrawals in the 2060 scenario.

Point ID	Sector	Withdrawal Demand (MGY)				Impacted Withdrawal Volume, 1961–1967 (MGY)			
		Baseline	2060	Δ (MGY)	Δ (%)	Baseline	2060	Δ (MGY)	Δ (%)
B03	Ski	269	378	+109	+40%	85	132	+47	+55%
C07	Public Water Supply	243	464	+221	+91%	155	279	+124	+80%
L02	Public Water Supply	3890	5938	+2049	+53%	2384	3864	+1480	+62%
L08	Public Water Supply	309	729	+421	+136%	97	222	+125	+129%
L11	Industrial	155	59	–96	–62%	50	19	–31	–62%
R01	Public Water Supply	793	688	–105	–13%	135	126	–9	–7%
S14	Industrial	372	284	–88	–24%	4.6	3.9	–0.7	–15%
S18	Thermoelectric Power	13964	16885	+2921	+21%	2740	3340	+600	+22%

A complete table for all SW Points can be found in Appendix B.

Three points that were impacted in the baseline scenario, Palmerton Borough's Pohopoco Creek intake (L11), Aqua Pennsylvania's Ridley Creek intake (R01), and Cambridge-Lee Industries Inc.'s Schuylkill River intake (S14) currently have decreasing water use trends; based on recent data, these points are projected to decrease their annual withdrawal volumes by 62%, 13%, and 24%, respectively, by 2060 (**Figure 3-17A**). During a repeat drought of record, these points fare better, having reduced impacts in the 2060 withdrawals scenario than with current-day withdrawal volumes. Five points that were impacted in the baseline scenario are projected to withdraw more surface water in 2060, resulting in greater impact to surface water availability. These include four public water supply withdrawal points: Camelback Mountain Resort's Pocono Creek intake (B03), PAWC's West Branch Brandywine Creek intake (C07), LCA's Little Lehigh Creek intake (L02), HCA's Lehigh River intake (L08), and one thermoelectric power generation point: Constellation Energy's Limerick Generating Station Schuylkill River intake (S18). In this scenario, LGS's consumptive use makeup requirements would still be in effect.

For the remaining SW points that were impacted in the baseline scenario, including public water supply intakes for City Newark (C05), PAWC (L14), and Birdsboro Municipal Authority (S07), there was no clear temporal trend in the data, and the average of the entire record was used to estimate withdrawal volumes in 2060. Nine points that are not projected to have any change in surface water withdrawal volumes did have minor changes to their total impacted withdrawals during a repeat drought of record due to projected changes in groundwater withdrawal volumes and/or upstream surface water withdrawal volumes.

3.5 DROUGHT MANAGEMENT SCENARIO

The drought management scenario included decreased modeled conservation releases at three major reservoirs (**Table 2-4**) and decreased model PBFs at two intakes (**Table 2-5**), in accordance with revised operations during drought conditions. This scenario did not include reduced withdrawal demand that could occur during critical low-flow conditions. All changes were located within the Lehigh and Schuylkill watersheds, which have a total of 32 modelled withdrawal points. Five withdrawal points were affected by the shift from normal operations to drought management, and the remaining 27 SW points in these two watersheds had no change in total impacted withdrawals or days not meeting their PBF requirement.

Hazleton City Authority's Lehigh River intake (L08) is the first withdrawal point downstream of F.E. Walter Reservoir, and Northampton Generating Company's Lehigh River intake (L15) is located downstream of both F.E. Walter and Beltzville Reservoirs. Reduced conservation releases from the F.E. Walter and Beltzville Reservoirs due to modeled drought management reduced flow at the L08 and L15 intakes and thus increased their modeled impacted withdrawals by 15 MGY and 17 MGY, respectively, during a repeat drought of record with current withdrawal volumes (**Table 3-6**). Notably, Lehigh River intakes L01 (Northampton Borough Municipal Authority) and L09 (Northampton Generating Company) are also located downstream of F.E. Walter and Beltzville reservoirs and are upstream of L15. Despite reduced streamflow in the drought management scenario, L01 and L09 had no modeled impacted

withdrawals, as in the baseline scenario. These intakes may be relatively more resilient in terms of surface water availability.

The following modeled withdrawals, downstream of Blue Marsh Reservoir along the Schuylkill River, were not affected by the reservoir's reduced conservation release: Pottstown Borough (S36), PAWC Royersford (S30), Phoenixville Borough (S35), Aqua Pennsylvania (S01), and PAWC Norristown (S31).

Palmerton Borough Municipal Authority's Pohopoco Creek intake (L11) and Calpine Corporation's Lehigh River intake (L18) are the only two SW points in this study to have PBF requirements that adjust during drought conditions (**Table 2-5**). When Beltzville and F.E. Walter Reservoirs are operated under drought conditions, the PBF requirements at these two points are reduced to account for reduced conservation releases. Considering the effect of reduced conservation releases and reduced PBF requirements, the modeled impacted withdrawals at L11 and L18 are reduced by 30 and 1.6 MGY, respectively, relative to the baseline scenario during a repeat drought of record (**Table 3-6**).

Table 3-6. Comparison of total impacted withdrawals (in MGY) with normal and drought management.

Point ID	<u>HC1961–1967</u>			<u>HC1998–2002</u>		
	Baseline	Drought	Difference	Baseline	Drought	Difference
L08	97	112	+15	85	103	+18
L11	50	20	–30	45	10	–35
L15	54	71	+17	28	60	+32
L18	241	240	–1.6	97	96	–0.5
S18	2743	3227	+484	1764	2206	+443

3.6 ECOLOGICAL PASS-BY FLOWS SCENARIO

Nearly half of the SW points in this study, 25 out of 54, were not evaluated with an ecological PBF because their withdrawal volumes were below the de minimis threshold in each month, suggesting that these points are currently withdrawing water sustainably from the perspective of aquatic ecosystems. These 25 points include seven PWS withdrawals:

- Northampton Borough Municipal Authority's Lehigh River intake (L01)
- Hazleton City Authority's Lehigh River Intake (L08)
- East Greenville Borough's Perkiomen Creek intake (S17)
- Pennsylvania American Water Company's Royersford and Norristown Schuylkill River intakes (S30 and S31)
- Phoenixville Borough's Schuylkill River intake (S35)
- Pottstown Borough's Schuylkill River intake (S36)

Eight of the 25 points for which an ecological PBF was not evaluated, including L08 from the list above, have an existing PBF in place that is roughly equivalent to a 7Q10 flow. All eight of those points had impacted withdrawals in the baseline scenario and similar impacts in the ecological PBF scenario, as their PBFs were unchanged. This result demonstrates that even withdrawal points that are below the de minimis withdrawal threshold as defined above (Section 2.6.1) could impact streams during low-flow times with their withdrawals.

For 20 points, a hypothetical ecological PBF was evaluated in at least one month of the year; this includes 10 points with an existing PBF that was increased and 10 points without an existing PBF. As a result of the more-stringent PBFs, all of these points had more impacted withdrawals in the ecological flows scenario as compared to the baseline scenario. **Table 3-7** shows results for the 16 public water supply points which had a hypothetical ecological PBF imposed. For each of the two drought periods evaluated, the median of these PWS intakes could only take about 50% of their intended withdrawal volume. Because ecological PBFs are designed to protect the complete flow regime, rather than exclusively focusing on low-flow periods, these points also had substantial impacts outside of drought conditions (**Figure 3-18**). The Brandywine-Christina River, Chester-Ridley-Crum Creeks, and Schuylkill River watersheds had the most PWS points with new ecological PBFs and therefore saw the greatest impacts from this hypothetical change. A few intakes experienced a decrease in impacted withdrawals in the ecological PBF scenario relative to the baseline scenario. These points were downstream of a SW withdrawal whose intake volumes were limited by a new PBF, leaving more downstream water available for them.

Table 3-7. Results for PWS points with hypothetical ecological pass-by flows imposed.

Point ID	SW Withdrawals (MGY)	1961–1967 Drought				1998–2002 Drought			
		Impacted Withdrawals		Difference from Baseline		Impacted Withdrawals		Difference from Baseline	
		MGY	Percent	MGY	Percent	MGY	Percent	MGY	Percent
B02	298	50	17%	+50	+17%	48	16%	+48	+16%
C02	1546	1318	85%	+1318	+85%	1228	79%	+1228	+79%
C04	5182	3845	74%	+3844	+74%	3204	62%	+3204	+62%
C05	692	414	60%	+317	+46%	438	63%	+341	+49%
C06	232	74	32%	+74	+32%	71	31%	+71	+31%
C07	243	178	73%	+23	+10%	152	63%	+18	+7%
L02	3890	3376	87%	+993	+26%	2870	74%	+1022	+26%
N01	3788	1914	51%	+1914	+51%	1485	39%	+1485	+39%
R01	793	598	75%	+463	+58%	569	72%	+478	+60%
R02	6011	3280	55%	+3280	+55%	3319	55%	+39	+1%
R03	566	253	45%	+251	+44%	205	36%	+201	+35%
S01	6380	495	8%	+495	+8%	347	5%	+347	+5%
S02	3724	1875	50%	+1875	+50%	1507	40%	+1507	+40%
S07	44	31	70%	+30	+69%	26	58%	+24	+55%
S33	21607	6782	31%	+6782	+31%	5436	25%	+5436	+25%
S34	17186	4442	26%	+4442	+26%	3875	23%	+3875	+23%

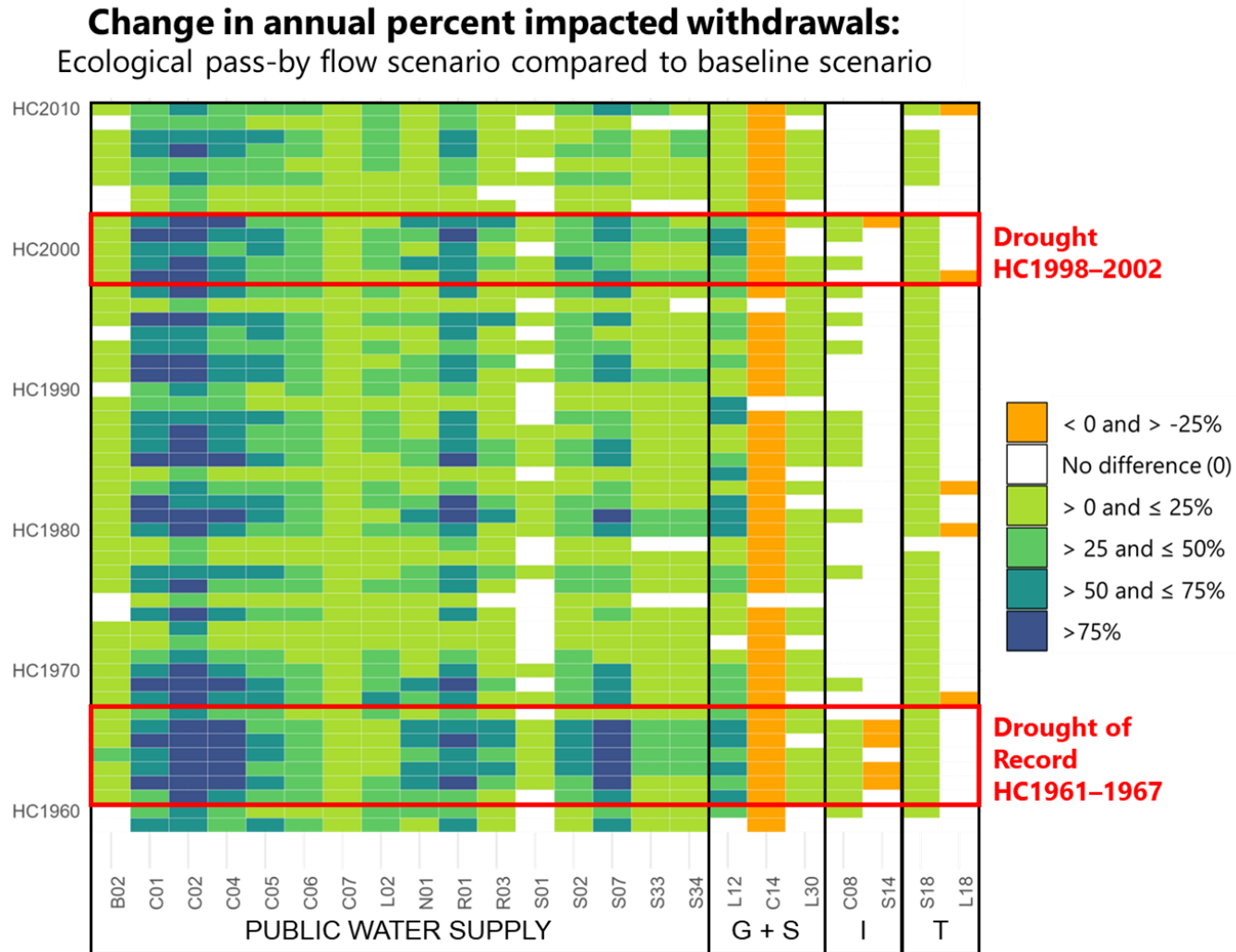


Figure 3-18. Change in annual percent impacted withdrawals in the ecological pass-by flows scenario for HC1960–2010.

Red boxes indicate the HC1961–1967 and 1998–2002 drought periods. SW Points are organized by sector. G= Golf, S = Ski, I = Industrial, and T = Thermoelectric power generation.

4. INTERPRETATIONS AND RECOMMENDATIONS

4.1 LITERATURE COMPARISON

In this section, we compare results from this study with other work relevant to surface water availability in the DRB region.

4.1.1 Schuylkill River Flow at Norristown, PA (S20)

Surface water availability for the lower Schuylkill River, notably for two major intakes for the Philadelphia Water Department (PWD), has been evaluated using a modeled flow objective at the USGS gage on the Schuylkill River at Norristown, PA (Hesson, 2013; Kali et al., 2023). The Norristown gage (S20) is located 10 miles upstream of the two PWD intakes, which withdraw an average of 59.2 MGD (S33) and 47.1 MGD (S34). The modeled flow objective at the Norristown gage is 484.9 cfs (313.4 MGD), which is enough to meet PWD's PBF requirement (100 cfs; 64.6 MGD) at the Fairmount Dam, PWD's maximum permitted withdrawal volume, and a safety factor to account for gage error and other uncertainties (Hesson, 2013).

In the SWEET baseline, 2060 withdrawals, and drought management scenarios, these two intakes were able to take their full intended withdrawal on every simulated day. Kali et al. (2023) developed a hydrologic model for the Schuylkill watershed to evaluate the performance of this modeled flow objective under historical and future conditions. They find that historically, over the 1990–2010 period, the flow objective is met 89.8% of the time. Using a repeat of hydrologic conditions from the same period and present-day water use, SWEET similarly predicts that the flow objective would be met 87% of the time (**Figure 4-1**). In this study, projected changes to withdrawals upstream of the Norristown gage do not result in meaningful change to the frequency with which the flow objective is met under future demand.

This analysis also allows for exploration of the volumetric shortfall in years that the modeled flow target at Norristown is not met. The bottom panel of **Figure 4-1** shows, for each year, how much additional water would be needed to meet the 484.9 cfs modeled flow target. **Table 4-1** shows the maximum annual volumetric shortfall for various modeled flow target values, ranging from 342.25 cfs (representing a 15% reduction in withdrawals from the maximum permitted volume considered above and no safety factor) to 484.9 cfs (the modeled flow target described above). The magnitude of both the safety factor and maximum demand have significant impacts on the additional volume of water needed to meet the resulting flow target. Up to 9.5 BGY would be needed to meet the modeled flow target described above, while up to 0.6 BGY would be needed to meet a 342.25 cfs flow target. DRBC presently has access to 2.2 BG of storage in Blue Marsh Reservoir.

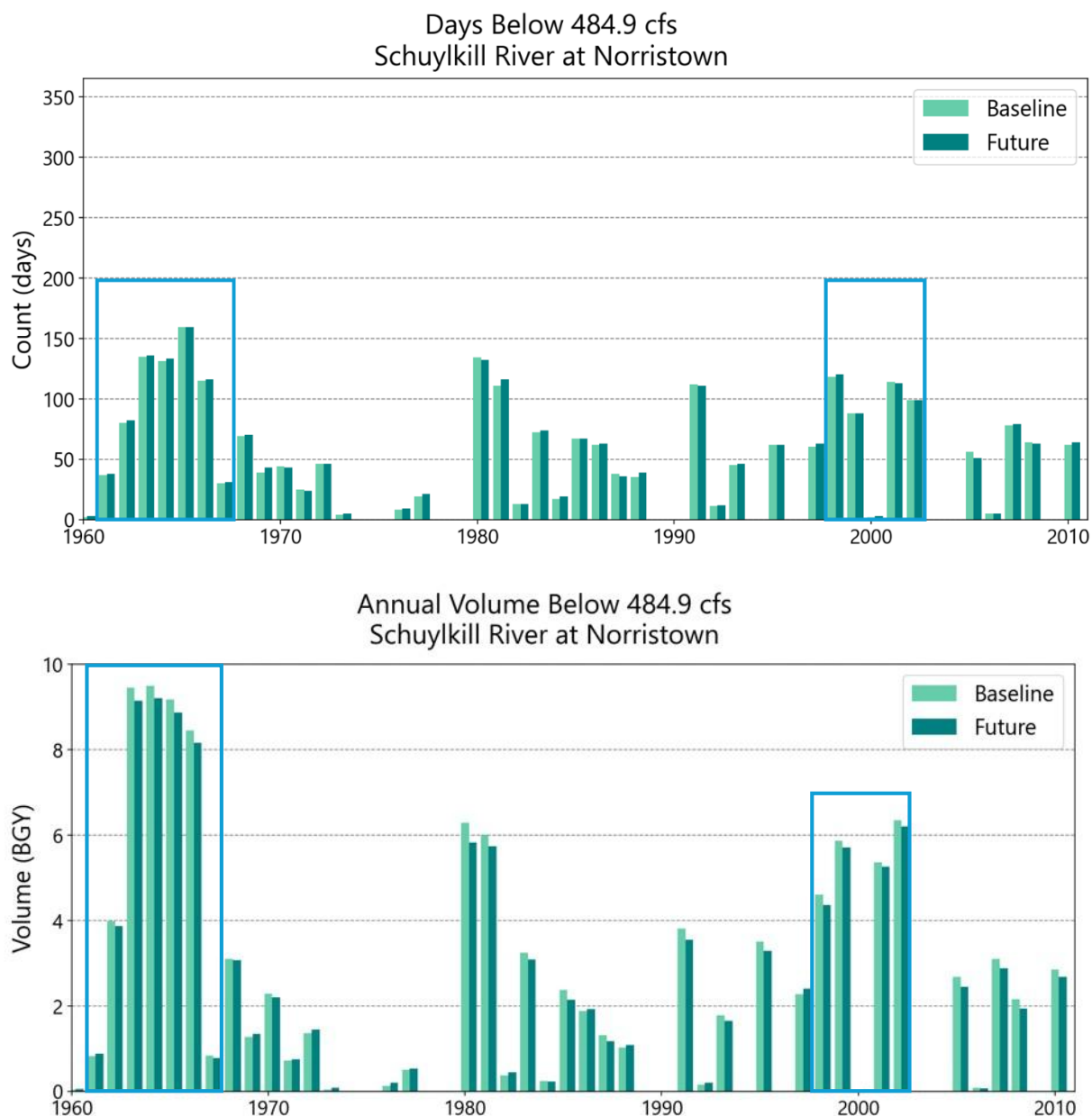


Figure 4-1. Modeled flow objective results for the Schuylkill River at Norristown, PA.

Light green bars show the baseline scenario and dark green bars show the future (2060 withdrawals) scenario. Blue outlines indicate the two drought periods of focus in this study. Top: For each year 1960–2010, the number of days each year that the SWEET model shows less than 484.9 cfs (313.4 MGD) at the Norristown gage is plotted. Bottom: For each year 1960–2010, the total volume of water that would be needed to meet the flow objective on every day of that year is plotted.

Table 4-1. Maximum annual volumetric shortfall for the Schuylkill River at Norristown, PA, relative to various modeled flow thresholds.

Threshold description	Value (cfs)	Maximum annual volumetric shortfall (BG)
PBF + Maximum demand + safety factor	484.9	9.5
PBF + 15% reduced demand + safety factor	442.25	6
PBF + 15% reduced demand + 50% reduced safety factor	392.25	2.6
PBF + 15% reduced demand + no safety factor	342.25	0.6

4.1.2 USGS's National Integrated Water Availability Assessment

The USGS recently released a national model and dataset, called the Integrated Water Availability assessment, evaluating water use and availability across the nation, with the DRB as a region of specific focus (Medalie et al., 2025). Part of this work involved a series of machine learning models to represent public water supply use as a function of population, land use, climate, infrastructure, and other factors (Alzraiee et al., 2024). The end product is monthly estimates of surface water use, groundwater use, and consumptive use for public water supply in each HUC-12 in the continental United States. An effort was made to compare the output from these national modeling tools with local withdrawal data specific to the DRB that was compiled for SWEET. However, several factors make a true apples-to-apples comparison impossible.

Most notably, the USGS estimates indicate where water is *used*, not where it is *withdrawn*. In contrast, SWEET use data are linked to withdrawal points, not end distribution points. To address this discrepancy, we performed the comparison on a large spatial scale, comparing the total modeled use across all 148 HUC-12s that comprise the six watersheds in this study to the sum total of PWS withdrawal volumes and consumptive use for all surface water and groundwater withdrawals in all 148 catchments in the SWEET model.⁴ At this scale, it is assumed that most water withdrawn within one of these six watersheds was also used in one of these six watersheds (with most being used within the same watershed). A bigger discrepancy is additional sources of water *withdrawn* from outside these watersheds, but are imported and *used* within these watersheds:

⁴ It is a coincidence that the 148 SWEET catchments cover the same spatial extent as 148 HUC-12s.

- There are several intakes on the main-stem Delaware River which supply water to parts of these watersheds:
 - Over one million Pennsylvania residents, many of them within these six watersheds, receive their water from the main-stem Delaware River. For example, the Baxter intake on the main-stem Delaware River supplies approximately 60% of water for the city of Philadelphia, a large portion of whose population resides within the Schuylkill River watershed.
 - Nearly 100,000 Pennsylvanians are served by the Easton Area Water System in the Lehigh River watershed which sources all of its water from the main-stem Delaware River.
- Chester Water Authority, whose service area overlaps with the Brandywine-Christina River and Chester-Ridley-Crum Creeks watersheds, imports up to 30 MGD (~11 BGY) from the Susquehanna River Basin (DRBC Docket D-1969-060 and SRBC Docket No. 19961104).

Because these water sources were not included in the SWEET withdrawal data but are included in the integrated water availability assessment, it is expected that SWEET data would provide an underestimate of the total consumptive use in these six watersheds. While the USGS directly modeled consumptive use, DRBC assumes that 10% of water withdrawn for public water supply is consumptive use. This assumption may be conservative and would also cause SWEET withdrawal data to provide an underestimate of PWS consumptive use. Finally, the SWEET withdrawal data rely on data from CY2018–2022, and USGS model estimates cover CY2000–2020. For a closer comparison, we use the final 5 years, CY2016–2020. For each month of the year, we took the average consumptive use from 5 values to compare and also compared the annual total.

Figure 4-2 shows a monthly comparison of surface water withdrawals, groundwater withdrawals, total withdrawals, and consumptive use from DRBC data and USGS models, summed across the six watersheds, and **Table 4-2** shows the annual totals. Though it was expected that SWEET data would provide an underestimate of PWS use, the compiled SWEET data show 20% greater total withdrawals than the USGS model (140 BGY compared to 113 BGY), suggesting that the USGS models represent a notable underestimate of water use within these watersheds. The breakdown between surface water and groundwater withdrawals shows that the USGS model overestimates groundwater use by about half and underestimates surface water use by about a third, with these discrepancies between the DRBC data and USGS model persisting throughout the year.

In terms of consumptive use, the annual totals from DRBC data and USGS model differ by just 5%. However, the monthly distribution of consumptive use in the USGS model looks very different from the DRBC estimates. The USGS models maximum consumptive use in July of over 2000 MG and minimum consumptive use in December of 515 MG. This represents a monthly peaking factor of 3.9. In comparison, DRBC consumptive use estimates reach a

maximum in July of 1316 MG and a minimum in November of 1106 MG, representing a monthly peaking factor of 1.2.

Aggregating the surface water and groundwater withdrawal data for the SWEET model required significant effort, including intensive QA/QC using local and regional knowledge of specific withdrawals, infrastructure, and regulations to ensure accuracy. Doing this level of work on a national scale would be impossible, illustrating the utility of tools such as the USGS's integrated water availability assessment. While this product may provide useful information to draw conclusions on a national scale, comparing model output with locally vetted withdrawal data demonstrates that at the regional scale there remains substantial uncertainty, and potentially inaccuracy. Thus, national model output has limited utility for regional stakeholders in the DRB. The USGS is currently conducting a multi-year, multi-phase assessment of water availability in the DRB (USGS, 2023), and we encourage collaboration with DRBC and other regional stakeholders to ensure accuracy and applicability when addressing these vital topics.

Figure 4-2. Comparison of public water supply withdrawals and consumptive use estimates from DRBC SWEET data and the USGS model.

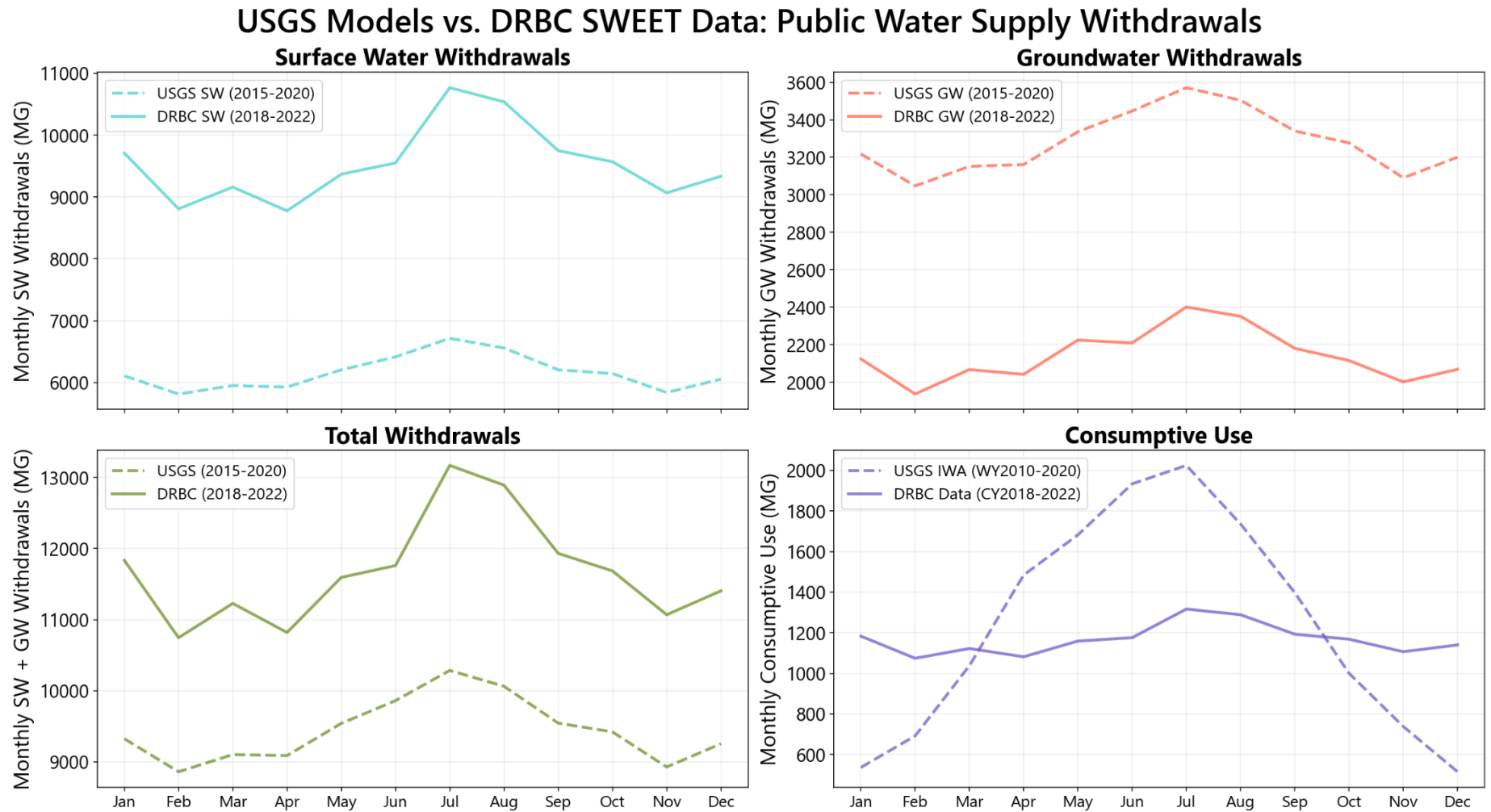


Table 4-2. Comparison of annual PWS withdrawals and consumptive use.

	Annual PWS Total (BGY)		Difference	
	DRBC Data	USGS Model	BGY	%
Consumptive use	14.0	14.8	0.8	5%
Withdrawals	140.1	113.3	-26.8	-19%
Surface water withdrawals	114.4	73.9	-40.5	-35%
Groundwater withdrawals	25.7	39.3	13.6	53%

4.1.3 Basin States' Water Availability Work

Pennsylvania

The Water Resources Planning Act, Act 220 of 2002, required the completion and adoption of a State Water Plan by March 2008. Additionally, it established processes for the designation of critical water planning areas (CWPAs) and the preparation and approval of critical area resource plans (CARPs) (27 Pa. Cons. Stat. § 3101, et seq.). CWPAs are defined as areas of the Commonwealth where existing or future demands exceed or threaten to exceed the safe yield of available water resources. CARPs are plans developed to address the key problem(s) identified during the CWPA designation process (PADEP, 2009a).

In 2003, the Pennsylvania Department of Environmental Protection (PADEP) entered into an agreement with the USGS Pennsylvania Water Science Center to develop a methodology for assessing statewide water use and availability, in support of identifying CWPAs. The resulting methodology, Water-Analysis Screening Tool (WAST), uses two primary inputs to assess a specified watershed area: (1) net withdrawals from the watershed, and (2) initial screening criteria (ISC) for the watershed (Stuckey, 2008). The ISC is taken as a percentage of the 7Q10, which was determined for over 10,000 watersheds across Pennsylvania (generally those larger than 15 mi²). The low flow statistics were calculated using the regression equations provided in Stuckey (2006).

In fall 2007, PADEP ran the WAST model statewide and screened out 90% of watersheds, shifting the focus of attention to the remaining 10% for further data verification and evaluation of mitigation effects. Regional sub-committees reviewed the results and created a shortlist of thirty-two watersheds that merited more intensive study (PADEP, 2009a). Of these thirty-two, six are in the Delaware River Basin, and all were included in the SWEET analysis: Brodhead Creek, Little Lehigh Creek, Neshaminy Creek, West Branch Brandywine Creek, Macoby

Creek (tributary to Perkiomen Creek), and Hay Creek (tributary to Schuylkill River). On this list, there is some overlap with the location of impacted PWS withdrawals in the SWEET analysis: Little Lehigh Creek (L02), West Branch Brandywine Creek (C07), and Hay Creek (S07). The overlap validates that multiple methodologies have found that these watersheds may face relatively greater water availability challenges than others in PA.

Ultimately, Brodhead Creek watershed, Little Lehigh Creek watershed, and parts of the Neshaminy Creek watershed were recommended by the Technical Subcommittee of the Statewide Water Resources for CWSA designation, accompanied by detailed reports of supporting documentation (PADEP, 2009b, 2009c, 2009d). None of the three were approved for CWSA designation; rather, the Brodhead Creek and Little Lehigh Creek watersheds were placed on the special watch list, and the Neshaminy Creek was not approved (PADEP, 2010).

New Jersey

In 2024, the New Jersey Department of Environmental Protection (NJDEP) released a water supply plan for the state, which includes a comprehensive analysis of natural water resource availability, current and future water demands, and expected impacts from climate change (Domber et al., 2024). The SWEET analysis did not include any points in New Jersey, as there are no public water supply withdrawals in New Jersey that are not from tidal waters, the main stem Delaware River, or an impoundment.

Delaware

The Delaware Department of Natural Resources and Environmental Control (DNREC) hosts a Water Supply Assessment and Protection (WSAP) program that assesses and protects public drinking water sources from surface water and groundwater wells. This program reviews permits for major water withdrawals, requires annual water usage reporting, and encourages water conservation and source water protection. The SWEET analysis included three systems in Delaware—Brandywine Creek (C04), White Clay Creek (C05), and Husbands Run (C14)—that are all subject to this program's review.

The Delaware Water Supply Coordinating Council (WSCC) was established to plan and manage water resources throughout the state to ensure supply is available during peak demand in periods of water shortage. The WSCC publishes annual reports with the projections for water supply and demand for each county of the state into the near future. Water availability research for surface water intakes is a top priority for the WSCC with a focus on self-sufficiency and functional drought operating plans.

4.1.4 Susquehanna River Basin Commission

In 2016, the SRBC published a Basin-wide assessment of water availability (Balay et al., 2016). Unlike the SWEET analysis, which focused on availability at specific withdrawal points, the SRBC analysis considered 170 watersheds that comprise the Susquehanna River Basin (SRB). In each watershed, current and projected consumptive water use was compared with

estimated water available during low flow conditions. This methodology is comparable to DRBC's approach to evaluating groundwater availability using 25- and 50-year baseflow recurrence intervals (Thompson et al., 2022). Most of the SRB (91%) was deemed to have adequate water supply to support allocated water use during dry times. Similarly, the DRBC groundwater and surface water availability studies have found that most of the DRB has adequate water availability to support water needs during dry conditions. The value of these Basin-scale screening studies is to highlight which localities merit more in-depth study.

4.1.5 Impacts of Climate Change

For any forward-looking water availability analysis, it is important to consider long-term trends in streamflow that may arise due to climate change, and it is recommended that future work with SWEET directly consider climate change impacts. A helpful place to start is evaluating observed trends in low flows over the last few decades, over which it is documented that temperatures have increased and precipitation patterns have shifted (IPCC, 2023). A forthcoming report from DRBC evaluates trends in flow statistics at tributary USGS gage locations across the DRB in the context of observed climate change. This work has demonstrated that for all selected gages except those located in the Atlantic Coastal Plain, low-flow metrics including annual 10th percentile flow and 7Q10 have increased over the past few decades. Those results are broadly consistent with Hammond and Fleming (2021), who found that across the DRB, 7-day low flows have increased and low-flow deficits have decreased as precipitation has increased over recent decades. However, in the Atlantic Coastal Plain, where water use and impervious area have increased, 7-day low flows have decreased. Similarly, McHugh et al. (2024) observed increasing high and low flows throughout New Jersey over the past century, with decreasing trends more common in the Coastal Plain. Taken together, these evaluations of the observed record show that climate change is associated with increasing low flows in most of the DRB and suggest that these increasing trends may continue.

Several studies have also evaluated how future climate change might impact flows in the DRB: Hawkins & Woltemade (2021) project an 8–17% increase in streamflow throughout the DRB and Williamson et al. (2016) project annual streamflow increases of 7 to 11% at three DRB locations. Notably, Hawkins & Woltemade (2021) project no change to flow or flow increases during every month of the year, while Williamson et al. (2016) project some flow decreases during April through November, depending on the location and methodological approach. In contrast, Kali et al. (2023) use climate model output to drive a hydrologic model of the Schuylkill River watershed and project that future low flows will decrease. However, like many hydrologic models, their model was not well-calibrated to low-flow periods and more accurately predicted streamflow during less-dry periods.

While these studies represent important first steps in characterizing future water availability in the DRB, many sources of uncertainty remain. Using hydrologic models to evaluate changes in streamflow, particularly during low-flow periods, is challenging under present day conditions, even with substantial observed data to drive sophisticated, well-calibrated models.

Hydrologic modeling under unprecedented future conditions presents additional challenges. Hydrologic models are commonly referred to as “rainfall–runoff models” because they are designed with a focus on these two processes that dominate streamflow generation during and after storms. However, different processes drive streamflow in drier times between storms, as low flows are heavily dependent on evapotranspiration, soils, and baseflow, processes that are less well-constrained in hydrologic models (Chegwidden et al., 2019; C. Chen et al., 2022).

The DRBC is currently developing a Water Resources Resilience Plan to evaluate the impacts of climate change and other challenges on the Delaware River Basin’s water resources and to formulate management approaches to improve resilience and adaptation to changing hydrologic conditions in the Basin (DRBC, 2026a). Analyses produced as part of the Water Resources Resilience Plan will support improved forward-looking water availability assessments for the DRB.

4.2 SUMMARY AND CONCLUSIONS

This report has outlined a methodology (SWEET) for evaluating surface water availability in the Delaware River Basin with a repeat of hydrologic conditions observed from 1960–2010, including the drought of record (1961–1967). This methodology was applied to evaluate whether streamflow during dry periods could support recent demand at 54 withdrawal points in six watersheds: Brodhead Creek (PA), Brandywine-Christina River (PA and DE), Lehigh River (PA), Neshaminy Creek (PA), Chester-Ridley-Crum Creeks (PA), and Schuylkill River (PA). These watersheds contain all run-of-river public water supply surface water intakes that withdraw from non-tidal tributaries to the Delaware River.

SWEET compares estimated available streamflow with intended withdrawal volumes (based on recent observed withdrawal data) each day to evaluate surface water availability. Although it is not quite an apples-to-apples comparison, SWEET streamflow estimations compare reasonably well with observed USGS gage data, indicating that the SWEET model adequately reproduces flow throughout these watersheds. SWEET conservatively estimates low flows, meaning it is more likely to underestimate than overestimate low flows. Thus, when a point is not projected to have any availability concerns during a repeat drought of record, this result has relatively high confidence. Conversely, when a point is projected to have availability concerns, it is an indication that additional consideration may be needed, but it is not a prediction.

Intended withdrawal volumes are based on a five-year average (2018–2022) of monthly water use for each point. Comparing withdrawal estimates used in this study with analogous estimates from the previous five years (2013–2017) showed significant changes to withdrawal volumes for many points in this study. Almost half of points had a change of more than 20% (increase or decrease) in total annual withdrawals when comparing 2018–2022 to 2013–2017. These large swings in withdrawal volumes over a relatively short time indicate that it is important to use up-to-date withdrawal data for any availability analyses and that these estimates may contain substantial uncertainty.

SWEET results from the baseline scenario show that the majority of run-of-river public water supply withdrawals from non-tidal tributaries to the Delaware River would likely be able to maintain supply during a repeat drought of record. Although several PWS intakes were flagged, most have alternative sources and site-specific drought management plans that were not accounted for in the model. A select few public water suppliers without interconnections may face supply challenges during a repeat drought of record, notably in the Lehigh River watershed. These suppliers are already undertaking additional site-specific studies to evaluate surface water availability and management options.

Nearly every point with impacted withdrawals in the baseline scenario has a pass-by flow requirement in place, indicating that PBFs are an important consideration for water availability during drought conditions. In the DRB, PBFs have historically been applied inconsistently, with only some intakes having them. Often, but not always, the PBF values are equivalent to the 7Q10 flow. SWEET is a valuable tool that can be used to evaluate the availability impacts of changing PBF requirements. If PBF requirements were to be universally applied throughout this region, it is likely that additional points would be flagged with potential water availability concerns. The Schuylkill River watershed would be particularly vulnerable, with 9 public water supply intakes that do not currently have a PBF requirement.

In addition to the baseline scenario, three additional scenarios were tested:

- **2060 Withdrawals:** Past withdrawal data were used to project possible withdrawal volumes in the year 2060, assuming that recent trends will continue. (These estimates have substantial uncertainty.) Total surface water withdrawals in the Brodhead Creek, Lehigh River, and Neshaminy Creek watersheds were projected to increase, while withdrawals in the Brandywine-Christina River, Chester-Ridley-Crum Creeks, and Schuylkill River watersheds were projected to decrease. Eight points with notable increases in projected withdrawal volumes would be expected to have increased availability challenges.
- **Drought Management:** Some pass-by flow and conservation release requirements in the Schuylkill River and Lehigh River watersheds change depending on whether DRBC has declared drought conditions are present. In this scenario, these PBFs and conservation releases were adjusted to reflect drought conditions. Decreased conservation releases increases the potential impacts to some downstream surface water intakes, while relaxed PBF requirements reduces impacts to other intakes.
- **Ecological Pass-by Flows:** Following recommendations from The Nature Conservancy that inspired the Susquehanna River Basin Commission's Low Flow Protection Policy, a set of hypothetical monthly pass-by flow requirements were devised for the DRB with the intention of evaluating further protections for aquatic life. Some withdrawal points, which withdraw relatively small volumes compared to streamflow each month, would not receive an ecological PBF. However, some points with a hypothetical ecological PBF imposed faced severe impacts, with limited ability to withdraw from the stream much of the time, even outside of drought conditions. This

evaluation confirmed that imposition of pass-by flow requirements needs to balance public water supply needs with aquatic life.

4.3 FUTURE WORK WITH THE SWEET MODEL

SWEET results can be used to inform planning efforts that seek to balance human and ecological needs, including considerations relating to siting and sizing future water supply projects and evaluation of pass-by flows, conservation releases, consumptive use mitigation triggers, wastewater assimilative capacity, and potential flow targets. Below are some potential future applications of the SWEET methodology:

1. Maintain the SWEET model for future applications.

In Section 2.4.3, a comparison of withdrawal data from 2013–2017 with analogous data from 2018–2022 demonstrated that “current conditions” often change rapidly. To keep the SWEET model relevant moving forward for any of the applications listed below, it is crucial to keep the model up to date for the watershed(s) of interest. Doing so will require, at minimum:

- Regularly updating surface water withdrawal points, catchments, and DRB-SET flows for each catchment to reflect any new withdrawals or any that are no longer in use;
- Regularly updating the withdrawal volumes for ground- and surface water withdrawals based on the most recent available data;
- Regularly updating return volumes and locations with the most recent available data; and
- Regularly reviewing the regulatory framework that is incorporated into SWEET, including pass-by flow requirements, conservation releases, and the intra-basin transfer.

2. Apply existing SWEET methodology to incorporate the impacts from recent dry periods.

We propose a method that could be applied to better understand how resilient specific public water systems are to conditions observed in more recent dry periods, such as 2016 and 2024. As noted in Section 2.9, a limitation of the SWEET method is that it cannot model hydrologic conditions occurring after WY2010 due to DRB-SET program constraints. This approach could assist water suppliers who are interested in more up-to-date availability analyses and rely on intake-specific operations data.

This methodology would consider USGS gage data or flow data at the intake (provided by the purveyor, if possible) along with qualitative information about times when low flows were problematic at this intake and the specific impacts that occurred. A cumulative probability function would first be generated for the relevant flow data. Using qualitative information, days when the purveyor experienced difficulties would

be identified on the plot. This analysis would help identify and characterize the challenges experienced in terms of flow. The data could then be directly compared to flows at this point generated by the SWEET model over HC1960–2010, to assess the following questions: (1) How frequently does SWEET predict that flow falls below the observed flow values at which specific challenges occurred? (2) How severe are the more recent dry periods at this location compared to SWEET predictions during hydrologic conditions from the drought of record? This method would not require additional SWEET model runs and could provide insight into which low flow levels would impact surface water availability and water quality.

3. Adapt the SWEET methodology to evaluate how much additional water may be needed to support the current surface water demand at a watershed scale during a repeat drought of record.

In this report, the two points with most significant water availability concerns, Hazleton City Authority's Lehigh River intake and Lehigh County Authority's Little Lehigh Creek intake, are located within the Lehigh River watershed. We recommend additional evaluation of surface water availability in this watershed.

As noted above, in addition to its Little Lehigh Creek intake, LCA operates a backup intake on the Lehigh River that did not have any impacted withdrawals in this study, based on recent withdrawal data from that intake. Future work could adapt the SWEET methodology to model backup intakes more accurately. For example, LCA's two surface water intakes would be treated as a single system with an intended withdrawal volume based on recent withdrawal data from both the primary and back-up intake. First, that intended withdrawal volume would be taken from the primary intake. If that withdrawal could not be entirely fulfilled at the primary intake, the remainder would be taken from the backup intake. Any remaining volume that could not be met by the backup intake would become impacted withdrawals.

This estimate of impacted withdrawals would give a more accurate accounting of the potential volumetric shortfall that could be expected during a repeat drought of record and would allow for watershed-level planning in the Lehigh River watershed. As noted in Section 4.4 below, accurate accounting in the Lehigh River watershed would also require improved flow estimations in the Little Lehigh Creek karst region.

4. Apply SWEET to evaluate how water loss impacts water availability.

DRBC collects water audit data from withdrawal systems to understand water loss and the opportunity for water loss conservation. Based on CY2022 data, DRBC found that public water supply systems across the Basin experience 176 MGD in real water losses, i.e. leakage. These findings could be applied to PWS systems included in SWEET to better understand how individual systems could decrease their withdrawal demand by improving upon their water conservation practices. A study could support the quantification of how water loss reduction on a system level can protect water availability for the Basin.

5. Apply SWEET to support evaluation of the cumulative impact of proposed surface water withdrawals on water availability throughout the watershed.

In accordance with the current Administrative Agreements with Basin states, if DRBC is the lead permitting agency for water withdrawals, DRBC approves dockets (permits) for surface water withdrawals above 100,000 gallons per day in any 30-day consecutive period. When a new (non-tidal, non-main stem, non-impoundment) surface water withdrawal is proposed SWEET could be applied to quantitatively evaluate the impact of that new withdrawal on streamflow at that location and on water availability downstream.

6. Explicitly incorporate the impacts of climate change on future surface water availability.

This study does not explicitly incorporate the potential impacts of climate change into surface water availability calculations. Doing so would require several updates to the methodology:

- Adjust or re-evaluate DRB-SET flows to represent future hydrologic conditions that reflect changing temperature and precipitation patterns.
- Adjust surface and groundwater withdrawal volumes to include responses to a changing climate (e.g., more water needed for irrigation, cooling, and public use in summer due to warmer temperatures).
- Adjust return volumes accordingly to reflect changes to withdrawal volumes.

4.4 RECOMMENDATIONS TO IMPROVE SURFACE WATER AVAILABILITY MODELING

Streamflow estimations from DRB-SET are the foundation of the SWEET model. **We recommend updating and improving this invaluable tool to support future surface water availability work in the DRB, including hydrologic conditions beyond WY2010.**

- DRB-SET could be improved with better representation of the impacts of bedrock geology, notably areas that are heavily influenced by springs and karst hydrogeology. The percentage of carbonate rock is included as a parameter in StreamStats but is not applied in DRB-SET. SWEET streamflow estimations were compared against gage data throughout the watersheds studied in this report and performed least well at Little Lehigh Creek, which is in a heavily karst-influenced region.
- The ability to apply DRB-SET to custom polygons is a critical feature in DRB-SET that should be maintained. This ability allowed this project to apply non-overlapping catchments and take an additive approach to incrementally summing streamflow.

SWEET results highlighted that pass-by flow and conservation release requirements are a critical component of surface water availability. If regulatory agencies adjust these requirements in the DRB, especially if imposing pass-by flow requirements for intakes that do not currently have one, the results of this surface water availability analysis would be significantly impacted. **If new or updated pass-by flow and conservation release requirements are considered in the future, it will be challenging yet crucial to balance both water availability and ecological needs.**

As currently configured, SWEET assumes that surface and groundwater have a 1:1 relationship, meaning that a specific groundwater withdrawal within a catchment has a volumetric impact on that catchment's surface water flows equal to the consumptive portion of groundwater extracted. This assumption supports SWEET's conservative nature, as groundwater withdrawals may in reality reduce surface water flows by no more than the total volume of groundwater withdrawn. However, this equivalency is likely an overestimate of groundwater withdrawals' impact on local surface water flows, because some aquifers can extend beyond surface water catchments defined by topography and may have varying degrees of connection to surface water (Sloto et al., 1991). Depending on the characteristics of the aquifer and direction of groundwater flow, some or all groundwater withdrawn could thus come from outside the surface water catchment, a likelihood that was not considered by the model. This disconnect was especially evident in the Little Lehigh Creek watershed, where groundwater withdrawal volumes often approached or exceeded DRB-SET inflows during dry periods. **A more accurate accounting of groundwater sources and impacts on surface water flows would be a challenging technical endeavor but would improve the accuracy of surface water availability analyses for points that were flagged in this study.**

An additional assumption built into the SWEET model is that non-consumptive use from SW and GW withdrawals is accounted for in NPDES return data along the same stream. **Having more accurate sewershed delineations, to specifically tie withdrawals to their associated returns, would allow for more accurate representation of consumptive and non-consumptive use within each watershed.**

This study considered all public water supply surface water intakes in the DRB that do *not* draw water from the main stem, a tidal water body, or an impoundment. **Yet it is also important to consider surface water availability at these excluded points.**

- **Impoundments:** The “safe yield” of a reservoir is generally considered the maximum amount of water that can be withdrawn over a specific period of time without causing long-term harmful effects. Understanding the safe yield of a reservoir helps inform water supply planning and the development of water supply allocations by regulatory agencies, including associated conservation release requirements. Depending on the safe yield determination method used, the safe yield calculation may not consider multi-year droughts, such as the DRBC's drought of record. Some hydrologic data in the DRB may not be available from the DoR (1961–1967), creating another challenge in determining the safe yield of reservoirs. Additional factors in

determining safe yields for reservoir systems are downstream needs, which can include both human and ecological considerations. Understanding how the Basin's regulatory agencies develop safe yield estimates for reservoirs operated by and relied upon by PWS systems is an important component of water availability assessments.

- Main stem (non-tidal): Water supply along the non-tidal main stem Delaware River is relatively robust, as reservoir releases are often made to support flow objectives at Montague, NJ, and Trenton, NJ. Intakes along the main stem are typically not subject to pass-by flow requirements. Thus, there is minimal concern in terms of water availability for these intakes.
- Tidal intakes: The largest challenge for tidal intakes is salinity, a water quality concern. During periods of low upstream freshwater flows, releases are made from reservoirs to meet the Trenton Equivalent Flow Objective, which was established in the Commission's Water Code to ensure sufficient freshwater inflow for salinity management and protect freshwater intakes in the Estuary. DRBC is evaluating the adequacy of this flow objective and these supply storage facilities to manage salinity through future changes, including sea level rise. A hydrodynamic model of the Delaware Estuary and its tidal tributaries would thus be the appropriate tool to evaluate surface water availability for these intakes. DRBC has developed a 3D salinity model to evaluate the impact of sea level rise on salinity intrusion (F. Chen, et al., 2025).

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