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# Appendices

## Appendix 1. Meeting Summaries

A. **March 2009 Orientation Meeting**

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C. **April 2010 Flow Recommendations Workshop**

## Appendix 1. Meeting Summaries

A. March 2009 Orientation Meeting

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C. April 2010 Flow Recommendations Workshop

# Susquehanna River Ecosystem Flows Study
# Orientation Meeting Summary

Monday, March 9, 2009
10 a.m. – 4 p.m.
Fort Hunter Centennial Barn, Harrisburg PA

## Meeting Objectives

The goal of the meeting was to (a) introduce the Susquehanna River Basin Ecosystem Flows Study process, describe intended outcomes and receive feedback from project advisors, (b) identify resources – both expert knowledge and existing data – that support the study, and (c) gather follow-up items / leads for staff to pursue in developing literature and model review.

## Presentation Summary

The meeting began with presentations from the three main project partners: the U.S. Army Corps of Engineers, the Susquehanna River Basin Commission, and The Nature Conservancy.

### Review of Susquehanna River Basin Low Flow Management Study

*Dan Bierly, U.S. Army Corps of Engineers (for Steve Garbarino)*

The USACE and the Susquehanna River Basin Commission (SRBC) entered into a cost-share agreement in December of 2008 to conduct a study of the Susquehanna River Basin under the Section 729 authority of the Water Resource Development Act. This authority authorizes an assessment of water resource needs of river basins and is unique to the Corps in that it does not involve construction of new infrastructure. The approach of this particular 729 study is to assess the Basin and develop recommendations to allow water managers to establish environmental flow release schemes that meet both human and ecosystem needs. This phase of the study emphasizes ecological impacts of changes to low flow conditions. The SRBC is interested in pursuing a second phase, which would focus on implementation of these recommendations using consumptive use mitigation and consideration of ecosystem needs. The estimated study cost is $380,000, with a 75:25 Federal- Non-Federal cost-share. The Nature Conservancy is not a signatory to the agreement but is a member of the Study Team and a contractor to the SRBC.

### Overview of Existing Water Management Programs in the Susquehanna River

*Drew Dehoff, Susquehanna River Basin Commission*

In response to surface and groundwater withdrawals, consumptive use, reservoir operations, land use and potentially climate change, we're noticing ecological impacts including: depletion of flow and aquatic habitat, alteration of the natural flow regime, temperature modifications, loss of dilution flows and concentration of pollutants.

The SRBC is currently managing resources in an effort to achieve sustainable water resource development. Current programs include their consumptive use mitigation program and a water withdrawal review program which includes pass-by guidance. The **Consumptive Use Regulation Program requires** the user to mitigate for that portion of their use that is consumptive, particularly during low flows. During defined low flow periods, the user is required to replace their consumptive use, either by stopping their use, releasing stored water, or paying a consumptive use fee which SRBC applies to aggregated mitigation (usually a reservoir release). Existing mitigation under this program occurs through releases from SRBC water stored in Cowanesque Lake and Curwensville reservoirs (owned and operated by USACE), and is specific to major water users in the basin (power plants). This water is released under a current operating agreement with USACE, when flows at the Harrisburg or Wilkes-Barre stream gages falls below Q7-10. The releases provide a 1-for-1 compensation for consumptive use at that time, they do not maintain Q7-10. It is important to note that at this time, the consumptive use associated with agricultural uses are not addressed in this program, however SRBC is starting to develop agreements to do so through treated releases from the Barnes and Tucker mine. Further, a new consumptive user, Marcellus shale extraction, is emerging in the Basin.

**Under the water withdrawal review and pass-by guidance**, SRBC assesses the potential of the withdrawal, whether ground or surface water, to adversely affect associated systems. Their current threshold for requiring a user to provide pass-by flows is 10% of Q7-10. For groundwater withdrawals pump tests are conducted, and for surface water withdrawals, the PA/MD instream flow model is used for small coldwater streams. The Tennant method is used for other systems, and 20% ADF (average daily flow) is a common pass-by requirement.

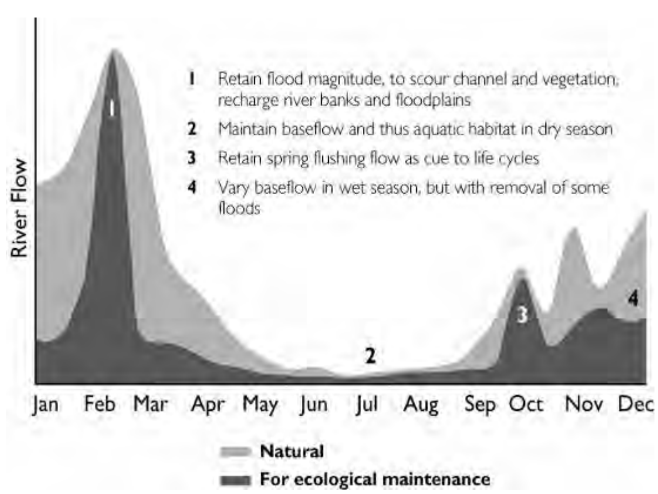
In addition to assessing impacts at the withdrawal point, SRBC also conducts a cumulative impact assessment to determine the extent of impact in combination with other basin users. This process is evolving. The Commission has identified water stressed basins (at the HUC8 scale). There are several **current challenges** to sustainably managing water in the Basin. Within the Basin there are dual (Q-FERC vs. Q7-10) and conflicting instream flow requirements, the latter of which is based on statistics and not ecosystem needs. Site-specific understanding of ecosystem needs is limited to cold-headwater streams (PA and MD instream flow model), specifically fish habitat. The statistical triggers for determining drought status are incompatible with the low-flow release trigger.

The **goal of the Low Flow Management Study** will be to better characterize flow alteration in the Basin, identify ecologically-based indicators and objectives, and attempt to meet localized and specific needs and will help SRBC to answer management questions such as: Is it appropriate to put caps or other limits on consumptive use? The influence of this study on flow requirements for the upper Chesapeake Bay is limited by the operation of Conowingo Dam. However, as Conowingo will undergo FERC relicensing in the near future, this study is seen as an opportunity to inform future operations. Additionally, SRBC is working with TNC staff to define flow needs for the Upper Chesapeake Bay.

## Ecologically Sustainable Water Management-Proposed Process for Assessing Environmental Flow Needs

*Michele DePhilip, The Nature Conservancy (TNC)*

The SRBC has contracted TNC in an effort to meet the goals of the Low Flow Management Study. With a mission to preserve biodiversity, TNC has identified a major gap in the protection of water quantity in relation to biological integrity. In an effort to fill that gap, TNC has developed the Ecologically Sustainable Water Management approach to meet both human and ecological needs by protecting



environmental flows. Environmental flows are defined as the flow of water in a natural river or lake that sustains healthy ecosystems and the goods and services that humans derive from them. Recognizing that we need to continue to use water, **the goal in restoring the natural variation in the hydrograph is not to restore natural, or pre-disturbance, flows all of the time, but rather create adequate conditions of all species enough of the time.**

TNC has implemented these concepts in several projects throughout the country under the Sustainable Rivers Project. The **Sustainable Rivers Project** is a partnership between TNC and the USACE to develop environmental flow recommendations and manage reservoirs in a way that meets both human and ecological needs[1]. The SRP uses the general approach of identifying ecosystem flow requirements, determining the influence of human activities, and identifying gaps or potential areas of incompatibility.

The SRP projects are all at different stages with respect to developing and implementing environmental flow recommendations and monitoring management changes. Case studies from the Savannah River (Georgia and South Carolina), the Green River (Kentucky) and the Willamette River (Oregon) were used to illustrate various steps for developing environmental flow recommendations.

These and other case studies share a common analytical framework, with each taking an individual approach to implementation. It's important to note that environmental flow recommendations are developed using existing information. The approach is to make recommendations in a way that documents the varying degrees of confidence around the recommendations. This allows an opportunity to implement those recommendations with greater confidence first, and time to gather additional information or conduct research on those with less confidence.

One key difference between this project in the Susquehanna River basin and the other case studies is that this project was not driven by a need for reoperations of a specific dam, but to provide an ecological foundation for basin-wide resource management. There is an emphasis on low flow conditions to meet the needs of SRBC, however the scope is not limited to assessing low flow conditions. We recognize that we will have information gaps, but this project benefits from the wealth of experience of the project partners and advisors.

In the first six months, the proposed process includes a hydrologic characterization and literature and model review. The goal of the **hydrologic characterization** is to summarize the range of baseline and current flow variability in the subwatersheds and along selected points on the mainstem. This will provide information on low, average, high and flood conditions, in addition to an understanding of magnitude, timing, frequency, duration and rate of change between flow conditions using gage and model data. The **literature and model review** will synthesize existing data literature and knowledge of flow-dependent species and relationships to support the development of basin-wide ecosystem flow recommendations. Both the hydrologic characterization and the literature and model review will result in summary reports to support flow recommendations for target species, habitats and river processes. Draft reports will be completed by August 2009. TNC has several good examples of summary reports developed for other rivers, including the Connecticut River, Savannah River, Willamette River, and Rivanna River (Virginia).

In August / September 2009, we plan to host a 1.5 day workshop to develop a set of hypotheses about potential responses to flow alteration that will help focus the remainder of the study. Hypotheses will be

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[1] More information about the Sustainable Rivers Project is available at http://www.nature.org/success/dams.html

based on information in the literature and model review, results of the hydrologic characterization, and input from the project advisors. At this workshop, we will also identify potential analyses that can be done using existing data to test these hypotheses.

In March 2010, we will host a second workshop to develop draft flow recommendations and assess the level of confidence in these recommendations. Recommendations will be included in the final report to SRBC and USACE.

## Project Timeline

**March 2009:** form project team and hold orientation meeting, begin literature and model review and assessment of flow alteration
**Aug / Sept 2009:** Complete draft summary report to support flow recommendations, hold first workshop to develop flow hypotheses
**March 2010:** Conduct analyses to test hypotheses, complete lit/model review and assessment of flow alteration, hold second workshop to develop flow recommendations
**April 2010:** TNC submits summary report and flow recommendations to SRBC and USACE

## Project Partners and Roles

**USACE:** Overall project coordination, Translate technical findings to scope for Phase 2
**SRBC:** Participate in assessment of hydrologic characterization, Provide direction to ensure development of useful flow recommendations
**TNC:** Lead technical portion of study. Summarize information on ecological flow needs, lead assessment of hydrologic characterization, host workshops, compile summary report and flow recommendations
**Project advisors:** This group is informal and includes those parties with information or expertise related to flow dependent species and processes in the Basin – including meeting participants and others unable to attend. Provide feedback for improving process, contribute information on ecosystem flow needs, provide input on flow hypotheses and flow recommendations through workshops and review

## Break-Out Group Summary

In the afternoon, participants divided into three breakout groups to:

- Identify flow-dependent species and communities that should be considered in this process
- Share existing sources of information to support the development of draft flow recommendations
- Identify potential data gaps

Each group had a facilitator and notetaker and was charged with the same task. **Below, we have combined and summarized highlights from the three group discussions.** This list includes potentially flow-sensitive taxa and conditions. For example, some invasive species may be flow-sensitive; particular flow conditions may facilitate their establishment or and other flows could help minimize their ecological impacts.

**I. Biological/Ecological Conditions**

Aquatic Invertebrates:

Mussels
Macroinvertebrates
Dragonflies (as a backwater indicator species)

Aquatic Vertebrates:

Resident Fish- brown, brook and rainbow trout, quillback sucker
Recreational Fish- walleye, smallmouth bass
Migratory Fish- American eel, shad, herring
Reptiles and amphibians (hellbenders)

Aquatic Vegetation:
Algae, Eel grass, invasive species

Terrestrial Vegetation
Invasive species (purple loosestrife)
Floodplain forests

Terrestrial Vertebrates
Waterfowl

**II. Physical Processes and Conditions**
Habitat Forming Flows
Water Quality
Suspended Sediment and Nutrients (algal blooms)
Assimilative Capacity, CSO's
Acid Mine Drainage
Temperature

**III. Reaches of Interest**
Susquehanna flats (Upper Chesapeake Bay), Middle Susquehanna,
Streams in NY that might be intermittent or glacial in nature

## List of Suggested Data & Literature and Academic & Professional Contacts

Participants provided the following names, contact information, and reports / studies related to each of these resources and topics

## BIOLOGICAL CONDITION AND PROCESSES

### Macroinvertebrates

| | |
|---|---|
| *Academics/Professional Contacts* | Mike Bilger, Aquatic Biologist, Manager EcoAnalysts' Northeast Office |
| | DEP: Dan Bogar, Aquatic Biologist, Clark Schiffer- DEP retired, dragonfly communities |
| *Data and Literature* | DEP Macroinvertebrate Samples- mostly on tributaries, georeferenced |
| | SRBC Basin-wide macroinvertebrate data |
| | Poff, N.L., J.D. Olden, N.K.M. Vierra, D.S. Finn, M.P.Simmons, and C.C. Kindratieff. 2006. Functional trait niches of North American lotic insects: traits-based ecological applications in light of phylogenetic relationships. Journal of the North American Benthological Society 25: 730-755. |

### Mussels

| | |
|---|---|
| *Data and Literature* | Cole, J.C., P.A. Townsend, K.N Eshleman, 2008. Predicting Flow and Temperature Regimes at Three Alasmidonata heterodon Locations in the Delaware River. Technical Report NPS/NEP/NRTR--2008/109. National Park Service. Philadelphia, PA. |

### Fish

| | |
|---|---|
| *Academics/Professional Contacts* | WPC/PNHP: Mary Walsh, Community Classification and Element Occurrences |
| | DEP Water Management Program, William Botts, Water Pollution biologist; Joe Hepp and Bob Schott Regional Biologists |
| | PAFBC: Doug Fischer, Biologist; Michael Hendricks, Biologist; Kris Kuhn-Lower Susquehanna; Jason Detar-West Branch; Rob Wnuk-North Branch, Geoff Smith-Susquehanna River Biologist |
| | Susquehanna River Institute: Dr. Brian Mangan, Director SRI, King's College Wilkes-Barre |
| | Penn State: Jay Stauffer, Professor of Ichthyology; Tim Stecko, Instructor and Researcher |
| | PA Amer. Fisheries Soc and PAFBC: Geoff Smith, Aquatic Ecologist |
| | York College: Dannacourt, (retired)- focused studies of fish of Susquehanna |
| | Ted Jacobsen- Consultant for Berwick power station 316b Entrainment Studies |
| *Data and Literature* | PAFBC: Index sites for smallmouth catch per unit effort in relation to flows- multi year study (Mark Hartle) |
| | DEP fish survey reports and data |
| | Cooper, Edwin 1983. Fishes of Pennsylvania and the Northeastern US. Penn State University Press |
| | Zorn, T.G., P.W. Seelbach, E.S. Rutherford, T.C. Wills, S.T. Cheng, and M.J. Wiley. In preparation. A regional scale habitat suitability model to assess the effects of flow reduction on fish assemblages in Michigan streams. |

### Amphibians and Reptiles

| | |
|---|---|
| *Academics/Professional Contacts* | Dr. Peter Petokas, Department of Biology, Lycoming College |
| | Chris Urban, PA FBC and PA Natural Heritage, Chief, Natural Diversity Section |

### Algae

| | |
|---|---|
| *Academics/Professional Contacts* | Dr. Jack Holt, Susquehanna University |
| | Dr. Hunter Carrick, Penn State |

### Birds

| | |
|---|---|
| *Academics/Professional Contacts* | Audubon Society |
| | DCNR |

### Riparian and Floodplain

| | |
|---|---|
| *Academics/Professional Contacts* | Chris Firestone, Botanist, DCNR, Bureau of Forestry |
| | Susquehanna Water Trails (canoe group) installing plots to track purple loosestrife |
| *Data and Literature* | DEP Dams and Waterways may have some floodplain mapping- also have a specific layer of the 1000's of lowhead dams in the state |

## PHYSICAL CONDITION AND PROCESSES

### Fluvial Geomorphology

| | |
|---|---|
| *Academics/Professional Contacts* | Craig Kochel, Bucknell University |

| | |
|---|---|
| *Data and Literature* | Recent Publication regarding the movement of legacy sediments through the Susquehanna River (Ben Hayes) |

## Suspended Sediment, Nutrients, Temp

| | |
|---|---|
| *Academics/Professional Contacts* | USGS: Contact for Backwater DO Studies and Floodplain Connectedness |
| | Elizabeth Boyer, Penn State |

## Acid Mine Drainage

| | |
|---|---|
| *Academics/Professional Contacts* | Scott Roberts, DEP Deputy Secretary for Mineral Resources Management |
| | Thomas Clark, SRBC |

# WATER USE AND HYDROLOGY

| | |
|---|---|
| *Academics/Professional Contacts* | PA Instream Flows Technical Committee |
| | USGS: Marla Stuckey, Hydrologist and Stream Stats lead |
| | Susquehanna River Heartland Coalition for Environmental Studies-Consortium |
| | Susan Veleski: Copies of environmental studies for power plant construction |
| | Dr. Thorsten Wagner, Penn State (climate change) |
| | NRCS- Land use |
| *Data and Literature* | HSPF- Chesapeake Bay Program |
| | OASIS- SRBC |
| | Susquehanna Literature Review- Access Database (Ben Hayes, Bucknell University) |
| | USGS Stream gage data, USACE Reservoir Daily State levels and inflow data |
| | USGS Study- Influence of Juniata inflows to the mainstem |
| | Whitney Point Low Flow Release Study (Drew Dehoff, SRBC) |
| | Denslinger, T.L., W.A. Gast, J.J. Hauenstein, D.W. Heicher, J. Henriksen, D.R. Jackson, G.J. Lazorchick, J.E. McSparran, T.W. Stoe, and L.M. Young. 1998. Instream flow studies: Pennsylvania and Maryland. Susquehanna River Basin Commission, Harrisburg, PA. |
| | Lake, P.S. 2003. Ecological effects of perturbation by drought in flowing waters. Freshwater Biology 48: 1161-1172. |
| | Olden, J.D. and N.L. Poff. 2003. Redundancy and the choice of hydrologic indices for characterizing streamflow regimes. River Research and Applications 19:101-121. |
| | Roland, M.R. and Stuckey, M.H. 2008. Regression Equations for Estimating Flood Flows at Selected Recurrence Intervals for Ungaged Streams in Pennsylvania. Scientific Investigations Report 2008-5102. U.S. Geological Survey, Washington, D.C. |
| | Sloto, R.A. 2004. Geohydrology of the French Creek Basin and simulated effects of drought and ground-water withdrawals, Chester Country, Pennsylvania. Water Resources Investigations Report 03-4263. U.S. Geological Survey, Washington, D.C. |
| | Sloto, R.A. and D.E. Buxton. 2005. Water budgets for selected watersheds in the Delaware River Basin, Eastern Pennsylvania and Western New Jersey. Scientific Investigations Report 2005-5113. U.S. Geological Survey, Washington, D.C. |

Stuckey, M.H. 2006. Low-flow, base-flow, and mean-flow regression equations for Pennsylvania Streams. Scientific Investigations Report 2006-5130. U.S. Geological Survey, Washington, D.C.

Weiskel, P.K., R.M. Vogel, P.A. Steeves, P.J. Zarriello, L.A. DeSimone, and K.G. Reis, III. 2007. Water use regimes: characterizing direct human interaction with hydrologic systems. Water Resources Research 43: 1-11.

Young, L. 2006. Pennsylvania Statewide Instream Flow Studies Issues Paper. Division of Fisheries Management, Pennsylvania Fish and Boat Commission, Harrisburg, PA.

## STREAM CLASSIFICATION

*Data and Literature*

Walsh, M.C., J. Deeds, and B. Nightingale. 2007a. Classifying Lotic Systems for Conservation: Methods and Results of the Pennsylvania Aquatic Community Classification. Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy, Middletown, PA and Pittsburgh PA.

Walsh, M.C., J.Deeds, and B. Nightengale. 2007b. User's Manual and Data Guide to the Pennsylvania Aquatic Community Classification. Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy, Middletown, PA and Pittsburgh, PA.

Wolock, D.M. 2003. Hydrologic landscape regions of the United States. Open-File Report 03-145. U.S. Geological Survey, Washington D.C.

## Other Follow-up Items and Summary Points

- TNC will follow up with staff from the Sustainable Rivers Project (TNC-USACE) to determine if there is an opportunity to become an SRP site, the criteria for being included, the advantages of doing so, and the process / timing. TNC will share this information with SRBC, USACE and project advisors.
- For those parties unable to make it to the orientation meeting, TNC will visit and speak with them directly regarding information and knowledge available to support the project. We anticipate meeting with staff from NYSDEC, faculty from Penn State University, members of the Heartland Coalition and representatives from the natural resource agencies in Maryland.
- A similar flow study is beginning for the Potomac River basin. Some staff from TNC and USACE will be involved in both studies, and there is potential for a lot of efficiencies and shared information between the two studies. TNC, USACE, SRBC and ICPRB will work together to figure out common tasks and share the labor.
- The study will first focus on the scientific basis to support ecological flow needs .TNC will consult with SRBC and PA DEP to identify any active watershed groups and other non-government organizations that may have data or technical expertise to this phase of the project. Project partners anticipate that more stakeholder engagement will follow in the second phase of this study when potential management changes / reoperation alternatives are considered.
- TNC will assess hydrological alterations in general; this includes alterations coming from multiple sources such as reservoir operation and consumptive use (which are part of SRBC's water management programs), as well as land use and development. While the focus will on the consumptive use impact, the analysis might help to understand the relative contribution of land use and development
- Climate change is seen as a future change in baseline conditions. This project will assess the issue by documenting current ecological needs/demands. If a model becomes available to project future hydrology under a climate change scenario, we could compare the need deficit today to that of the future.

# Meeting Attendees

| | Name | Agency / Organization / Affiliation | Email |
|---|---|---|---|
| 1 | Ben Hayes | Bucknell | brh010@bucknell.edu |
| 2 | Curtis Schreffler | USGS-PA Water Science Ctr | clschref@usgs.gov |
| 3 | Dan Bierly | USACE - Baltimore District | Daniel.M.Bierly@usace.army.mil |
| 4 | Dave Ladd | SRBC | dladd@srbc.net |
| 5 | Drew Dehoff | SRBC | adehoff@srbc.net |
| 6 | Herb Sachs | Maryland Department of Environment | hsachs@mde.state.md.us |
| 7 | Hoss Lighat | PA Dept of Environmental Protection | aliaghat@state.pa.us |
| 8 | Jason Zhang | SRBC | jzhang@srbc.net |
| 9 | Jim Cummins | Interstate Commission on the Potomac River Basin | Jcummins@ICPRB.org |
| 10 | Julie Zimmerman | TNC, Maryland | Jzimmerman@tnc.org |
| 11 | Larry Miller | USFWS | Larry_M_Miller@fws.gov |
| 12 | Mark Bryer | TNC, Chesapeake Bay Program | mbryer@tnc.org |
| 13 | Mark Hartle | PA Fish & Boat Commission | mhartle@state.pa.us |
| 14 | Michele DePhilip | TNC, Pennsylvania | mdephilip@tnc.org |
| 15 | Rick Shertzer | PA Dept of Environmental Protection | rshertzer@state.pa.us |
| 16 | Rod Kime | PA Dept of Environmental Protection | rkime@state.pa.us |
| 17 | Stephanie Flack | TNC, Maryland | sflack@tnc.org |
| 18 | Tara Moberg | TNC, Pennsylvania | tmoberg@tnc.org |
| 19 | Yvonne Grant | USACE - Baltimore District | Yvonne.Y.Grant@usace.army.mil |
| 20 | Dave Heicher | SRBC | DHeicher@srbc.net |
| 21 | Matt McTammany | Bucknell | mmctamma@bucknell.edu |
| 22 | Matt Shank | SRBC | mshank@srbc.net |
| 23 | Andrew Roach | USACE - Baltimore District | Andrew.A.Roach@usace.army.mil |
| 24 | Jennifer Hoffman | SRBC | jhoffman@srbc.net |

# Susquehanna River Ecosystem Flows Study
## Flow Hypotheses Workshop–Meeting Summary
Wednesday and Thursday, October 14-15, 2009
Kings Gap Environmental Education Center, Carlisle, Pennsylvania

## Workshop Objectives
The goals of the workshop were to (a) draft hypotheses about the relationships between flow and the species, ecosystems, and physical processes in the Susquehanna River watershed using professional experience and workshop materials; (b) prioritize additional information to include in draft summary report; and (c) identify analyses that would support development of flow recommendations.

Attachment A includes a list of workshop participants.

## Presentation Summary

**Application of the Ecosystem Flow Study to Water Management Programs in the Susquehanna River Basin** *Mike Brownell, Susquehanna River Basin Commission (SRBC)*

SRBC began the workshop by reiterating the importance and application of the Susquehanna River Basin Ecosystem Flow Study to their current and future water management programs in the Basin, specifically the Consumptive Use Regulation Program and their Passby Guidance for water withdrawal permits. Currently, the basis for these programs range from species specific-habitat models (for cold headwater streams) to general rules based on streamflow statistics (i.e. passby of 20% average daily flow). SRBC is looking for a more consistent and ecologically-based approach to apply to all habitat types within the Basin. Further, demand for withdrawal permits from SRBC is increasing, especially for withdrawals associated with gas well development in the Marcellus Shale formation and power generation.

**Review of Project Goals, Schedule and Progress since March 2009 Orientation meeting**
*Michele DePhilip and Tara Moberg, The Nature Conservancy*

*Project Scope and Schedule*
The overarching goal of the Susquehanna River Ecosystem Flow Study is to develop flow recommendations for major habitat types within the Basin based on the needs of aquatic ecosystems. The process of developing flow recommendations includes a literature and model review to identify the flow needs of aquatic ecosystems within the Basin and a hydrologic assessment of how flow conditions have or are likely to change. Generally, flow needs are defined as the timing, magnitude, frequency, duration and rate of change of streamflow events that sustain healthy ecosystems. While there is an emphasis on low flow conditions as described in the needs of the Susquehanna River Basin Low Flow Management and Environmental Restoration Study[1], the scope is of this Project is not limited to assessing low flow conditions. A brief outline of the project schedule from start to finish is outlined in Table 1.

[1] The USACE and the Susquehanna River Basin Commission (SRBC) entered into a cost-share agreement in December 2008 to conduct a study of the Susquehanna River Basin under the Section 729 authority of the Water Resource Development Act. This approach of this particular 729 study emphasizes ecological impacts of changes to low flow conditions. SRBC has contracted with TNC to contribute to the technical portion of this study.

**Table 1. Susquehanna River Ecosystem Flow Study Project Schedule**

| | |
|---|---|
| Oct., 2008 | Study agreement signed between SRBC and The Nature Conservancy |
| Mar., 2009 | Project Orientation Meeting- The goal of the meeting was to (a) introduce the Susquehanna River Basin Ecosystem Flows Study process, describe intended outcomes and receive feedback from project advisors, (b) identify resources – both expert knowledge and existing data – that support the study, and (c) gather follow-up items / leads for staff to pursue in developing literature and model review |
| Mar.-Sept., 2009 | Conduct literature review, consult with academic and professional experts and summarize flow-sensitive biological and physical processes in the Basin |
| **Oct., 2009** | **Flow-Hypotheses Workshop with Project Advisors** |
| Oct.-Feb., 2010 | Continue literature review and academic and professional expert consultation, verify hypotheses, complete hydrologic characterization and draft summary report. |
| Mar., 2010 | Flow -Recommendations Workshop with Project Advisors |
| Apr., 2010 | Final Report to SRBC and USACE |

### *Progress since March 2009 Orientation Meeting*

The Orientation Meeting provided an excellent launching point for the literature review by identifying flow-sensitive resources within the Basin including biological resources (migratory and recreational fishes, mussels, reptiles and amphibians, floodplain forests) and physical and chemical processes (stream temperature, channel-forming flows, and acid mine drainage). Of those resources identified, the majority of literature review and summary to date has focused on fishes (migratory and resident, including recreational), aquatic insects, mussels, and vegetation (aquatic, riparian and floodplain vegetation). The intent is to continue literature review and consultation on all flow-sensitive resources after this workshop.

This workshop provides the opportunity to receive feedback on the information synthesized to date and the process used to aggregate that information. We followed a similar literature review process for each taxonomic group, starting with a follow up on the literature and contacts recommended at the Orientation Meeting. With relevant literature and academic and professional expert advice, we developed draft species lists with the goal of selecting species representative of the range of characteristic traits in the Basin (Table 2, *first column*). We then conducted a targeted literature review focusing on life histories of selected species, using published papers, in- and out-of-basin studies and reports, and gray literature. We used that information to aggregate species into groups based on similar life history traits, flow sensitivities and needs (Table 2, *second column*) and to develop the life history tables found in the materials distributed prior to the workshop. Major sources used to define species traits are outlined in Table 2, third column. A complete list of references to date and their full citations can be found in the Workshop Materials.

**Table 2: Summary of flow-sensitive taxa groups, relevant traits, and major information sources.** A complete list of species associated with each group, as well as full citations can be found in the Workshop Materials.

| | Traits | Flow-sensitive Groups | Major Sources |
|---|---|---|---|
| **Fishes** | body size,<br>fecundity,<br>home range,<br>habitat associations,<br>feeding habit,<br>flow-velocity tolerance | *Cold headwater*- similar needs defined by temperature thresholds<br><br>*Riffle Obligates*- small bodied, flow-velocity specialists who spend most of their life in riffle/run habitat<br><br>*Riffle Associates*- moderate-sized home range, species that migrate from large to small tributaries/headwaters to spawn in riffle habitats, share sensitivity in these habitats during spawning periods<br><br>*Nest Builders*- similar sensitivity in timing of flow needs (during nest building, spawning, and egg and larval development), but a diverse group in terms of nesting strategy<br><br>*Migratory (Diadromous)*- large-bodied, large home range species with sensitivity to connectivity during in- and out-migration, and during spawning (alosids) | Vadas and Orth 2000, Frimpong and Angermeier in review, Walsh et al 2007, Hitt and Angermeier 2008, PA and MD ISF Study 1998, Hudy et al 2005, ASFMC 2009, Cooper 1983, Jenkins and Burkhead 1993 |
| **Mussels** | host-specificity,<br>longevity,<br>habitat association,<br>velocity association,<br>brooding length,<br>spawning and glochidia release | *Primarily riverine*- predominantly occur in moderate to swift velocity riverine habitats<br><br>*Facultative riverine*- occur in slow to moderate, and sometimes swift, riverine and lake habitats<br><br>*Primarily lentic*- predominantly occur in slow backwater habitats on rivers and commonly found in lakes and reservoirs | Bogan and Proch 2004, Pers Com Villella 2009, Pers Com Crabtree 2009, Strayer and Jirka 1997, Fetterman and Strayer 1999, Meyer et al in review, CTDEP 2003, Grabarkiewicz 2008, Nedeau 2000, Normandeau Associates 2006, Johnson 2001 |
| **Aquatic Insects** | habitat association,<br>trophic habit | *Riffle Communities (erosional habitats)*- dominated by collector-filterers and herbivores; commonly occur in headwater streams<br><br>*Pool and Riffle Communities*- dominated by collector-gatherers and shredders, habitat type likely to occur on tributaries that have a variety of habitats, including pools, riffles, and runs<br>*Pool Communities (depositional habitat)*- dominated by collector-gatherers and predators, commonly found in backwaters of large tributaries and mainstem habitats | Poff et al 2006, Vieira et al 2006, Cummins 1973, Richards et al 1997, Lake 2003, McKay and King 2006 |
| **Aquatic, Riparian and Floodplain Vegetation** | inundation tolerance,<br>frequency and severity of flood and ice scour,<br>seed dispersal mechanism,<br>seed dispersal timing,<br>hydrophytic designation,<br>dominant disturbance regime | *Emergent bed*- characterized by semi-permanent inundation and severe flood and ice scour<br><br>*Herbaceous Community*- occurs in rapidly draining soils and is characterized by seasonal to temporary flooding, and severe flood and ice scour<br><br>*Scrub/Shrub Community*- characterized by seasonal to temporary flooding and moderate to severe flood and ice scour<br><br>*Floodplain Forest*- temporary flooding, low to moderate flood and ice scour, range of inundation lengths due to differences in soil texture, not flood duration | Fike 1999, Podniesinski et al 2002, Perles et al 2004, Eichelberger et al 200X, Bowler 2006, Zimmerman 2006, USFWS 1999, Burns and Honkala 1990 |

*Flow-Ecology Diagrams*

To illustrate the relationships between species life stages and seasonal hydrologic conditions, we developed flow-ecology diagrams that overlay life history information for various species with a representative hydrograph within the Basin (Figure 1). Daily hydrologic data was retrieved from USGS index gages, for the period of 1960 to 2008 (water years). This forty-nine year period was identified as representative of a range of hydrologic conditions from extreme droughts to major flood events. Each group of species was paired with a USGS index gages near where those particular species have been collected. Please note that the hydrograph is not intended to illustrate ideal or reference conditions for the group of species, but rather to illustrate the annual and interannual flow conditions that occur at a site where these particular species are known to be present and to facilitate conversation about how various flow components affect life stages of selected species. All flow-ecology diagrams are included in the Workshop Materials.

To illustrate both seasonal and interannual variability, the 10$^{th}$ to 90$^{th}$ percentile range of average daily discharge, as well as the median daily discharge were calculated and are included in the gray shaded hydrograph in Figure 1. The frequency, duration and magnitude of low (red line) and high flow pulses (blue line) were calculated as the Q90 and Q10 statistics, respectively, over the period of record. The frequency, magnitude and duration of the > 2 year recurrence flood event were also calculated and are represented by the purple line.

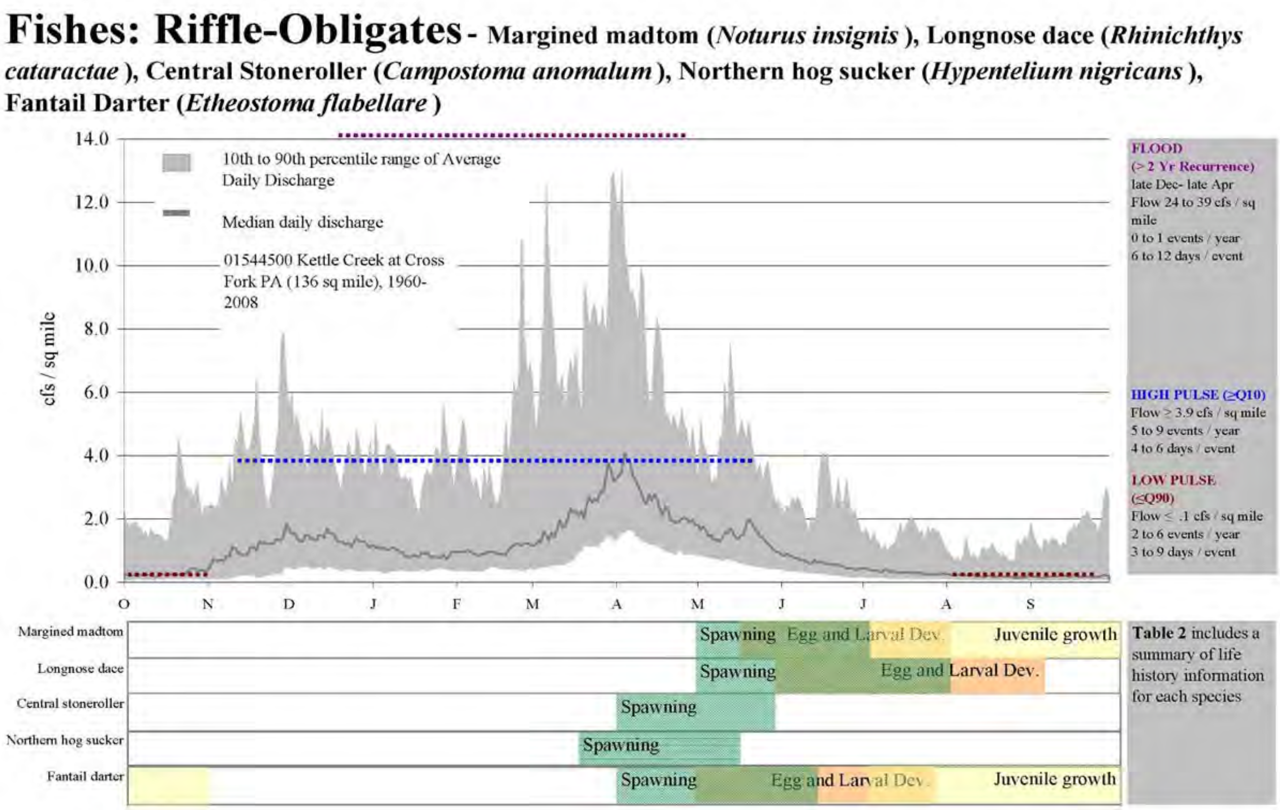



**Figure 1: Flow-ecology diagram relating life history information to a representative hydrograph**

*Linking Flow-sensitive Taxa Groups to River Types and Reaches*

Lastly, we used existing species and community distribution information to associate each group of flow-sensitive taxa with general river types or mainstem reaches within the basin. Much of the distribution information was taken from Walsh et al (2007). We created draft maps using the cold and warmwater stream designations for Pennsylvania and the Northeast Aquatic Habitat Classification (Anderson et al 2007) (Figure 2, for example). We identified **seven general river types or reaches** within the basin:

**1. Cold headwater and small streams-** cold/cool water streams within watersheds < 200 sq mi primarily found within the Appalachian Plateau and Ridge and Valley province. The type currently includes glaciated and unglaciated streams. We may consider further dividing this classification to reflect differences in glaciated versus unglaciated and/or Appalachian versus Ridge and Valley streams.
**2. Calcareous headwaters and small streams-** includes all streams < 200 sq mi classified as calcareous, or highly buffered systems, by Anderson et al (2007). These streams typically flow through limestone and have higher baseflow than other streams.
**3. Warm headwater and small streams-** warmwater streams within watersheds < 200 sq mi primarily found within the Ridge and Valley and Piedmont provinces, although they are present in other provinces.
**4. Upper Susquehanna and Chemung**- mainstem Chemung and Upper Susquehanna rivers as well as contributing tributaries >200 sq mi.
**5. West Branch and Juniata-** mainstem West Branch and Juniata rivers and contributing tributaries > 200 sq mi.
**6. Middle Susquehanna-** mainstem from the confluence of the Chemung to the confluence of the West Branch.
**7. Lower Susquehanna**- mainstem from confluence with West Branch to York Haven reservoir.

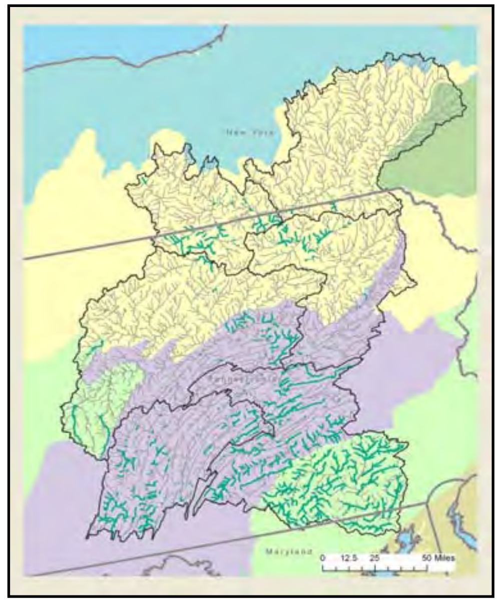


**Figure 2: Example Map Illustrating the Distribution of Warm Headwater and Small Streams**

*Constructing Hypotheses about Flow Needs*

The elements of a flow recommendation include an ecosystem function, specific location, time period, flow magnitude, frequency and duration of event, and rate of change. In drafting our hypotheses about the flow needs, we can target the elements by addressing who (species or group), what (flow component), when (month or season), where (habitat type or unit), why/how (ecological response). Figure 3 includes an example hypothesis outlining these components. The hypothesis can both be written as a positive (needs based) and negative (threshold based) statement.

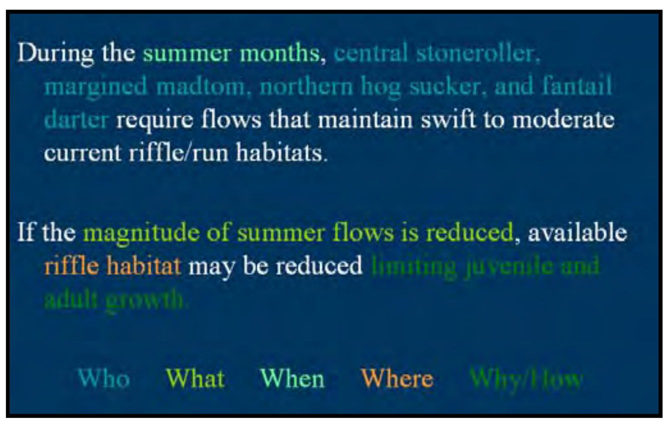



**Figure 3: Example hypothesis highlighting key elements**

# Break Out Groups - By River Type or Reach

TNC staff facilitated groups of 10 to 12 people in breakout groups by river type or reach to accomplish the following tasks: (1) develop a prioritized list of species, groups of species, or physical process for their river type or reach and identifying any missing species or groups, (2) construct hypotheses that include the components outlined above to describe responses to flow conditions based on life history information, and (3) document gaps, technical questions and uncertainties.

**Day 1 (3 groups):** Warm Headwater and Small Streams; West Branch of the Susquehanna; Lower Mainstem of the Susquehanna

**Day 2 (2 groups):** Upper Susquehanna River and Chemung; Cold/Cool Headwater and Small Streams and Calcareous Streams

On the morning of Day 2, we presented all hypotheses from the three groups that met on Day 1. As a large group, we filled gaps related to season, flow condition, or taxa, and this list was used as a starting point for Day 2 breakout groups. Attachment B includes all hypotheses associated with each river type.

# Summary and steps between now and project completion

**Follow up items:**

- Review hypotheses – clarify and revise as necessary, consolidate as appropriate
- Beginning with this list, develop hypotheses about flow needs for Middle Mainstem and Juniata
- Revise maps of major habitat types – the types were generally confirmed at the workshop, but we recognize we can improve our maps showing their distribution using additional data sources.
- Summarize information on other flow-sensitive resources, including reptiles and amphibians, water quality, and geomorphology
- Continue consultation with taxa experts to review and supplement life history information and information on flow needs

**We will host a second workshop focused on flow recommendations in Spring 2010. Between now and then, we will focus on:**

**Confirming hypotheses** – Although data does not exist to "test" all these hypotheses, there are several types of information sources that we can use to confirm that these hypotheses reflect the needs of aquatic species in the Basin. Major sources include: professional judgment, studies from other basins, existing studies within the Susquehanna, and new analyses of existing data. This project can also identify future studies that could help confirm or reject hypotheses about responses to flow changes. We will provide as much basis as possible to support each hypothesis, indicate gaps, and present this at the spring workshop.

**Draft flow recommendations** – We will use the qualitative flow hypotheses to develop draft flow recommendations that include the range of flows needed to sustain species and communities within the basin. We will draft recommendations that include acceptable ranges of values of a series of flow statistics representing flow magnitude and the frequency, duration, and rate of change of flow conditions. This will be a primary focus of the spring workshop.

**Draft summary report –** We will present all information compiled to date, including the outcomes of this workshop, in draft summary report that we will distribute for comment before the spring workshop.

# ATTACHMENT A
# WORKSHOP PARTICIPANTS

| Participant | Organizational Affiliation |
|---|---|
| Andrew Dehoff | Susquehanna River Basin Commission |
| Andrew Roach | USACE, Baltimore District |
| Andrew Warner | The Nature Conservancy |
| Chad Pindar | Delaware River Basin Commission |
| Claire O'Neill | USACE, Baltimore District |
| Colin Apse | The Nature Conservancy |
| Curtis Schreffler | US Geological Survey |
| Dan Bierly | USACE, Baltimore District |
| Dave Heicher | Susquehanna River Basin Commission |
| Dave Kovach | Delaware River Basin Commission |
| Dave Ladd | Susquehanna River Basin Commission |
| Doug Fischer | Pennsylvania Fish and Boat Commission |
| Erik Silldorff | Delaware River Basin Commission |
| Hoss Liaghat | Pennsylvania Department of Environmental Protection |
| Jen Hoffman | Susquehanna River Basin Commission |
| Jim Cummins | Potomac River Basin Commission |
| John Balay | Susquehanna River Basin Commission |
| Julie Zimmerman | The Nature Conservancy |
| Larry Miller | US Fish and Wildlife Service |
| Mark Hartle | Pennsylvania Fish and Boat Commission |
| Mark Smith | The Nature Conservancy |
| Mark Woythal | New York State Department of Environmental Conservation |
| Mary Walsh | Pennsylvania Natural Heritage Program |
| Matt Shank | Susquehanna River Basin Commission |
| Michele DePhilip | The Nature Conservancy |
| Mike Brownell | Susquehanna River Basin Commission |
| Pam Bishop | Pennsylvania Department of Environmental Protection |
| Randy Bennett | US Geological Survey |
| Rick Shertzer | Pennsylvania Department of Environmental Protection |
| Scott Stranko | Maryland Department of Natural Resources |
| Stephanie Flack | The Nature Conservancy |
| Steve Garbarino | USACE, Baltimore District |
| Sue Weaver | Pennsylvania Department of Environmental Protection |
| Tara Moberg | The Nature Conservancy |
| Tom Denslinger | Pennsylvania Department of Environmental Protection |

# ATTACHMENT B
# WORKING FLOW-HYPOTHESES FOR RIVER TYPES WITHIN THE SUSQUEHANNA RIVER BASIN

# Warmwater Headwater and Small streams, < 200 sq mi

<table>
<tr><th></th><th>Working Hypotheses</th><th>October</th><th>November</th><th>December</th><th>January</th><th>February</th><th>March</th><th>April</th><th>May</th><th>June</th><th>July</th><th>August</th><th>September</th></tr>
<tr><td></td><td>Fish</td><td colspan="12"></td></tr>
<tr><td>1</td><td>Riffle obligate (longnose dace)  Decrease in seasonal flows below normal lows will negatively affect species abundance through loss of high velocity habitat availability.</td><td></td><td colspan="6"></td><td colspan="5">Decreased low flows will reduce high velocity habitat</td></tr>
<tr><td>2</td><td>White sucker, N. hogsucker, shorthead redhorse (riffle associates):  Increase of extreme high flow events (frequency and magnitude) during spawning can negatively effect development of larvae through flushing of larvae downstream</td><td colspan="5"></td><td colspan="2">Increase in high flow events flushes larvae downstream</td><td colspan="5"></td></tr>
<tr><td>3</td><td>White sucker, N. hogsucker, shorthead redhorse (riffle associates):  Increase of extreme low flow events (decreased magnitude, increased duration) pre-spawning and spawning will restrict adult movement into spawning habitats through riffles.</td><td colspan="5"></td><td colspan="2">Increase extreme low flow events restricts movement b/t habitats</td><td colspan="5"></td></tr>
<tr><td>4</td><td>Walleye: Decrease in spring or summer flows and/or increased duration of low flows leads to increased temperatures, so in summer movements, need increased connectivity and adequate flows to move between pools and over riffles.</td><td colspan="7"></td><td colspan="5">Decreased flow magnitude reduces connectivity between pools over riffles</td></tr>
<tr><td>5</td><td>All Nestbuilders: Lack of spring flushing flows may result in accumulation of fines, reducing spawning success due to a lack of suitable substrate for nest building</td><td colspan="4"></td><td colspan="2">Loss of flushing flows reduces spawning success</td><td colspan="6"></td></tr>
<tr><td>6</td><td>Small mouth bass, redbreast sunfish (and inverts, same issue, any time of year when there are scouring floods)</td><td colspan="7"></td><td colspan="2">Increased high flows reduces spawning success</td><td colspan="3"></td></tr>
<tr><td>7</td><td>Smallmouth bass</td><td colspan="7"></td><td colspan="2">Stable flows are needed to keep males on nest</td><td colspan="3"></td></tr>
<tr><td>8</td><td>Central stoneroller (riffle obligate): reduced low flows, less preferred habitat (depth, velocity), increased frequency and duration of low flows, reduced area for their preferred food (algae) to live.</td><td></td><td colspan="7"></td><td colspan="4">Decrease flow magnitude leads to decreased habitat and food availability</td></tr>
<tr><td>9</td><td>All headwater fishes (shorthead redhorse, northern hogsucker and smallmouth mentioned), decrease in magnitude of low flows caused by groundwater withdrawals will result in loss of small-stream habitats and lead to faunal shift of small-stream species to larger streams</td><td colspan="12">Decreased flow magnitude leads to loss of small-stream habitats</td></tr>
<tr><td></td><td>Mussels</td><td colspan="12"></td></tr>
<tr><td>10</td><td>Riverine mussels, and host fish (all three mussel groups): Decreased magnitude or frequency of winter or spring scouring flows can lead to embeddedness, lack of appropriate substrate size, aggrading channel morphology, reduced carrying capacity.</td><td colspan="3"></td><td colspan="3">Decreased mag or frequency of scouring flows leads to embeddedness (all year, esp winter & spring)</td><td colspan="6"></td></tr>
<tr><td>11</td><td>Mussels, and inverts, if stream is flashier (rate of change outside of natural variation), will see reduced habitat stability, reduced recruitment, and reduced carrying capacity of mussel habitat.</td><td colspan="12">Increased flashiness reduces suitable habitat</td></tr>
<tr><td>12</td><td>Mussels, all groups, an increase in the magnitude and variation of high flows in the Spring  may decrease host fish availability, likewise a decrease in low flow magnitudes in the Summer may decrease host fish availability</td><td colspan="5"></td><td colspan="2">Flows too high decreases host fish availability</td><td colspan="2"></td><td colspan="3">Flows too low decreases host fish availability</td></tr>
</table>

# Warmwater Headwater and Small streams, < 200 sq mi

| | Working Hypotheses | October | November | December | January | February | March | April | May | June | July | August | September |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | **Mussels, other invertebrates, YOY fish, herps,** reduced low flow magnitudes may reduce both access and quality (temperature and DO) of slow-moving backwater refugia | | | | | | | | | | | Decreased quality and quantity of available habitats (temp and water quality) with decreased magnitude of low flow | |
| 14 | **Mussels, all groups,** extreme lows increase risk of exposure and predation of mussel beds | | | | | | | | | | | Extreme lows increses risk of exposure and predation of mussel beds | |
| | **Additions** | | | | | | | | | | | | |
| 15 | **Herps** (turtles frogs overwinter in banks) | Flows maintain wetted margins for hibernating herps | | | | | | | | | | | |
| 16 | **For herps**, maintain range of variability of highs and lows | | | | | | | | | | | | |
| 17 | **For all taxa,** support of baseflow within normal range to support aquatic habitat | Baseflows required to maintain habitat for all taxa | | | | | | | | | | | |
| 18 | **For bank-nesting mammals**, specifically muskrats, dens may be exposed under extreme low flow conditions | | | Extreme low flows expose muskrat dens | | | | | | | | | |

# Cold/Cool Headwaters and Small streams < 200 sq mi

<table>
<tr><th></th><th>Working Hypotheses</th><th>October</th><th>November</th><th>December</th><th>January</th><th>February</th><th>March</th><th>April</th><th>May</th><th>June</th><th>July</th><th>August</th><th>September</th></tr>
<tr><td colspan="14">COLDEST STREAMS</td></tr>
<tr><td></td><td>Fish</td><td colspan="12"></td></tr>
<tr><td>1</td><td>Brook trout (Cold headwater)- maintaining the natural variation of flushing flows, or high flow pulses, necessary to clear gravel and maintain riffle habitat before Fall spawning</td><td colspan="2"></td><td colspan="6">High flows for habitat maintenance</td><td colspan="4"></td></tr>
<tr><td>2</td><td>Brook trout (Cold headwater)- during overwinter egg incubation period, redds and riffle habitats must be kept sediment free with high flows, but not so high that redds are scoured and eggs are flushed from the redds</td><td></td><td colspan="6">Avoid high flow events outside of range that may scour redds or flush eggs</td><td colspan="5"></td></tr>
<tr><td>3</td><td>See above</td><td></td><td colspan="6">Maintain flows over redds and riffles, keeping them wetted and silt-free</td><td colspan="5"></td></tr>
<tr><td>4</td><td>Brook trout (Cold headwater)- During the spawning period, flows must be high enough to maintain connectivity, allowing migration to spawning areas</td><td colspan="2">Maintain longitudnal connectivity during spawning</td><td colspan="10"></td></tr>
<tr><td>5</td><td>Brook trout (Cold headwater)- extreme summer low flow magnitudes can negatively affect juvenile and adult growth and survival by reducing habitat availability and temperatures, as well as reducing connectivity between source populations</td><td colspan="9"></td><td colspan="3">Maintain summer flows for habitat, temperature, and source population connectivity</td></tr>
<tr><td>6</td><td>Sculpin- covered by previous day's recommendations for riffle obligates- See below</td><td colspan="12"></td></tr>
<tr><td>7</td><td>Riffle Obligates, all, In all seasons, significantly reduced flow magnitudes will cause local extirpation or reduced growth</td><td colspan="12">Decreased flows lead to loss of riffle habitat</td></tr>
<tr><td>8</td><td>Riffle Obligates, all, During the spawning season (March-July), decreased low flows during spawning would reduce recruitment</td><td colspan="5"></td><td colspan="5">Decreased flows during spawning limits recruitment</td><td colspan="2"></td></tr>
<tr><td>9</td><td>Riffle Obligates, all, A decrease in low flow magnitudes during the juvenile growth (July-Sept) and development period could reduce population size</td><td colspan="9"></td><td colspan="3">Decreased flows during spawning limits juvenile growth</td></tr>
<tr><td></td><td>Macroinvertebrates</td><td colspan="12"></td></tr>
<tr><td>10</td><td>Stenothermal invertebrates- avoid extreme low flows in the summer to maintain temperature regime, increased low flows may lead to a shift from univoltine to multivoltine inverts</td><td colspan="9"></td><td colspan="3">Maintain summer flows for habitat and temperature</td></tr>
<tr><td></td><td>Herps, Vegetation, and Geomorph</td><td colspan="12"></td></tr>
<tr><td>11</td><td>Salamanders- sensitive to extreme high flows, and increased flashiness (rate of change) within the system as they reduce quality and quanity of available margin habitats</td><td colspan="12">Increases to rate of change alter quality and availability of stream margin habitats</td></tr>
<tr><td>12</td><td>Salamanders- sensitive to flow changes that would influence temperatures, particularly increases</td><td colspan="12"></td></tr>
<tr><td>13</td><td>Glaciated cold headwaters- these systems are particularly susceptible to changes in habitat availability (wetted perimeter, depth, velocity) and increased temperatures during the summer</td><td colspan="9"></td><td colspan="3">Maintain summer flows for habitat and temperature</td></tr>
</table>

# Cold/Cool Headwaters and Small streams < 200 sq mi

<table>
<tr><th></th><th>Working Hypotheses</th><th>October</th><th>November</th><th>December</th><th>January</th><th>February</th><th>March</th><th>April</th><th>May</th><th>June</th><th>July</th><th>August</th><th>September</th></tr>
<tr><td>14</td><td>Downstream impacts can lead to loss of coldest headwater streams – extreme low flows downstream of small hw/seeps can result in disappearance of these u/s habitats (tie to gw withdrawals)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>15</td><td>Wetlands and Vegetation- in these small systems, riparian wetlands/plant communities are dependent on high flow pulses</td><td></td><td></td><td></td><td colspan="5">High Flow Pulses necessary to maintain wetland and riparian communties</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="14">TRANSITIONAL STREAMS</td></tr>
<tr><td>16</td><td>Similar flow needs to coldest streams, but less sensitive to flow changes. Incorporate flow needs of rock bass, spottail shiner, and megaloptera</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="14">CALCAREOUS HEADWATER STREAMS</td></tr>
<tr><td></td><td>Fish</td><td colspan="12"></td></tr>
<tr><td></td><td>Add Brook trout and sculpin needs from Coldwater</td><td colspan="12"></td></tr>
<tr><td>17</td><td>Brook trout (Cold headwater)- maintaining the natural variation of flushing flows, or high flow pulses, necessary to clear gravel and maintain riffle habitat before Fall spawning</td><td></td><td></td><td colspan="6">High flows for habitat maintenance</td><td></td><td></td><td></td><td></td></tr>
<tr><td>18</td><td>Brook trout (Cold headwater)- during overwinter egg incubation period, redds and riffle habitats must be kept sediment free with high flows, but not so high that redds are scoured and eggs are flushed from the redds</td><td></td><td colspan="6">Avoid high flow events outside of range that may scour redds or flush eggs</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>See above</td><td></td><td colspan="6">Maintain flows over redds and riffles, keeping them wetted and silt-free</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>19</td><td>Brook trout (Cold headwater)- During the spawning period, flows must be high enough to maintain connectivity, allowing migration to spawning areas</td><td colspan="2">Maintain longitudnal connectivity during spawning</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>20</td><td>Brook trout (Cold headwater)- extreme summer low flow magnitudes can negatively affect juvenile and adult growth and survival by reducing habitat availability and temperatures, as well as reducing connectivity between source populations</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">Maintain summer flows for habitat, temperature, and source population connectivity</td></tr>
<tr><td>21</td><td>Sculpin- covered by previous day's recommendations for riffle obligates- See below</td><td colspan="12"></td></tr>
<tr><td>22</td><td>Riffle Obligates, all, In all seasons, significantly reduced flow magnitudes will cause local extirpation or reduced growth</td><td colspan="12">Decreased flows lead to loss of riffle habitat</td></tr>
<tr><td>23</td><td>Riffle Obligates, all, During the spawning season (March-July), decreased low flows during spawning would reduce recruitment</td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Decreased flows during spawning limits recruitment</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>24</td><td>Riffle Obligates, all, A decrease in low flow magnitudes during the juvenile growth (July-Sept) and development period could reduce population size</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">Decreased flows during spawning limits juvenile growth</td></tr>
<tr><td></td><td>Additional Needs in this System Type</td><td colspan="12"></td></tr>
<tr><td>25</td><td>All species (see notes for team-derived taxa priorities), sensitive to reduced base flows</td><td colspan="12">Baseflows required to maintain habitat for all taxa</td></tr>
<tr><td>26</td><td>Cave-dwelling species- particularly T&E cave shrimp and amphipods occupy very specific niche- needs should be researched/considered</td><td colspan="12"></td></tr>
</table>

## Cold/Cool Headwaters and Small streams < 200 sq mi

| | Working Hypotheses | October | November | December | January | February | March | April | May | June | July | August | September |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | Increased frequency and magnitude of high flow events will destabilize the stream **banks and beds** of these systems | | | | Increased frequency and magnitude o fHigh Flow pulses will destabilize streambanks and beds | | | | | | | | |
| 28 | **Aquatic Invertebrates**- maintenance of baseflows for winter emerging species | | Maintain baseflows for winter emergence | | | | | | | | | | |
| 29 | An increase in the magnitude and frequency of High flow pulses during the summer could increase **temperatures** and alter community composition | | | | | | | | | | High flow events dilute groundwater inputs/ temperature influences and potentially increase temperatures | | |

## Large Rivers: West Branch and Lower Mainstem Susquehanna (including tributaries > 200 sq mi)

| | Working Hypotheses | October | November | December | January | February | March | April | May | June | July | August | September |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **Riffle Obligates, all,** In all seasons, significantly reduced flow magnitudes will cause local extirpation or reduced growth | Decreased flows lead to loss of riffle habitat | | | | | | | | | | | |
| 2 | **Riffle Obligates, all,** During the spawning season (March-July), decreased low flows during spawning would reduce recruitment | | | | | | Decreased flows during spawning limits recruitment | | | | | | |
| 3 | **Riffle Obligates, all**, A decrease in low flow magnitudes during the juvenile growth (July-Sept) and development period could reduce population size | | | | | | | | | | Decreased flows during spawning limits juvenile growth | | |
| 4 | **White sucker and shorthead redhorse (riffle associates)** need riffles for spawning (depth should be covered by riffle obligate needs) during the spawning season (March-June), | | | | | | Decreased flows during spawning limits recruitment | | | | | | |
| 5 | **For smallmouth bass (nest builder)**, flood flows during Apr-May could delay spawning, reducing recruitment | | | | | | | High flows could delay spawning | | | | | |
| 6 | **For smallmouth bass (nest builder)**, high base flows, steady flows from April through May are necessary to maintain spawning habitat in stream margins | | | | | | | Stable flows needed to maintain stream margin habitat | | | | | |
| 7 | **For smallmouth bass (nest builder)** June flows outside of the mean (specify) reduces juvenile recruitment and growth (cite study) | | | | | | | | | Flows outside mean reduce recruitment | | | |
| 8 | **For smallmouth bass (nest builder)** adults, pools must be maintained for successful adult growth | | | | | | | | | | Pools maintained for adult growth | | |
| 9 | **All nestbuilders**, need stable flows for nest success; extreme low flows can expose nests | | | | | | | | Extreme low flows expose nests | | | | |
| 10 | **MIgratory Fish-** maintenance of large open water habitats as well as SAV cover | | | | | | | | Juvenile habitat maintenance before outmigration | | | | |
| 11 | **MIgratory Fish-** Cue outmigration of juvenile alosids and Adult american eel, need estimated velocities of .3 ft/s | Cue outmigration of juvenile alosids and Adult american eel | | | | | | | | | | | |
| 12 | **Migratory (Diadromous) Fish** | | | | | | | Adult upstream migration | | | | | |
| 13 | **Migratory (Diadromous) Fish-** draft guideline for sufficient migration flows include a cross-sectional area 12' wide, 3'deep with velocities of 1 to 3 ft/s [Larry Miller FWS] | | | | | | | Adult upstream migration | | | | | |
| 14 | **For all fishes,** increase in the freq. of winter high flow pulses could negatively impact overwinter survival | | | Increased high pulses could affect overwinter survival | | | | | | | | | |

## Large Rivers: West Branch and Lower Mainstem Susquehanna (including tributaries > 200 sq mi)

<table>
<tr><th></th><th>Working Hypotheses</th><th>October</th><th>November</th><th>December</th><th>January</th><th>February</th><th>March</th><th>April</th><th>May</th><th>June</th><th>July</th><th>August</th><th>September</th></tr>
<tr><td>15</td><td>Walleye: Decrease in spring or summer flows and/or increased duration of low flows leads to increased temperatures, so in summer movements, need increased connectivity and adequate flows to move between pools and over riffles.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5">Decreased flow magnitude reduces connectivity between pools over riffles</td></tr>
<tr><td>16</td><td>Riverine Mussels, During the spawning season and glochidia release, need flows that support riffle habitat adequate for host fishes (should be covered by Riffle Ob and Riffle Assoc)</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="6">Flows to maintain riffle habitat during spawning and glochidia release</td></tr>
<tr><td>17</td><td>Submerged / emergent aquatic vegetation- needs unknown at this time, but instream species dependent on SAV for habitat</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">flows to maintain SAV</td></tr>
<tr><td>18</td><td>For herps, increase in the freq. of winter high flow pulses could negatively impact overwinter survival (wood turtle)</td><td></td><td></td><td colspan="3">Increased high pulses could affect overwinter survival</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>19</td><td>For bank-nesting mammals, specifically muskrats, dens may be exposed under extreme low flow conditions</td><td></td><td></td><td colspan="3">Extreme low flows expose muskrat dens</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>20</td><td>Water Quality- Extended periods below 7Q10 (natural or due to withdrawal) may not provide assimilative capacity for WWTP discharges</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>21</td><td>Water Quality For some rivers(dependent on mine type), increased freq. of low fow events could increase AMD concentrations</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">Increased frequency of low flow events could increase AMD concentration</td></tr>
<tr><td>22</td><td>Water Quality- Increased freq. of low flow events decreases DO, increases temps (research on correlations) in mainstem and backwater habitats</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">Flows to maintain oxygenated conditions</td></tr>
<tr><td>23</td><td>Backwater habitat - connectivity- reduced low flow magnitudes may reduce both access and quality (temperature and DO) of slow-moving backwater refugia</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">Flows to maintain connections between channel and backwater</td></tr>
</table>

## Large Rivers: Upper Susquehanna and Chemung (including tributaries > 200 sq mi)

| | Working Hypotheses | October | November | December | January | February | March | April | May | June | July | August | September |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Fishes** | | | | | | | | | | | | |
| 1 | **Riffle Obligates, all,** In all seasons, significantly reduced flow magnitudes will cause local extirpation or reduced growth | Decreased flows lead to loss of riffle habitat | | | | | | | | | | | |
| 2 | **Riffle Obligates, all,** During the spawning season (March-July), decreased low flows during spawning would reduce recruitment | | | | | | Decreased flows during spawning limits recruitment | | | | | | |
| 3 | **Riffle Obligates, all**, A decrease in low flow magnitudes during the juvenile growth (July-Sept) and development period could reduce population size | | | | | | | | | | Decreased flows during spawning limits juvenile growth | | |
| 4 | **White sucker and shorthead redhorse (riffle associates)** need riffles for spawning (depth should be covered by riffle obligate needs) during the spawning season (March-June), | | | | | | Decreased flows during spawning limits recruitment | | | | | | |
| 5 | **For smallmouth bass (nest builder)**, flood flows during Apr-May could delay spawning, reducing recruitment | | | | | | | High flows could delay spawning | | | | | |
| 6 | **For smallmouth bass (nest builder)**, high base flows, steady flows from April through May are necessary to maintain spawning habitat in stream margins | | | | | | | Stable flows needed to maintain stream margin habitat | | | | | |
| 7 | **For smallmouth bass (nest builder)** June flows outside of the mean (specify) reduces juvenile recruitment and growth (cite study) | | | | | | | | | Flows outside mean reduce recruitment | | | |
| 8 | **For smallmouth bass (nest builder)** adults, pools must be maintained for successful adult growth | | | | | | | | | | Pools maintained for adult growth | | |
| 9 | During the spawning season and glochidia release, **riverine mussels** need flows that support riffle habitat adequate for host fishes (should be covered by Riffle Ob and Riffle Assoc) | | | | | | | | Extreme low flows expose nests | | | | |
| 10 | **MIgratory Fish-** maintenance of large open water habitats as well as SAV cover | | | | | | | | Juvenile habitat maintenance before outmigration | | | | |
| 11 | **MIgratory Fish** (note: for juvenile alosids in Chemung/Upper Susq, can go from Sept-Oct., based on high flow pulses -- as early as Aug. or as late as Nov.) | Cue outmigration of juvenile alosids and adult american eel | | | | | | | | | | | |
| 12 | **Migratory (Diadromous) Fish** | | | | | | | Adult upstream migration | | | | | |
| 13 | **Migratory (Diadromous) Fish-** draft guideline for sufficient migration flows include a cross-sectional area 12' wide, 3'deep with velocities of 1 to 3 ft/s [Larry Miller FWS] | | | | | | | Adult upstream migration | | | | | |
| 14 | **For all fishes, increase in the freq. of winter high flow pulses could negatively impact overwinter survival** | | | Increased high pulses could affect overwinter survival | | | | | | | | | |
| 15 | **Submerged / emergent aquatic vegetation** | | | | | | | | | flows to maintain SAV | | | |
| 16 | **Backwater habitat - DO** | | | | | | | | | flows to maintain oxygenated conditions | | | |
| 17 | **Backwater habitat - connectivity** | | | | | | | | | flows to maintain connections between channel and backwater | | | |
| 18 | **Increased freq. of low flow events decreases DO, increases temps (research on correlations)** | | | | | | | | | | | | |
| 19 | **For some rivers(dependent on mine type), increased freq. of low fow events could increase AMD concentrations** | | | | | | | | | Increased frequency of low flow events could increase AMD concentration | | | |
| | **Additions** | | | | | | | | | | | | |
| 20 | **For herps,** increase in the freq. of winter high flow pulses could negatively impact overwinter survival (wood turtle) | | | Increased high pulses could affect overwinter survival | | | | | | | | | |
| 21 | **For bank-nesting mammals**, specifically muskrats, dens may be exposed under extreme low flow conditions | | | Extreme low flows expose muskrat dens | | | | | | | | | |
| 22 | **Water Quality-** Extended periods below 7Q10 (natural or due to withdrawal) may not provide assimilative capacity for WWTP discharges | | | | | | | | | | | | |

## Large Rivers: Upper Susquehanna and Chemung (including tributaries > 200 sq mi)

October | November | December | January | February | March | April | May | June | July | August | September

| | Working Hypotheses | |
|---|---|---|
| 23 | **Riffle obligates -- habitat maintenance**, high channel forming flows that redistribute substrate. These may not be impacted by hydro alteration | Channel-forming flows for habitat maintenance |
| 24 | **Riffle obligates -- pool connectivity**, making sure SAV standing water is not becoming stagnant in low flow periods. In glaciated landscapes with fines, this is a particular issue. | low flows effects on pools |
| 25 | **Stream margins and juvenile fish, mussels, SAV, inverts** -- Increase in rate of change and frequency of flow fluctuations, rapid wetting and drying an issue throughout the year but particularly during low flow seasons | juvenile fish subject to increased predation, loss of habitat, stranding |
| 26 | **Stream margins** continued | SAV subject to dessication, thermal stress |
| 27 | **Stream margins** continued | Mussels and other inverts subject to increased predation, stranding, dessication |
| repeat | **Migratory (Diadromous) fish** (ie, for shad restoration in this area) -- want to have connected zone of passage, 12 ft. wide by 3 ft. deep channel with flow velocities between 1 and 3 ft./sec. | Upstream migration, spawning time |
| 28 | **Riparian and aquatic veg** -- not much in these systems, b/c of nature of substrates and groundwater flow. High flows take out large willows. | |
| 29 | Maintain flow through **hyporheic zone** for **groundwater invertebrates** along stream margins -- | Groundwater and hyporheic flow important important for invertebrates |
| 30 | Flow as strategy to deal with **non-native invertebrates (mussels) or vegetation?** Maintaining natural and moderate to high baseflows would be decent first iteration control strategy for zebra mussels. Currently found in pools below hydropower reservoirs i | |
| | **Mussels** | |
| 31 | **Riverine mussels, and host fish (all three mussel groups):** Decreased magnitude or frequency of winter or spring scouring flows can lead to embeddedness, lack of appropriate substrate size, aggrading channel morphology, reduced carrying capacity. | Decreased mag or frequency of scouring flows leads to embeddedness (all year, esp winter & spring) |
| 32 | **Mussels, and inverts**, if stream is flashier (rate of change outside of natural variation), will see reduced habitat stability, reduced recruitment, and reduced carrying capacity of mussel habitat. | increased flashiness reduces suitable habitat |
| 33 | **Mussels, all groups,** an increase in the magnitude and variation of high flows in the Spring may decrease host fish availability, likewise a decrease in low flow magnitudes in the Summer may decrease host fish availability | flows too high decreases host fish availability; flows too low decreases host fish availability |
| 34 | **Mussels, other invertebrates, YOY fish, herps,** reduced low flow magnitudes may reduce both access and quality (temperature and DO) of slow-moving backwater refugia | decreased quality and quantity of available habitats (temp and water quality) with decreased magnitude of low flow |
| 35 | **Mussels, all groups,** extreme lows increase risk of exposure and predation of mussel beds | extreme lows increases risk of exposure and predation of mussel beds |

# Susquehanna River Ecosystem Flows Study
## Flow Recommendation Workshop–Meeting Summary

Wednesday and Thursday, April 7-8, 2010
Kings Gap Environmental Education Center, Pennsylvania

# Workshop objectives

The goals of the workshop were to
- review updated flow needs revised through literature review and consultation
- discuss proposed flow statistics to track flow needs and assess alteration
- review and receive comments on draft flow recommendations for headwaters and small streams, major tributaries and the mainstem Susquehanna River.

# Presentation summary

### **Project Scope and Schedule –** Michele DePhilip, The Nature Conservancy (TNC)

The overarching goal of the Susquehanna River Ecosystem Flow Study is to describe the flow needs and develop flow recommendations for major habitat types within the Basin. The project began in October 2008 under US Army Corps of Engineers' (USACE) WRDA 729 study authority with the specific goal of informing water management programs implemented by the Susquehanna River Basin Commission (SRBC) and USACE, including consumptive use mitigation and water withdrawal permitting.

Since March 2008, we have completed several major project elements:
(1) identification of flow-sensitive species, communities and habitats,
(2) a targeted literature review on flow-sensitive biological and physical processes,
(3) definition and basin-wide mapping of major habitat types, and
(4) two advisory group workshops – Orientation and Scoping (March 2009) and Flow Hypotheses/Needs (October 2009)

The goal of this third and final workshop was to review and discuss draft recommendations. We will incorporate input on these draft recommendations into a final report that we will submit to SRBC and USACE this summer.

Workshop presentations and discussion were structured to follow the organization of the Draft Flow Recommendations table that we included in the workshop materials. This table includes Flow Needs (Column 1), Flow Components and Statistics (Column 2), draft Recommended Ranges (Column 3) and Supporting Literature and Studies (Column 4).

### **Literature Review and Revisions to Flow Needs –** Tara Moberg, TNC

As of the October 2009 workshop, the majority of literature review and flow hypotheses focused on life history stages and needs of fishes (diadromous and resident), aquatic insects, mussels, and vegetation (aquatic, riparian and floodplain vegetation). Since then, we added information on reptiles and amphibians, water quality, geomorphology and birds and mammals. This review followed a similar process, including the development of a list of flow-sensitive species and physical processes in consultation with regional experts within the respective disciplines.

At the October workshop, the group developed over 60 flow hypotheses that described the anticipated changes to biological and physical processes in response to changing hydrologic conditions in the basin. After adding reptiles and amphibians, water quality, geomorphology and birds and mammals, this list included over 70 flow needs statements.

Between workshops, we consolidated the hypotheses by grouping those with similar timing, taxa and/or function in similar habitats. This consolidation resulted in 19 flow needs statements. Each statement was then associated with its characteristic season, either fall, winter, spring or summer. Some needs span multiple seasons – in these cases, we listed them in the season when they begin but indicate the months when this need is relevant.

The workshop materials contain one diagram illustrating the needs associated with each of the five major habitat types: Cold/Cool headwater and small streams, High baseflow headwater and small streams, Warm headwater and small Streams, Major Tributaries, and Mainstem. The diagrams include needs related to low flows, seasonal flows and high flows. These components are described in the workshop materials and below.

## **Proposed Flow Statistics –** Michele DePhilip

In the workshop materials, we proposed a series of flow statistics for defining flow components and tracking changes to the hydrologic regime. Our goal was to select hydrologic statistics that

- represent the natural variability in the flow regime,
- are sensitive to change and have explainable behavior,
- are easy to calculate, repeatable and have limited redundancy,
- are/can be correlated to ecological response, and
- facilitate communication/are understood by scientists, water managers and water users.

We used flow exceedance values ($Q_{ex}$) to divide flows into low flow, seasonal and high flow components. For example, a 5-percent exceedance probability ($Q_5$) represents a high flow that has been exceeded only 5-percent of all days of the flow period. Conversely, a 95-percent exceedance probability ($Q_{95}$) represents a low flow, because 95 percent of daily mean flows in the period are greater than that amount. The statistics associated with each of those components are outlined in Table 1.

Table 1. Summary of draft flow statistics related to each flow component

| | |
|---|---|
| Low Flows<br>(Monthly Q95-Q75) | Monthly Q95, and<br>% of long term daily flows between monthly Q95 and Q75 |
| Seasonal Flows<br>(Monthly Q75-Q10) | Monthly mean, and<br>% of long term daily flows between monthly Q75 and Q10 |
| High Flows<br>(> Monthly Q10) | Seasonal<br>Frequency of events > monthly Q10 in fall, spring, and summer<br><br>Annual/Internannual<br>Magnitude and frequency of bankfull event<br>Magnitude and frequency of small flood (1 in 5 year event)<br>Magnitude and frequency of large flood (1 in 20 year event) |

**Draft Flow Recommendations –** Tara Moberg and Michele DePhilip

We used a combination of peer reviewed literature, research reports, unpublished studies and professional input to support these flow recommendations. Our sources included data, literature, and expertise specific to the Susquehanna Basin; studies with the same or similar species or processes in the mid-Atlantic region; and studies on other temperate rivers with similar taxa. These sources either provided *qualitative* information that confirms the flow need or *quantification* of an ecological response to flow alteration. In general, studies included (1) measured responses to a quantified hydrologic alteration; (2) modeled responses to simulated hydrologic alterations; (3) species-specific habitat models; or (4) observations related to extreme conditions (droughts, summer low flows, floods). We gave an example of each type of study, explained how we applied it to the draft recommendations, and discussed some of the strengths and weaknesses of each type of study (specifically for identifying thresholds at a regional scale). A list of works cited is included in the workshop materials.

# Breakout groups and comments on flow recommendations

A significant portion of the workshop was dedicated to breakout sessions to discuss the needs, flow statistics, draft recommended ranges, and additional information that may be available to support each recommendation.

Breakout groups were organized by season. Each participant had an opportunity to comment on three seasons. All participants commented on Summer and Fall. Half of the participants commented on Winter and the other half on Spring.

In general, the group agreed that the framework for and the structure of the recommendations was useful. Specifically, they agreed it was useful to divide the flow regime into components and identify statistics related to magnitude and distribution of flows – this structure emphasizes the importance of limiting alteration to the entire flow regime.

We received very specific input on several of the flow needs – specifically related to timing of events and additional references that could be used to refine these recommendations. In addition, we received several more general suggestions for changes to the statistics and recommended ranges, including:

- Consider using monthly median instead of monthly mean as the central tendency statistic associated with seasonal flows.

- When defining recommendations for seasonal and low flow ranges, use percentile values instead of a percent change. For example, rather than stating that we recommend <20% change to monthly median, state that the monthly median should be within the reference Q65 and Q35.

- Incorporate some flexibility into the seasonal and low flow ranges. For example, consider replacing ">65% of daily flows within seasonal range (between the monthly Q75 and Q10)" with "58-72% of daily flows within seasonal range" (this example was based on a rule of thumb suggestion that no statistic should change more than 10%).

- Consider tighter ranges for low flow statistics than for seasonal statistics. For example, perhaps low flow-related statistics should only change 5% but seasonal statistics (e.g., median) could change 10%.

- Consider defining a category of headwater streams (e.g, <38 sq mi) because these streams are likely to be especially sensitive. Then:

    - For minimum flow, consider replacing Q95 with Q75 based on responses in literature and expert opinion.
    - Consider tighter ranges around statistics to protect seasonal and low flow related needs (in other words, accept less alteration to headwater streams than to other small streams and major tributaries).

- Define rate of change statistic and acceptable alteration – especially for rate of change during bankfull conditions when rapid recession could lead to stranding and/or bank instability.

- Eliminate defining acceptable change in magnitude of high flow/ flood events.

- Use USGS publications (Chaplin 2005) and associated empirical equations to estimate magnitude and recurrence statistic for bankfull events.

- Consider adding a duration statistic to fall pulse events.

## Summary of steps between now and project completion

We will either incorporate these general suggestions or explore how we could incorporate them after additional analyses. Specifically, we will:

(1) Update flow needs based on specific comments from workshop participants. This includes specific follow up with experts (e.g., on flows related to shad migration) and incorporating information from recommended studies (e.g., USGS publication on estimating bankfull discharge). These revisions will be incorporated into the revised flow recommendations table and included in the draft report.

(2) Conduct pilot hydrologic analyses to refine flow statistics and recommended ranges. Specifically, we will:
   a. Compare the variation in flow statistics for index and non-index (altered) gages. We will use this understanding of variability during the last 40+ years of record to help define an acceptable range for selected statistics.
   b. Test sensitivity of draft flow statistics by developing reasonable water withdrawal scenarios and determining how these withdrawals affect draft flow statistics. Determine whether different stream types are more or less sensitive (e.g. do headwater streams <38 sq mi respond differently than larger streams; do high baseflow streams warrant specific recommendations)
   c. Correlate changes in these flow statistics with changes in habitat based on the PA-MD IFIM.

   TNC and SRBC will define a scope of work for these analyses. We'll review the results with SRBC staff and others and determine together how to incorporate them into the flow recommendations.

(3) Draft report. We will incorporate the results of the pilot analyses into draft our final report. We will circulate the final report for comments in July. TNC will submit our final report to SRBC and USACE by July 2010.

**Thanks again for your participation!**

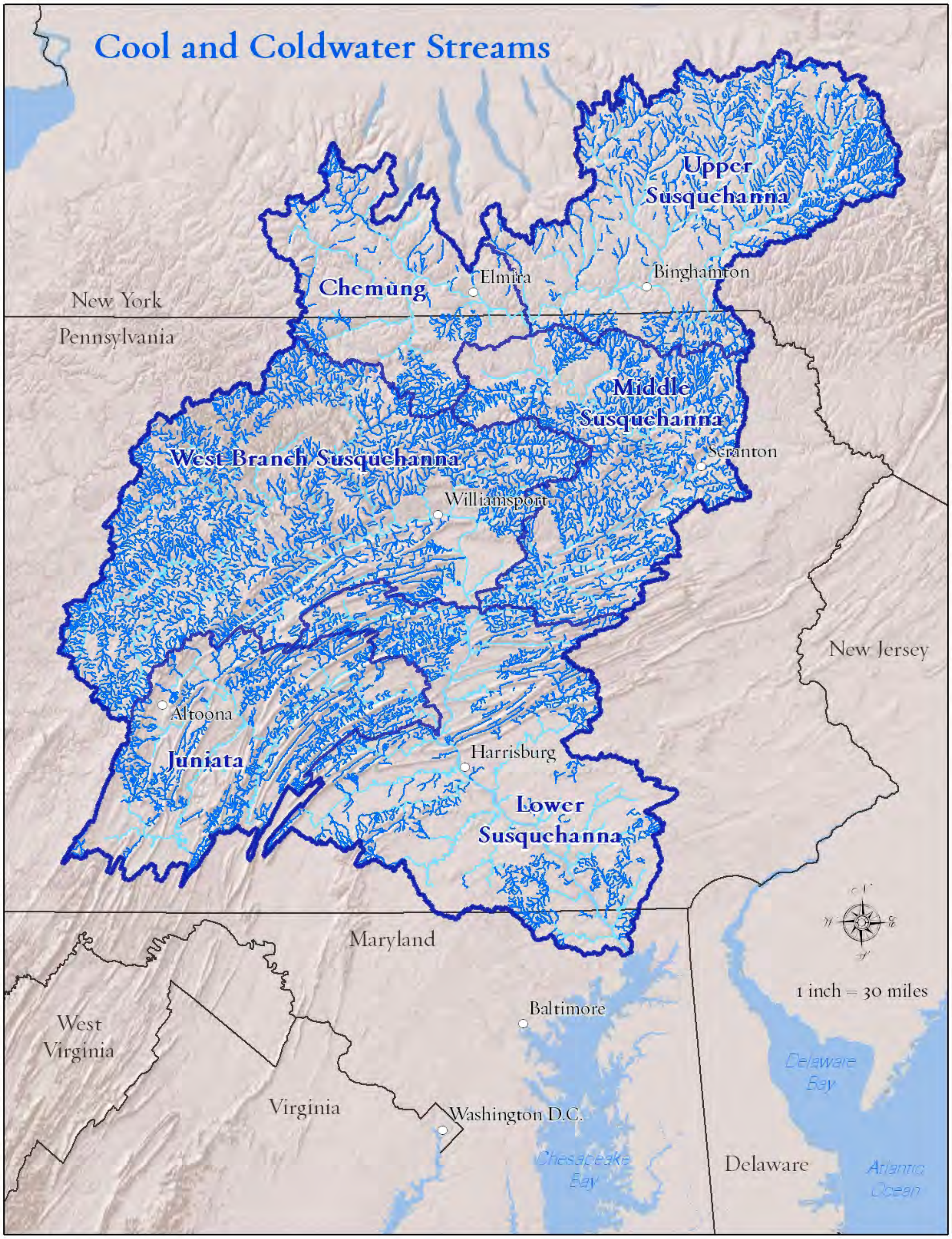
# WORKSHOP PARTICIPANTS

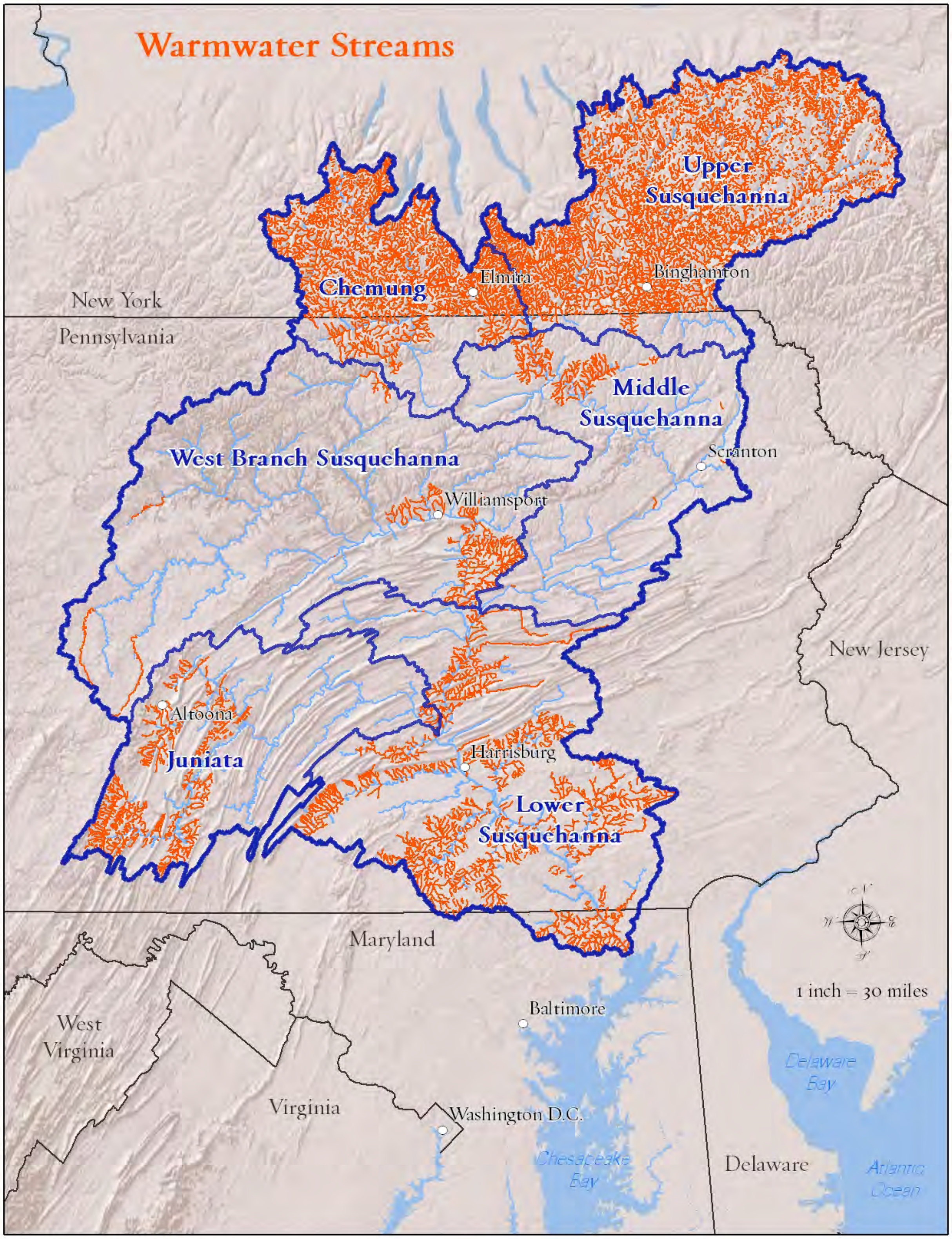
| Participant | Organizational Affiliation |
|---|---|
| Andrew Dehoff | Susquehanna River Basin Commission |
| Andrew Roach | USACE, Baltimore District |
| Claire Buchanan | Potomac River Basin Commission |
| Claire O'Neill | USACE, Baltimore District |
| Colin Apse | The Nature Conservancy |
| Curtis Schreffler | US Geological Survey |
| Dan Bierly | USACE, Baltimore District |
| Dave Heicher | Susquehanna River Basin Commission |
| Dave Kovach | Delaware River Basin Commission |
| Dave Ladd | Susquehanna River Basin Commission |
| Doug Fischer | Pennsylvania Fish and Boat Commission |
| Erik Silldorff | Delaware River Basin Commission |
| Erin Lynam | Susquehanna River Basin Commission |
| Hoss Liaghat | Pennsylvania Department of Environmental Protection |
| Jen Hoffman | Susquehanna River Basin Commission |
| Jim Cummins | Potomac River Basin Commission |
| John Balay | Susquehanna River Basin Commission |
| Julie Zimmerman | The Nature Conservancy |
| Larry Miller | US Fish and Wildlife Service |
| Mark Bryer | The Nature Conservancy |
| Mark Hartle | Pennsylvania Fish and Boat Commission |
| Mark P. Smith | The Nature Conservancy |
| Mary Walsh | Pennsylvania Natural Heritage Program at WPC |
| Michele DePhilip | The Nature Conservancy |
| Michele Moses | Pennsylvania Department of Environmental Protection |
| Paula Ballaron | Susquehanna River Basin Commission |
| Stephanie Flack | The Nature Conservancy |
| Steve Garbarino | USACE, Baltimore District |
| Sue Weaver | Pennsylvania Department of Environmental Protection |
| Tara Moberg | The Nature Conservancy |
| Tim Fox | Maryland Department of the Environment |
| Tom Denslinger | Pennsylvania Department of Environmental Protection |

## Appendix 2. Description of Streams within each Physiographic Province.

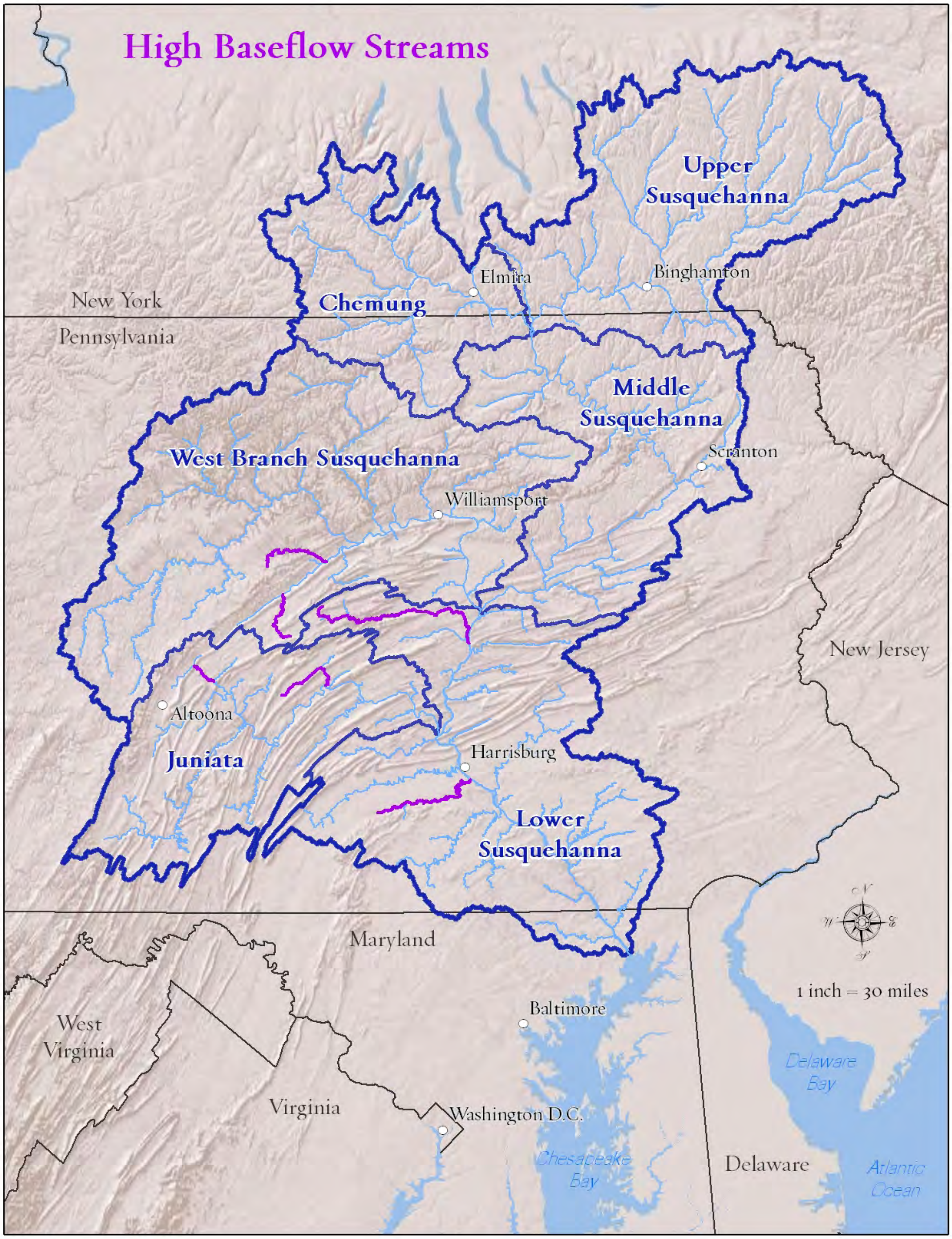
| Physio graphic Province | Subbasins | Section | Dominant Form | Underlying Rock | Local Relief | Min | Max | Drainage Pattern | Dominant Channel Forming Processes |
|---|---|---|---|---|---|---|---|---|---|
| Appalachian Plateau | West Branch, Juniata | Allegheny Mountain | Wide ridges separated by broad valleys, ridge elevations decrease in north | Sandstone, siltstone, shale and conglomerate, some limestone and coal | Mod to High | 775 | 3210 | Dendritic | Fluvial erosion, some peri-glacial mass wasting |
| | West Branch, Juniata | Allegheny Front | East: rounded to linear hills rising by steps to an escarpment, hills cut by narrow valleys, west, undulating hills sloping away from escarpment | Shale, siltstone and sandstone | Mod to High | 540 | 2980 | Parallel and trellis | Fluvial, peri-glacial mass wasting |
| | Upper Susquehanna, West Branch | Deep Valleys | Very deep, angular valleys and some broad to narrow uplands | Sandstone, siltstone, shale and conglomerate | Mod to Very High | 560 | 2560 | Angulate and rectangular | Fluvial erosion, some peri-glacial mass wasting |
| | Upper Susquehanna, Chemung | Glaciated High Plateau | Broad to narrow, rounded to flat, elongate uplands and shallow valleys | Sandstone, siltstone, shale and conglomerate some coal | Low to High | 620 | 2560 | Angulate and dendritic | Fluvial and glacial erosion, glacial deposition |
| | Upper Susquehanna, Middle Susquehanna, Chemung | Glaciated Low Plateau | Rounded hills and valleys | Sandstone, siltstone and shale | Low to Moderate | 440 | 2690 | Dendritic | Fluvial and glacial erosion, glacial deposition |
| Ridge and Valley | West Branch, Juniata | Appalachian Mountain | Long narrow ridges and broad to narrow valleys, some karst | Sandstone, siltstone, shale, conglomerate, limestone and dolomite | Moderate to Very High | 440 | 2775 | Trellis, angulate and some karst | Fluvial erosion, solution of carbonate rocks, peri-glacial mass wasting |
| | Middle Susquehanna, West Branch, Juniata | Susquehanna Lowland | Low to moderately high linear ridges, linear valleys, Susquehanna River Valley | Same | Low to Moderate | 260 | 1715 | Trellis and angulate | Fluvial erosion, some glacial erosion and deposition in northeast |
| | Middle Susquehanna | Anthracite Valley | Narrow to wide canoe shaped valley having irregular to linear hills, valley enclosed by steep sloped mountain rim | Sandstone, siltstone, conglomerate and anthracite | Low to moderate | 500 | 2368 | Trellis and parallel | Fluvial and glacial erosion, some glacial deposition |
| | Mainstem Tributaries, Lower Susquehanna | Great Valley | Very broad valley, northwest half, dissected upland, southeast half, low karst terrain | northwest Shale and sandstone, slate, southeast, limestone and dolomite | Low to Moderate | 140 | 1100 | Dendritic and Karst | Fluvial erosion, solution of carbonate rocks, some peri-glacial mass wasting |
| | Mainstem Tributaries, Lower Susquehanna | South Mountain | Linear ridges, deep valleys and flat uplands | Metavolcanic rocks, quartzite, and some dolomite | Moderate to High | 450 | 2080 | Dendritic | Fluvial erosion of highly variable rocks, some peri-glacial mass wasting |
| Piedmont | Mainstem Tributaries, Lower Susquehanna | Gettysburg-Newark Lowland | Rolling lowlands, shallow valleys and isolated hills | Mainly red shale, siltstone and sandstone, some conglomerate and diabase | Low to Moderate | 20 | 1355 | Dendritic and trellis | Fluvial erosion of rocks with variable resistance |
| | Mainstem Tributaries, Lower Susquehanna | Piedmont lowland | Broad, moderately dissected karst valleys separated by broad low hills | Dominantly limestone and dolomite, some phylitic shale and sandstone | Low | 60 | 700 | Dendritic and Karst | Fluvial erosion, some peri-glacial mass wasting |
| | Mainstem Tributaries, Lower Susquehanna | Piedmont upland | Broad, rounded to flat-topped hills and shallow valleys | Mainly schist, gneiss, and quartzite, some saprolite | Low to Moderate | 100 | 1220 | Dendritic | Fluvial erosion, peri-glacial mass wasting |

## Appendix 3. Maps of All Major Habitat Types

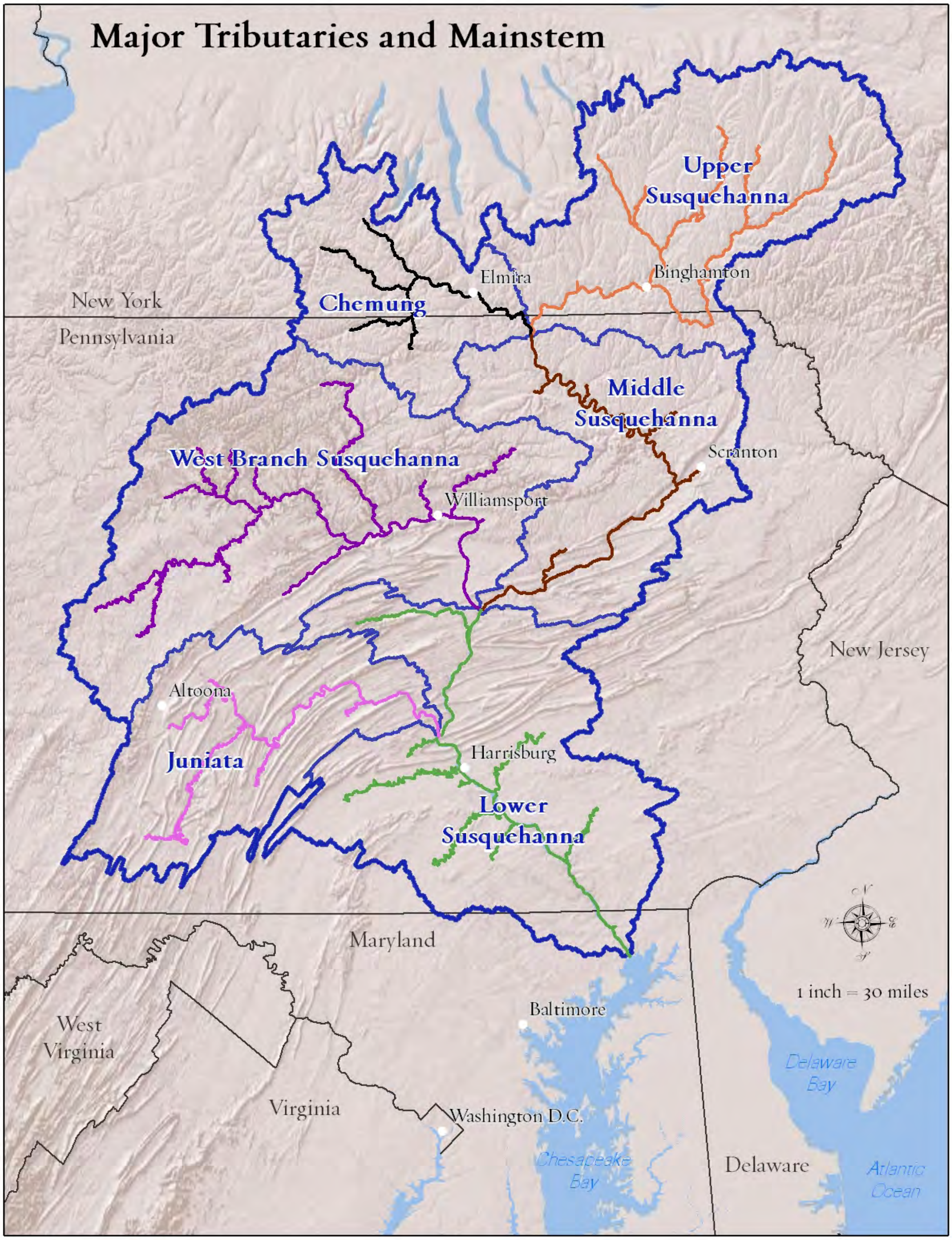




Warmwater Streams
Upper Susquehanna
Chemung
Elmira
Binghamton
New York
Pennsylvania
Middle Susquehanna
West Branch Susquehanna
Scranton
Williamsport
New Jersey
Altoona
Juniata
Harrisburg
Lower Susquehanna
Maryland
1 inch = 30 miles
Baltimore
West Virginia
Delaware Bay
Virginia
Washington D.C.
Chesapeake Bay
Delaware
Atlantic Ocean



High Baseflow Streams
Upper Susquehanna
Chemung
Elmira
Binghamton
New York
Pennsylvania
Middle Susquehanna
West Branch Susquehanna
Scranton
Williamsport
New Jersey
Altoona
Juniata
Harrisburg
Lower Susquehanna
Maryland
1 inch = 30 miles
Baltimore
West Virginia
Delaware Bay
Virginia
Washington D.C.
Chesapeake Bay
Delaware
Atlantic Ocean


Major Tributaries and Mainstem
Upper Susquehanna
Binghamton
Elmira
Chemung
New York
Pennsylvania
Middle Susquehanna
Scranton
West Branch Susquehanna
Williamsport
New Jersey
Altoona
Juniata
Harrisburg
Lower Susquehanna
Maryland
1 inch = 30 miles
Baltimore
West Virginia
Delaware Bay
Virginia
Washington D.C.
Chesapeake Bay
Delaware
Atlantic Ocean

# Appendix 4. Life History Diagrams and Tables

## Fish

Cold headwater

Riffle obligates

Riffle associates

Nest builders

Diadromous (migratory)

## Mussels

Primarily riverine

Facultative riverine

Primarily lentic

## Reptiles and Amphibians

Aquatic –lotic

Semi-aquatic lotic

Riparian and floodplain-terrestrial and vernal

## Aquatic and Riparian Vegetation

# Fishes: Cold Headwater - Brook trout (*Salvelinus fontinalis* ) and *Cottus spp* .

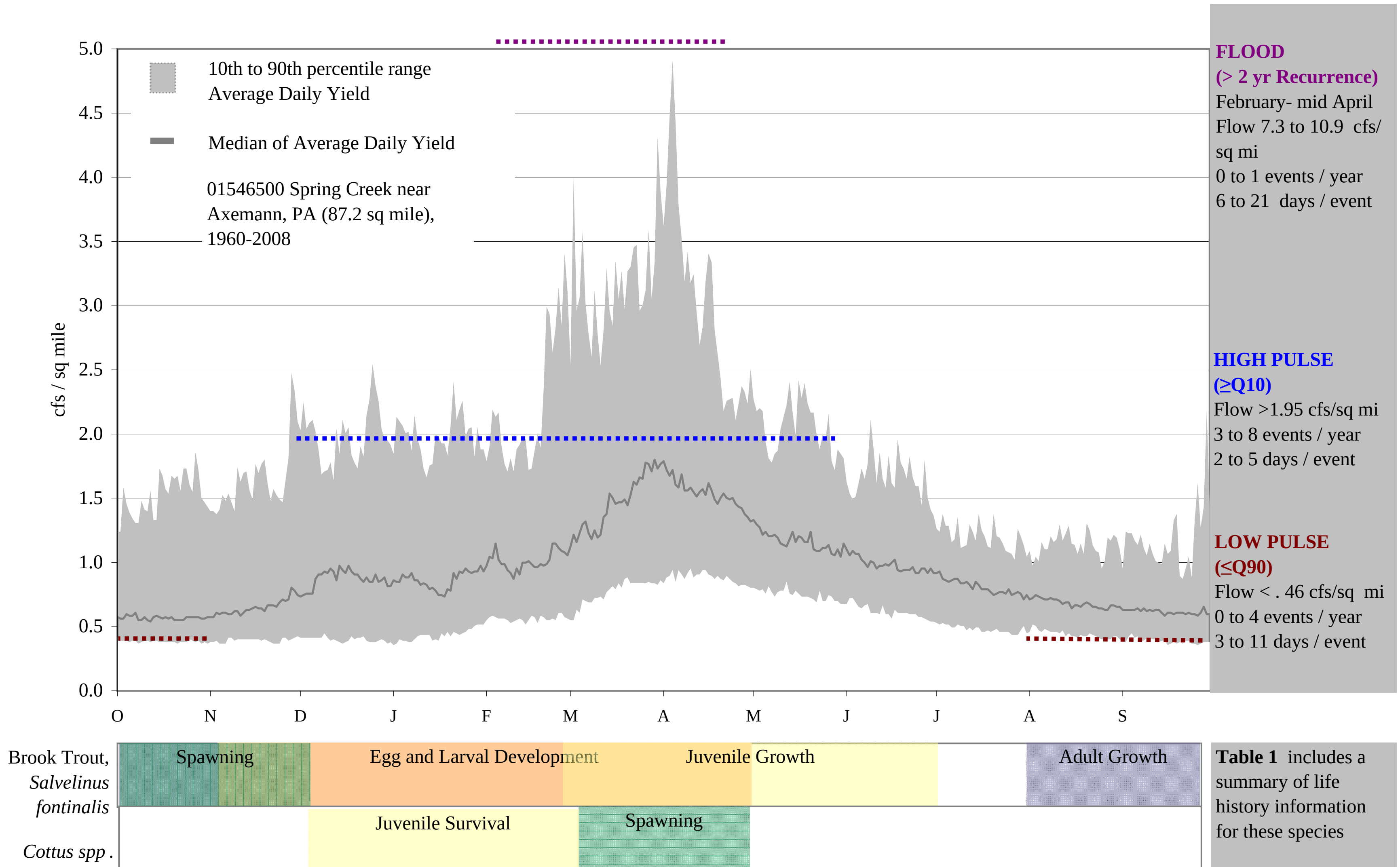



**Table 1** includes a summary of life history information for these species

**Table 1 Cold headwater fishes life history summary**

| | Life Stage | Timing | | Habitat | | | | Hydro- Ecology Relationships | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Event | Cue | Substrate | Temp | DO + | pH | Q or Velocity | Depth | Hydraulic Habitat Unit | Comments |
| **Brook Trout, *Salvelinus fontinalis*** | **Egg and Larval development** | November through April: Fry emergence- 28 to 165 days depending on temperature | | 10-40 cm; eggs buried in gravel, presence of fines limits development | range 14.8 to 2.8 C, warmer temperatures decrease development time | | | Range: 0 - .88 ft/s, Opt. 0-.38 ft/s, | Range: .38- 2.88 ft, Opt: 1.13- 1.88 ft | | embryo development maximized at v 30 to 60 cm/s, fry overwinter in shallow areas with low velocity (.984 to 1.96 ft/s) |
| | **Juvenile Growth** | Cool months (March-June): Juvenile Growth | | use substrate (10 to 40 cm) as winter cover | | | | Range: 0 to 1.63 ft/s, Opt: 0 to .88 ft/s; 8-9 cm/s, max 24 cm/s (.26-.78 ft/s) | Range: .63- 2.88, Opt: 1.13-1.88 ft | margins, shallows | |
| | **Adult Growth** | Aug-Dec: most critical period during baseflow (lowest flows of late summer to winter) | sexual maturity varies, as early as age '0', Usually age 1 or 2 | rocky | cold, range: 0 to 24 C, with optimal range 11-16 C, the most limiting factor in suitable habitat | feeding habits greatly influenced by turbidity | tolerance 4-9.5, optimal 6.5-8 | Range: 0 to .25 ft/s, Opt 0 to .38 ft/sBFI > 50% excellent, <25% poor | Range .63-5 ft, Opt 1.13 to 2.63 ft | riffle-run areas with 1:1 pool-riffle ratio including areas of slow, deep water | |
| | **Spawning** | October and November | temperature 3 to 10 C, | redds built in gravel, sometimes sand | | intergravel $O_2$ concentration important for spawning success | | Opt. 0-.38 ft/s, Range: 0 - .88 ft/s, | Range: .38- 2.88 ft, Opt: 1.13- 1.88 ft | strong preference for areas of groundwater upwelling; found in all habitat types, higher tendency in downstream end of pools | |
| **Mottled Sculpin, *Cottus bairdi*** | **Egg and Larval development** | | | | | | | | | | |
| | **Juvenile Survival** | Dec-February: population size regulated by overwinter density-dependence among juveniles and adults | | | | | | | shallowest habitats throughout life cycle | margins and shallow riffles, specific habitat is dependent on adult sculpin density | |
| | **Adult Growth** | | Mature by age 2 | use interstitial spaces in substrate for cover, generalistic patterns in preference | tolerant of warm water | | | habitat specialist with regard to velocity (fast)* site specific values in Gray and Stauffer 1999 25 cm/s | shallow habitats throughout life cycle | riffles | |
| | **Spawning** | Mid March and April (Early spring) | small home range, same reach recapture, average 12.9 m | | | | | | | males select cavity beneath a rock in a stream riffle, eggs laid on underside of stones | |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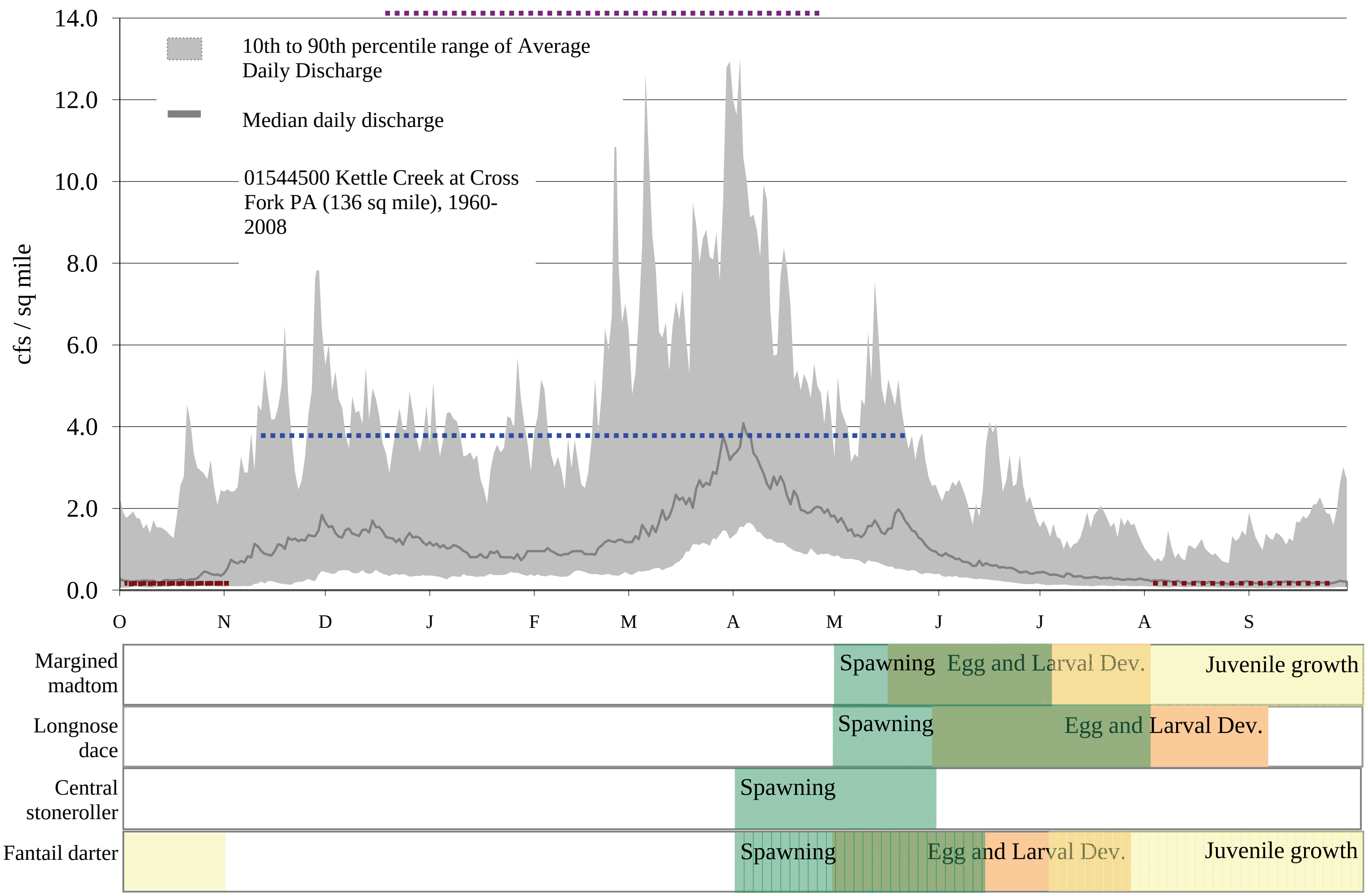
# **Fishes: Riffle-Obligates** - Margined madtom (*Noturus insignis*), Longnose dace (*Rhinichthys cataractae*), Central Stoneroller (*Campostoma anomalum*), Fantail Darter (*Etheostoma flabellare*)




**FLOOD**
**(> 2 Yr Recurrence)**
late Dec- late Apr
Flow 24 to 39 cfs / sq mile
0 to 1 events / year
6 to 12 days / event

**HIGH PULSE (≥Q10)**
Flow ≥ 3.9 cfs / sq mile
5 to 9 events / year
4 to 6 days / event

**LOW PULSE (≤Q90)**
Flow ≤ .1 cfs / sq mile
2 to 6 events / year
3 to 9 days / event

**Table 2** includes a summary of life history information for each species

**Table 2 Riffle-obligate fishes life history summary**

| | Life Stage | Timing | | Habitat | | | Hydro- Ecology Relationships | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Months | Cue | Substrate | Temp | DO | Q or Velocity | Depth | Hydraulic Habitat Unit | Comments |
| **Margined Madtom,** *Noturus insignis* | Egg and Larval development | Late May to August, 1 to 3 weeks from spawning | Incubation 7-10 days at 15.6 C yolk sac absorbed 7 days after hatch | | | | | | riffles | |
| | Juvenile Growth | Most growth occurs in July, August and Sepember after Spawning has occured | | | | | | | | |
| | Adult Growth | | Mature by age 2, live up to 4 years | sand or gravel bottom | warm water | | moderate current | | riffles | |
| | Spawning | May to June | | nests beneath flat rocks | | | moderate current | | | |
| **Longnose dace,** *Rhinichthys cataractae* | Egg and Larval development | June-end Aug. (three weeks after fertilization) | | | | | within 6 weeks of age, move to swift water areas ( > 45 cm/s) | | fry abundant in protected margins of quiet shallow water, | |
| | Juvenile Growth | | | | | | v > 45 cm/s | < .3 m rarely > 1m | riffles | juveniles and adults are adapted to high velocity areas |
| | Adult Growth | | mature at age 2, live up to 5 years | | | | v = 45 to 60 cm/s, observed living as high as 182 cm/s | < .3 m rarely > 1m | swift flowing, steep gradient headwater streams of larger river systems, shelter from current must be present | small home range, most recaptures in same reach, average distance 13.4 m |
| | Spawning | As early as May, Late as August, peak from June to early July | when daily maximum temp exceeds 15 C (Bartnik 1970) | gravel and rock smaller than 20 cm diameter | Optimum 14-19 C | | | < .3 m rarely > 1m | | |
| **Central Stoneroller,** *Campostoma anomalum* | Egg and Larval development | | | in a depression of gravel or gravel and sand mix | | | | | | |
| | Juvenile Growth | | | | | | | | | |
| | Adult Growth | | Mature in 1 to 5 years | hard bottomed streams | | | | | runs and riffles, males commonly school over Nocomis nests | |
| | Spawning | April to May | | males dig pits in shallow-gravel bottomed areas, may maintain spawning pits in close proximity | | | slow to moderate | | | |
| **Fantail darter,** *Etheostoma flabellare* | Egg and Larval development | May-July: Hatch one month behind spawning (30 to 35 days at 17-20 C) | 14-16 days at 23 C | | | | | | | |
| | Juvenile Growth | Mid July-November- Juvenile development | | | | | | | pools and slackwater areas downstream of riffles | |
| | Adult Growth | | Mature at age 1 or 2 | particularly abundant in streams with slabs of limestone or shale; many stones and rocks for cover | cool and warm streams | | | shallow to very shallow | riffles or along the shallow banks | |
| | Spawning | April to Mid June | correlated with temperature | | temps 15 to 24 C | | | | runs and slow riffles including shallows | |

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# Fishes: Riffle-Associates - White Sucker (*Catostomus commersoni*), Shorthead redhorse (*Moxostoma macrolepidotum*), Northern hogsucker (*Hypentelium nigricans)*

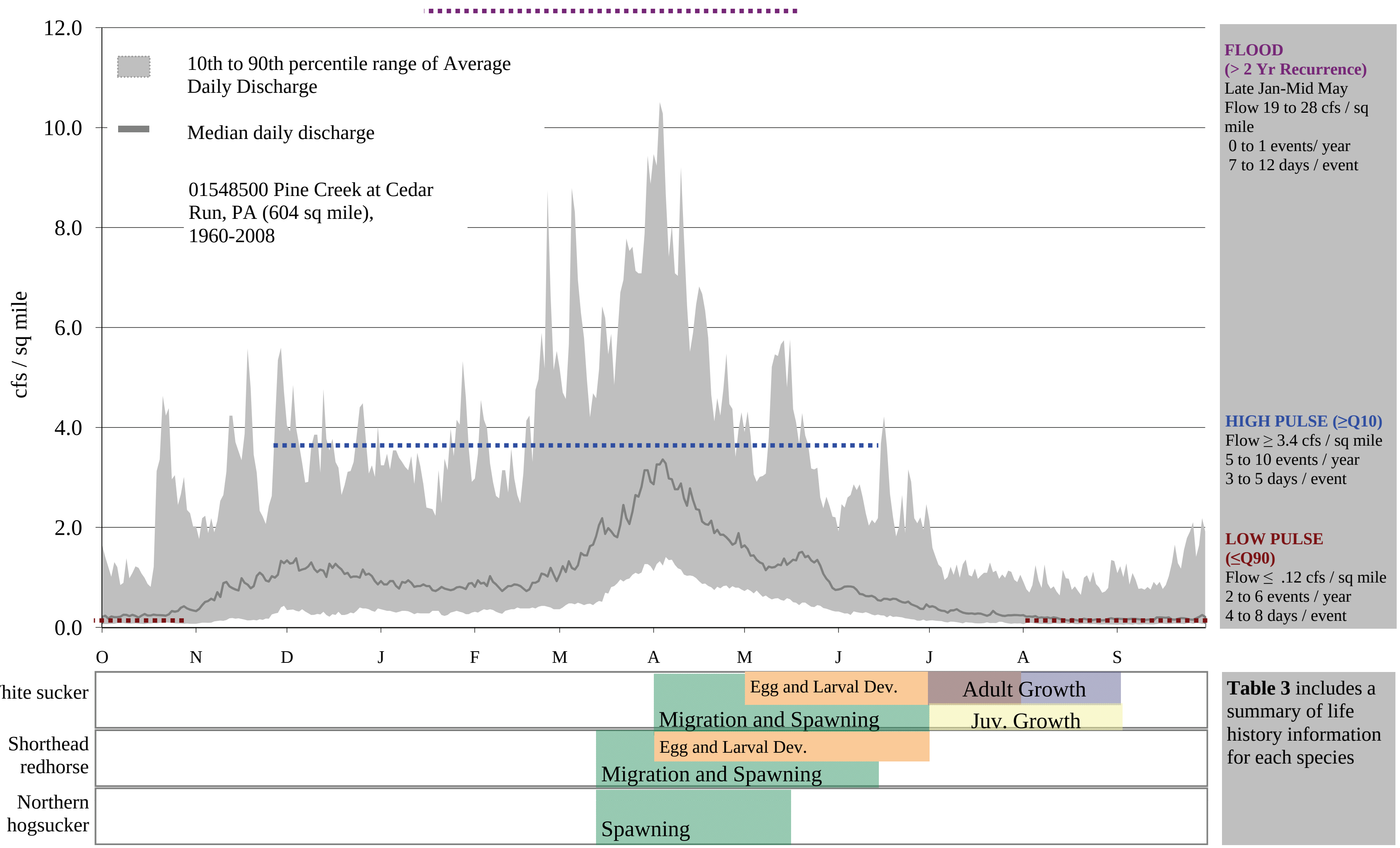

**Table 3 Riffle-associate fishes life history summary**

| | Life Stage | Timing | | Habitat | | | Hydro- Ecology Relationships | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Event | Cue | Substrate | Temp | DO + | Q or Velocity | Depth | Hydraulic Habitat Unit | Comments |
| **White sucker,** *Catostomus commersoni* | **Egg and Larval development** | May-July (three weeks to one month after spawning) | embryo development temperature dependent | | max hatching success 15 C | | riffle velocity Opt: 30 to 60 cm/s | | | longlived (common 10, max found up to 17 years) |
| | **Juvenile Growth** | July-August: Max growth occurs July through August | | | | | | | pools: HSI Optimal 30 to 60 % pools | |
| | **Adult Growth** | July-August: Max growth occurs July through August | | | geographically dependent, but wide range | optimal 6 to 10, Range 1.2 to 10 | moderate current, migration can be impeded by swift currents | | deep connected pools and slow runs (10-19 cm/s), Max abundance in low to moderate gradient streams ( 2.8 to 7.8 km/m, few inhabit > 28.4 m/km), Pools: 30 to 60 % (HSI) | growth inhibited during gonadal development and spawning |
| | **Migration and Spawning** | April through June | upstream migration triggered temperature (50 deg F) or streamflow | gravel (2 to 16 mm), can have clean sand, but gravel necessary | range 6 to 24 C, Opt 12 to 16 C, migration ceases > 18 C | | spawning site selection influenced primarily by water velocity and depth of substrate type, HSI riffle velocity Opt: 30 to 60 cm/s | shallow waters (HSI Range: about 4 to 45 cm, Optimal 15 to 27 cm) | migrate from stream pools to riffles of small creeks and rivers, | migration distance ranging from a few hundred meters to 6.4 km, |
| **Shorthead Redhorse,** *Moxostoma macrolepidotum* | **Egg and Larval development** | April through late June: 1 to 2 weeks after fertilization | | | hatched at mean temperature of 15.6 C | | | | | |
| | **Juvenile Growth** | Oct-February | | | | | .75-3.4 ft/s optimal | 1.5-3.0 ft | | |
| | **Adult Growth** | | | | | | 1.5-4.3 ft/s optimal, 23-63 cm/s, 0-1 ft/s | 2.0-12 ft, 1-6 ft, 1-2 m | | |
| | **Migration and Spawning** | Mid March-Early June | | course mixed substrate, gravel and cobble | | | 0-.5 ft/s, .6-.9 m/s | 30-60 cm, 1-2 ft | | |
| **Northern Hogsucker,** *Hypentelium nigricans* | **Egg and Larval development** | April through late May | estimated 2 weeks to hatch another 1 to 2 for yolk sac absorbtion | hatch in 10 days at mean temp 17.4 C; | | | | | | eggs and small young predated by other fish |
| | **Juvenile Growth** | | | | | | | | | disturb bottom sediment, sympatric relationship with fish following to take advantage of drift |
| | **Adult Growth** | | | mature at age 2-4 | gravelly/ stony streams | | | | feeds and rests in very shallow riffles | rests on bottom of stream in shallow riffles |
| | **Spawning** | late March through early May | | | gravel; gravel and sand | 60 F | | fast-flowing | shallow | move from larger streams to smaller headwaters to spawn, over riffles, like other suckers |


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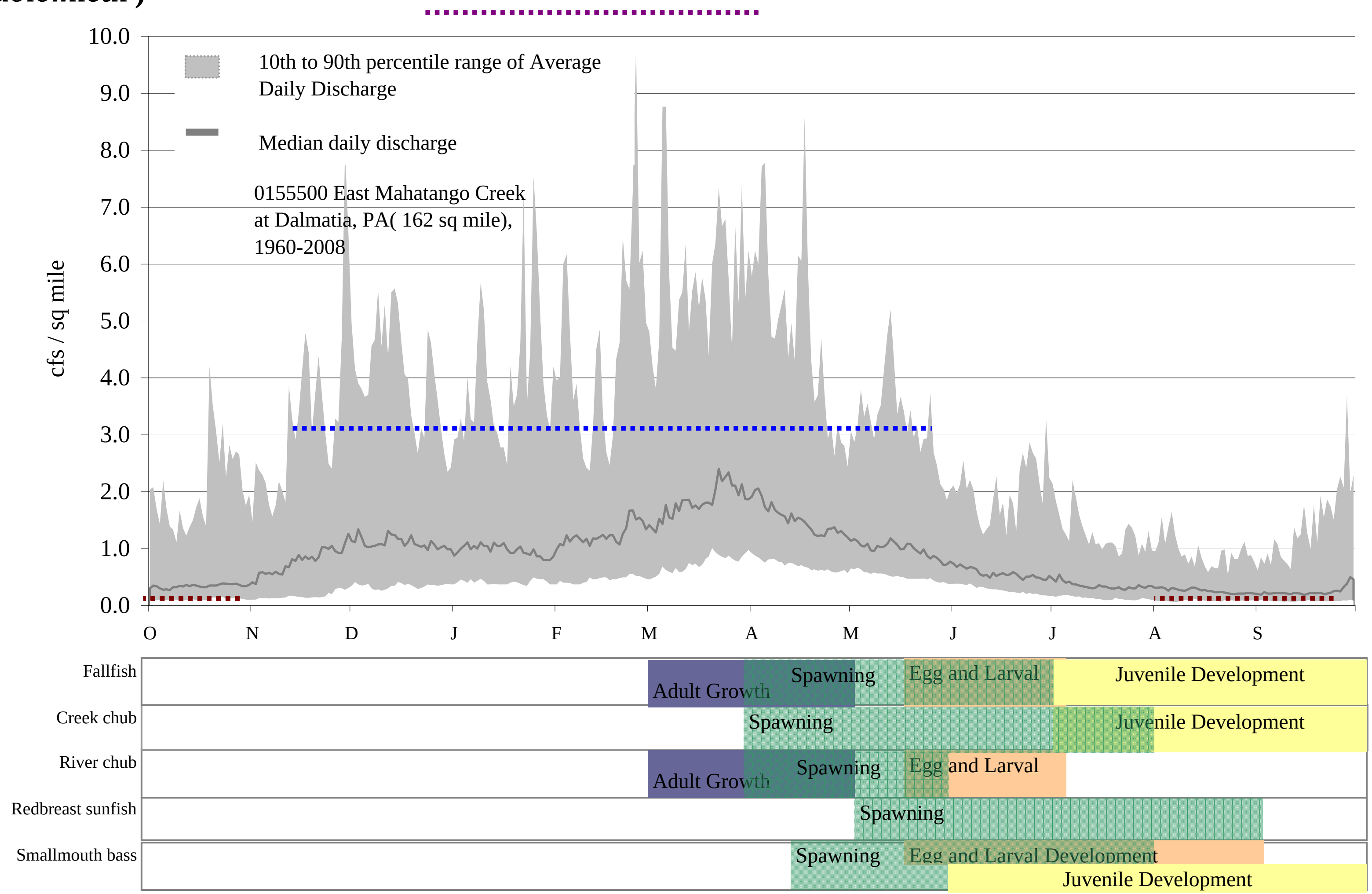
# Fishes: Nest-builders - Fallfish (*Semotilus corporalis* ), Creek chub (*Semotilus atromaculatus* ), River chub (*Nocomis micropogon* ), Redbreast sunfish (*Lepomis auritus* ), Smallmouth bass (*Micropterus dolomieui* )




**FLOOD**
**(> 2 Yr Recurrence)**
End Dec- Early Apr
Flow 21 to 39 cfs / sq mile
0 to 1 events/ year
6 to 12 days / event

**HIGH PULSE (≥Q10)**
Flow ≥ 3.1 cfs / sq mile
7 to 12 events / year
3 to 4 days / event

**LOW PULSE**
**(≤Q90)**
Flow ≤ .1 6 cfs / sq mile
1to 6 events / year
3 to 10 days / event

**Table 4** includes a summary of life history information for each species

**Table 4 Nest-builder fishes life history summary**

| | Life Stage | Timing | | Habitat | | | Hydro- Ecology Relationships | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Months | Cue | Substrate | Temp | DO + | Q or Velocity | Depth | Hydraulic Habitat Unit | Comments |
| **Fallfish**, *Semotilus corporalis* | **Egg and Larval development** | Late May-June | eggs hatch in 5 to 6 days, fry emerge 9 to 11 days after hatching and drift downstream at night | | incubation occurs between 16 and 18 C, | | | | | Longlived (up to 11 years), similar to creek chub |
| | **Juvenile Growth** | Warm months | | | | | | | juveniles occur in smaller streams than adults | largest minnow east of the rockies, constructs the largest stone mound nest known |
| | **Adult Growth** | | Reach maturity at age 4 (as early as 2) | Sand and gravel | warmest water temperatures, Range 5-27 C, Opt- 10-20 C; seldom occur > 28 C | | tolerant to high flows in early spring | | clear gravel bottomed streams, commonly found near base of cascades and falls | Turbidity < 30 JTU's * assumption that this equates to clear water |
| | **Nest building and spawning** | April - June | temperature | | Throughout spawning season Range: 15-18, Opt: 16.5-17.5, spawning may cease if temps drop below 15 C | | 5-69 cm/s | Avg depth across stream Opt: ≤.5 m | move from larger waters into smaller streams to spawn, prefer habitats with overhead cover, | Select spawning grounds based on abundance of instream cover over preferred substrate type |
| **Creek Chub**, *Semotilus atromaculatus* | **Egg and Larval development** | | | | 15 -20 C | 5 mg/L; some studies have shown tolerance to low DO concentrations (last to die at AMD sites) | Opt < 10 cms | between 30 and 100 cm | fry- edges of stream edges and margins | Cover is also an important compentent to habitat quality (an HSI var) |
| | **Juvenile Growth** | Warm months | | | | | 10 cm/s | < 1m depth | juveniles prefer stream edges and margins | |
| | **Adult Growth** | | Mature between ages 2 and 5 | gravel | average temperature 18-22 C; always < 32 C | | | < 1 m average depth and .5 to 7 m in width | small, clear, cool stream with moderate to high gradient, well defined riffles and pools (greatest abundance in gradients 7 to 13.4 m/km), 45-60% pools | |
| | **Nest building and spawning** | Apr- July | temperature | | temp 14 C | | < 1.25 cfs (xxx), 20-60 cms in riffle areas from April to June (HSI) | depth > 100 cm, width .15-7 m | immediately up or downstream of riffles in shallow water | |
| **River Chub** *Nocomis micropogon* | **Egg and Larval development** | Late May - June | | gravel | | | slow to moderate current | | | Bigmouth chub a similar species, bigmouth chub closely related relative to cladistic analysis, |
| | **Juvenile Growth** | | mature at age 2 or 3 | | | | | | | |
| | **Adult Growth** | March-April: gonadal development | | | temp 13 C (during gonadal development) | | tolerant to high flows in early spring (during gonadal development) | | riffles in high gradient streams of moderate size; medium to large tributaries, pools runs and riffles | |
| | **Nest building and spawning** | Apr-May | temp > 20 C, 17-26.7 C | gravel | Range: 17-26.7 C | | | slow to moderate current, 5 - 69 cm/s or .16- 2.2 ft/s (bigmouth chub) | > 15 cm, a nest height at center recorded as 10 cm | 3 to 8 m in width; 27 minnow species recorded to be nest associates of Nocomis |

**Table 4 Nest-builder fishes life history summary**

| Species | Life Stage | Timing: Months | Timing: Cue | Habitat: Substrate | Habitat: Temp | Habitat: DO + | Hydro- Ecology Relationships: Q or Velocity | Hydro- Ecology Relationships: Depth | Hydro- Ecology Relationships: Hydraulic Habitat Unit | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| **Redbreast Sunfish** *Lepomis auritus* | **Egg and Larval development** | | | redds preferrably located in sand or gravel | | | very succeptible to high flows (male guarders desert nests), 0-.25 ft/s optimal | stable water levels are critical for egg adhesion, nests in shallow water <1 m optimal | physical obstructions in lotic systems (logs, stumps, etc.) | |
| | **Juvenile Growth** | | | | | | .4-.6 ft/s optimal | .5-5.2 ft optimal | | |
| | **Adult Growth** | | | gravel and cobble optimal | | | .5-.8 ft/s optimal | 2-6.1 ft optimal | | |
| | **Nest building and spawning** | May- August | | coarse sand, gravel no silt | temperature 20 to 28 C | optimal - seldom below 5 mg/L | varies by study, < 20 cm/s, .59 ft/s and 0 to .5 ft/s | .2 to 1.5 meters | calm pools, protected areas such as near logs, fallen trees, or stumps | suceptible to high flow after nest building, adults desert nest and/or nests destroyed in high flow events |
| **Smallmouth Bass** *Micropterus dolomieui* | **Egg and Larval development** | up to 1 month past spawn | | nests built on sand, gravel, or rock | 15-25 C | | < .2 m/s, flood after spawning reduces survival if scouring occurs | .3-.9 m deep | pools, successful nests closer to the stream bank | |
| | **Juvenile Growth** | June flows have significant influence on survival, growth during warm months | | no clear preference | | | strongest year classes when June flows within 40% of the longterm mean | | | |
| | **Adult Growth** | | | no clear preference | 21-27 C in summer | | 10 cm/s or less | | pools | |
| | **Nest building and spawning** | Mid April-July | mean daily water temperature most important variable (as it interacts with discharge), tend to spawn during the receding limb of a high flow event | nests built on sand, gravel, or rock with almost always under protection of cover | > 15 C and < 25 C | | slow current, a flood event can split the spawning season in two | .3-.9 m deep | pools, protected areas, very strongly prefer areas of abundant shade and cover | |

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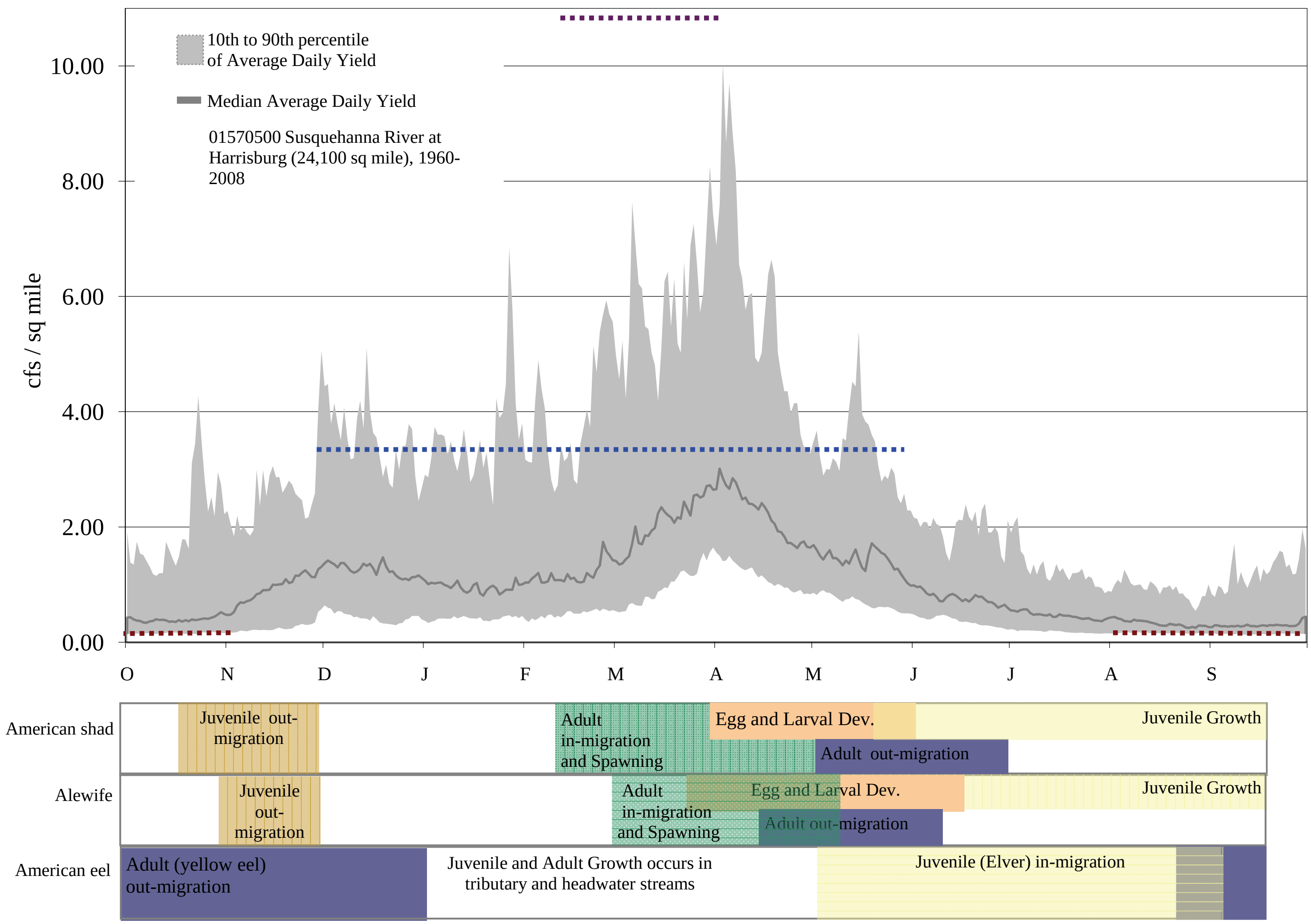
# Fishes: Migratory - American shad (*Alosa sapidissima*), Alewife (*Alosa pseudoharengus*), and American eel (*Anguilla rostrata*)




**FLOOD**
**(> 2 yr Recurrence)**
Late Feb. to Early April
Flow 10.8 to 16.6 cfs / sq mile
0 to 1 events / year
0 to 27 days / event

**HIGH PULSE (≥Q10)**
Flow ≥ 3.2 cfs / sq mile
4 to 8 events / year
4 to 6 days / event

**LOW PULSE**
(≤Q90)
Flow ≤ .2 cfs / sq mile
1 to 4 events /year
4 to 17 days / event

**Table 5** includes a summary of life history information for each species

**Table 5. Migratory Fishes life history summary**

| | Life Stage | Timing | | Habitat | | | | Hydro- Ecology Relationships | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Event | Cue | Substrate | Temp | DO + | pH | Q or Velocity | Depth | Hydraulic Habitat Unit | Comments |
| **American Shad** *Alosa Sapidissima* | **Egg and Larval development** | Early April to Late May | development time correlated inversely to temperature | eggs drift 5- 25 m downstream of spawning area; higher survival in gravel, rubble and sand | range 10 to 30 C, Optimal 15-25 C | DO ≥ 5 mg/L | | optimal .3 to .9 m/s (.98 to 2.95 ft/s), minimum flow beneficial to prevent suffocation and infection | tolerable .46-15.4 m, Optimal: 1.5 to 6.1 m | yolk sac larvae found deeper in the water column, offshore-near bottom | year class strength is negatively correlated to river flow (Marcy 1976), survival rates greater when spring high flows preceed hatch, decrease when June pulse occurs |
| | **Juvenile Growth and emigration** | Emigration late Oct to Late Nov | cue likely a combination of temperature and lunar cycle; juveniles can't tolerate a change +/- 1 to 4 C from ambient | boulder cobble gravel sand, where SAV exists, there is a correlation between SAV habitat (>50% cover) and juvenile abundance, | 8 to 19 C | DO ≥ 5 mg/L | | optimal: .1 - .8 m/s (.33 to 2.62 ft/s), moderate velocity needed for migration, also thought to orient juveniles downstream | range: .46-15.4 m, Optimal: 1.5 to 6.1 m | | |
| | **Adult Growth** | Adults return to sea and migrate to summer feeding grounds after spawning | remain in ocean 2 to 6 years before sexual maturity (male avg. 4.3, and female 4.6 yrs), return to spawn in natal river | | | | Anadromous- In marine environment for this life stage | | | | |
| | **Migration and Spawning** | Begin to enter freshwater in winter, gonadal development early March-Apr, spawning peak in early May (on Delaware) | temperature 13-20 C* in CT River, temp at peak spawning found to vary from year to year | substrate not constraining to site selection | Range: 8-26 C, Optimal: 14-24.5 C | DO ≥ 4 mg/L | | velocity an important factor, Optimal .3 to .9 m/s (.98 to 2.95 ft/s) | < 300 cm, tolerable .46-15.4 m (1.5-50'), Optimal: 1.5 to 6.1 m (4.92-20'), | broad flats, runs, shallow water with moderate current, avoid pools but prefer slow flow | |
| **Alewife** *Alosa pseudoharengus* | **Egg and Larval development** | Range 2 to 15 days after spawning, most often 3 to 5 days after spawning | development time after fertilization, correlated inversely to temperature | 75% silt or substrate containing detritus and vegetation | Optimal: 14-21 C Range 10-27 , cease hatching >29.7 C, | ≥5.0 mg/L | 5 to 8.5 | velocity one of strongest predictors of egg presence (O'Connell 1997), rapid decline when flows too high (Pamunkey 1989), or too low (Rhode Island 1981) | | | |
| | **Juvenile Growth and emigration** | Growth March-Oct, Emigration November | changes in water flow, stage, precipitation, light intensity or temperature and moon phases | 75% silt or substrate containing detritus and vegetation, HSI available (1) ≥ 75% mud or silt or other soft material containing detritis and vegetation, (2) ≥ 50% mud or silt, some sand and vegetation, (3) ≥ 75% sand or other | Range: 5 to 27 C, Optimal: 15 -20 C, | min 3.6 mg/L | 8.2 | avoid high flows, avoid narrow channels where v > 10 cm/s | | | net gain in biomass highest at 26.4 C in Kellogg 1982 study |
| | **Adult Growth** | After spawning, adults return to estuary and feed until migrating to wintering grounds | sexual maturity occurs at a minimum age of 2, spawning populations 3 to 8 in the Ches. Bay | | | | Anadromous- In marine environment for this life stage | | | | |
| | **Migration and Spawning** | Enter freshwater in March and April, spawning begins 2 to 3 wks earlier than shad (late April) | most predictably temperature, may also be triggered by high flow periods | | 10.5 C-21.6, Cease spawning when > 27 C | ≥5 mg/L | found spawning in streams from 5.0 to 7.3 | sluggish water flows | 15 cm to 3 m, typically less than 1 m | floodplains, river margins, ponds, backwaters of lower CT River, slow moving sections of rivers, in rivers with headwater ponds; shore-bank eddies or deep pools below dam | |
| **American Eel** Anquilla rostrata | **Egg and Larval development** | | | | | | Catadromous- In marine environment for this life stage | | | | |
| | **Juvenile Growth and immigration** | Juveniles (elvers) enter Susquehanna from May - September, peaking in June and July | bottom habitat with coarse substate preferred | burrow in sand, mud, tubes, snags, plant masses, etc. during the day and in between movements | wide range | | | tolerant of 25 cm/s | | | no feeding during migration |
| | **Adult Growth- Yellow Eel** | May-Oct | migration continues | | | | | most in areas with wide variety of velocities | most in areas with wide variety of depths | | |
| | **Emigration of Silver Eel** | Mid-Sept to Dec: emigrate to Sargasso Sea to spawn mostly during the fall | | | reported at 18-19 C | | | | | | |

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# Mussels: Primarily Riverine - Green floater (*Lasmigona subviridis*), Elktoe (*Alasmidonta marginata susquehannae*), Brook floater (*Alasmidonta varicosa*) and Creeper (*Strophitus undulatus*)

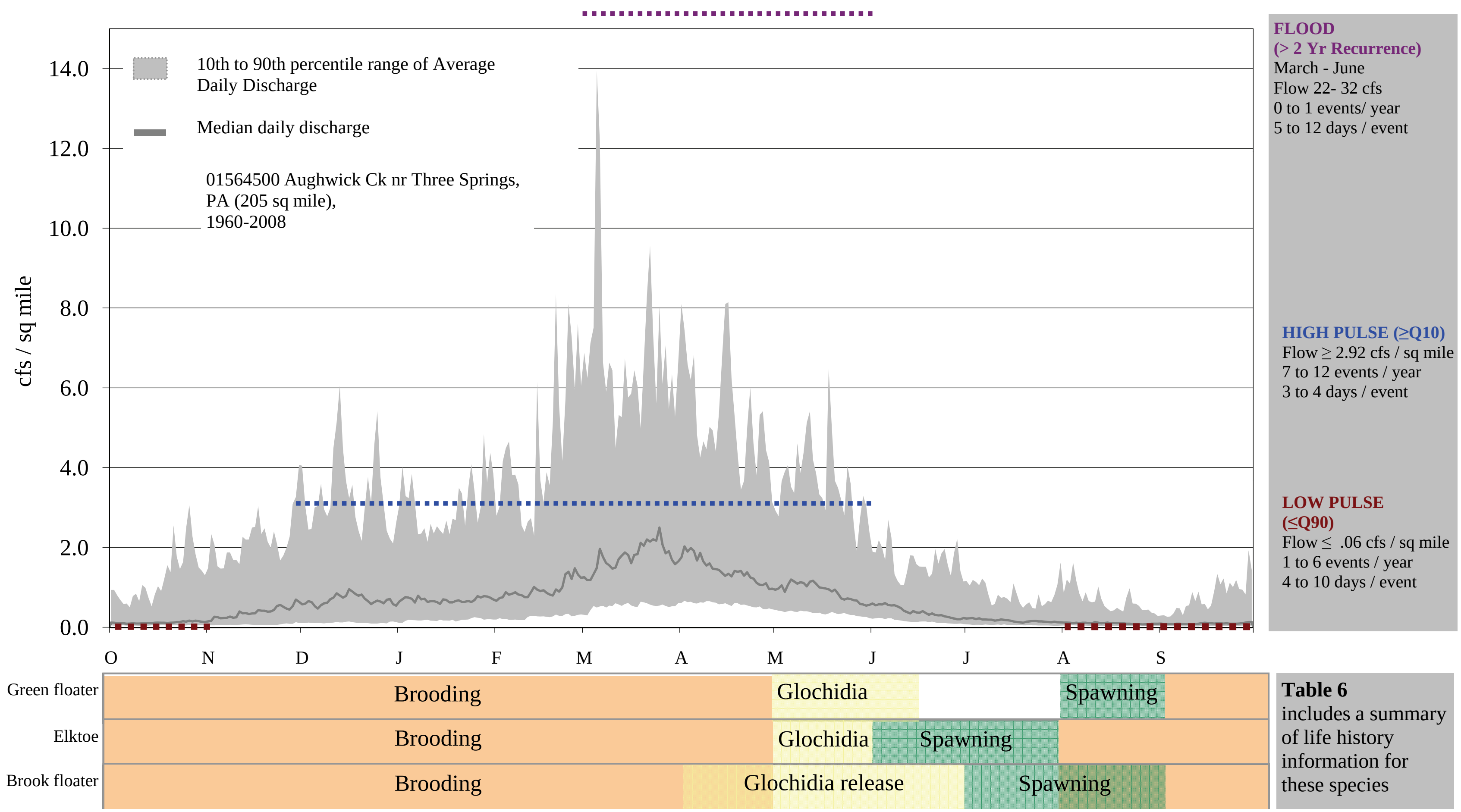


**Table 6** includes a summary of life history information for these species

**Table 6. Primarily riverine mussels life history summary**

| | Life Stage | Timing: Months | Timing: Cue | Habitat: Substrate | Habitat: Temp | Habitat: DO | Hydro-Ecology: Stream type | Hydro-Ecology: Hydraulic Habitat Unit | Hydro-Ecology: Q or Velocity | Hydro-Ecology: Depth | Reproduction: Host Traits | Reproduction: Host Fish | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Green floater,** *Lasmigona subviridis* | Spawning | August | most Unionids cue on temp | sand and gravel | | | more abundant in small streams, also found in medium streams and rivers | areas protected from scour including backwaters and sidechannels near islands, quiet but not stagnant water, active inflow required | moderate, intolerant of strong currents | shallow, 1-4 ft | not known | not known | not drought tolerant, found to be at sites with stable hydrograph as opposed to ones with droughts or spates, associated with good to excellent water quality conditions |
| | Brooding | August-May | | | | | | | | | | | |
| | Glochidia Release | May-Early June | | | | | | | | | | | |
| **Elktoe,** *Alasmidonta marginata susquehannae* | Spawning | June-July | most Unionids cue on temp | sand, gravel and small cobble substrate | | | small to medium streams and rivers, but can be found in medium to large streams | fast currents and riffles | moderate to swift | | range of mobile, larger bodied and smaller localized species | identified host species of white sucker, northern hog sucker, shorthead redhorse, rock bass and warmouth sunfish | indicative of rivers with high water quality, does not tolerate impoundment |
| | Brooding | August-May | | | | | | | | | | | |
| | Glochidia Release | May | | | | | | | | | | | |
| **Brook floater,** *Alasmidonta varicosa* | Spawning | in the summer | most Unionids cue on temp | relatively stable, course sands gravel and cobble | | | small to large streams and rivers | riffles | moderate to swift | | small bodied, localized species | longnose dace, golden shiner, pumpkinseed, slimy sculpin | frequently found in streams with low calcium levels/ oligotrophic or nutrient-poor, trait in common with many other Alasmidonta |
| | Brooding | August-May | | | | | | | | | | | |
| | Glochidia Release | April-June | | | | | | | | | | | |
| **Creeper,** *Strophitus undulatus* | Spawning | July-August | most Unionids cue on temp | coarse and fine substrates, gravel, fine gravel and sand | | | small to medium streams and rivers | | slow to moderate | shallow, < 3- 4 ft deep | range of mobile, larger bodied and smaller localized species | largemouth bass, creek chub, fallfish, fathead minnow, golden shiner, common shiner, slimy sculpin, bluegill, long-nose dace, yellow perch, | relatively tolerant species, widely distributed, rarely abundant |
| | Brooding | August-May | | | | | | | | | | | |
| | Glochidia Release | Late April-Early June | | | | | | | | | | | |

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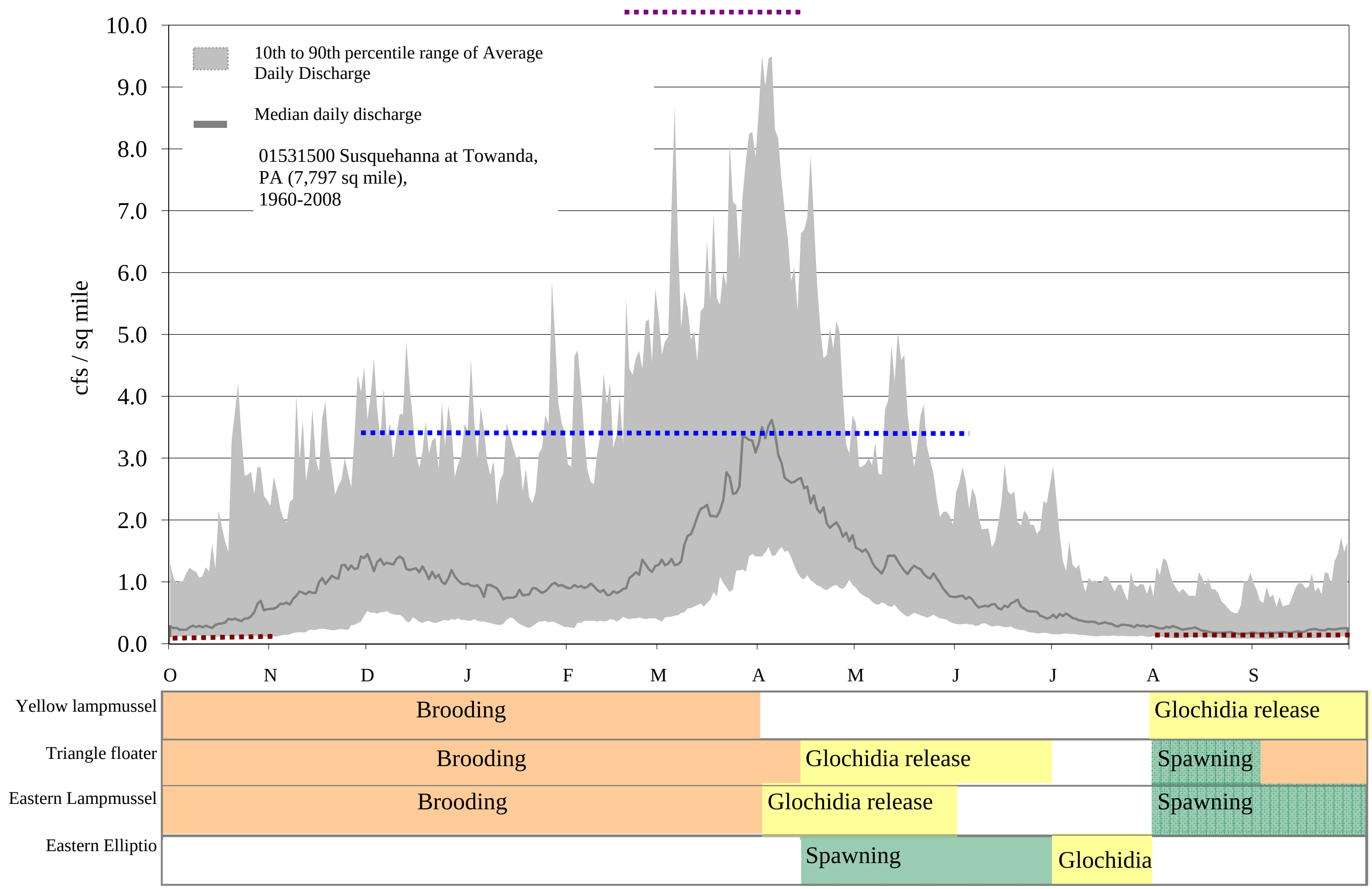
# **Mussels: Facultative Riverine** - Yellow lampmussel (*Lampsilis cariosa*), Triangle floater (*Alasimidonta undulata*), Eastern lampmussel (*Lampsilis radiata*) and Eastern Elliptio (*Elliptio complanata*)




**FLOOD**
**(> 2 Yr Recurrence)**
Late Feb-Early Apr
Flow 12 to 19 cfs / sq mile
0 to 1 events / year
7 to 17 days / event

**HIGH PULSE (≥Q10)**
Flow ≥ 3.4 cfs / sq mile
5 to 10 events / year
3 to 4 days / event

**LOW PULSE (≤Q90)**
Flow ≤ .16 cfs / sq mile
1 to 4 events / year
6 to 17 days / event

**Table 7** includes a summary of life history information for each species

**Table 7 Facultative riverine mussel species life history table**

| | | Timing | | Habitat | | | Hydro-Ecology | | | | Reproduction | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Life Stage** | Months | Cue | Substrate | Temp | DO | Stream type | Hydraulic Habitat Unit | Q or Velocity | Depth | Host Traits | Host Fish Species | **Comments** |
| **Yellow lampmussel,** *Lampsilis cariosa* | Spawning | Early Summer | most Unionids cue on temp | Various (sand, silt and gravel) | | | Medium to Large Rivers and Lakes | gravel bars, and river margins | Slow to moderate | | larger-bodied, mobile species | Yellow perch, white perch, small mouth bass, large mouth bass | declining through its range, with the exception of the Chemung and Upper Susquehanna |
| | Brooding | | | | | | | | | | | | |
| | Glochidia Release | Late summer (August - September) | | | | | | | | | | | |
| **Triangle floater,** *Alasmidonta undulata* | Spawning | August | most Unionids cue on temp | Sand and gravel | | | Small to medium-sized rivers and lakes | can tolerate standing water | Slow to moderate | | small bodied, localized species | Broad range of host fish, primarily blacknose dace, commmon shiner, blacknose dace, longnose dace, shite sucker, pumpkinseed sunfish, fallfish, large-mouth bass, slimy sculpin | considered rare in the Susquehanna, generally valuable indicator of flowing habitat and stable substrates, widely distributed-rarely abundant |
| | Brooding | August-April | | | | | | | | | | | |
| | Glochidia Release | Late April-June | | | | | | | | | | | |
| **Eastern lampmussel,** *Lampsilis radiata* | Spawning | Late Summer spawning | most Unionids cue on temp | Sand and gravel | | | Small to medium-sized rivers and lakes | | Slow to moderate | | larger-bodied, mobile species | Broad range of host fish, warm water species including yellow perch, largemouth bass, smallmouth bass, black crappie, and pumpkinseed fish | tolerant of a range of environmental conditions, stable or increasing through its range |
| | Brooding | Late summer-spring | | | | | | | | | | | |
| | Glochidia Release | Spring | | | | | | | | | | | |
| **Eastern elliptio,** *Elliptio complanata* | Spawning | Late April-June | temperature | All types | temp rise to 20 C | when exposed to low O2, increased stress and mortality | Small to large streams and rivers and lakes | Generalist: riffles, runs, pools, near banks and in channels | Slow to swift current | most commo n from 1-1.6 m | larger-bodied, mobile species | Broad range of host fish, banded killifish, green sunfish, pumpkinseed , bluegill, orange-spotted sunfish, largemouth bass , yellow perch, and white crappie, potentially American eel | tolerant of emersion (drought) ability to withstand many forms of habitat disturbance, |
| | Brooding | May-July | | | | | | | | | | | |
| | Glochidia Release | July-August | | | | | | | | | | | |

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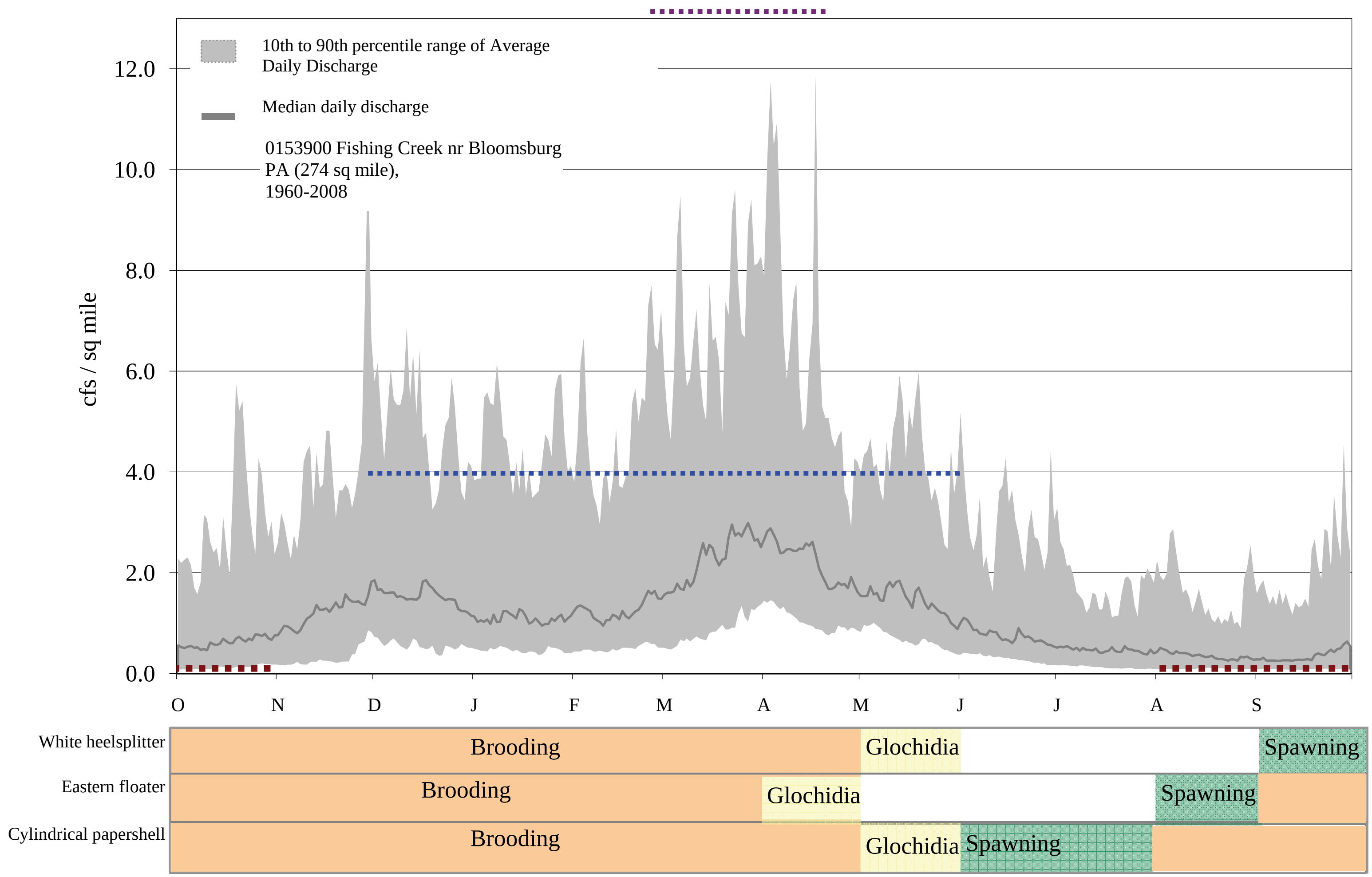
# **Mussels: Primarily Lentic -** White heelsplitter (*Lasmigona complinata*), Eastern floater (Pyganodon cataracta) and Cylindrical papershell (*Anodontoides ferussacianus*)




**FLOOD**
**(> 2 Yr Recurrence)**
Early Feb-Early Apr
Flow 28-37 cfs / sq mile
0 to 1 events/ year
7 to 11 days / event

**HIGH PULSE (≥Q10)**
Flow ≥ 3.94 cfs / sq mile
7 to 12 events / year
2 to 3 days / event

**LOW PULSE**
**(≤Q90)**
Flow ≤ .21 cfs / sq mile
1 to 5 events / year
4 to 16 days / event

**Table 8** includes a summary of life history information for these species

**Table 8: Primarily lentic mussels life history summary**

| | | Timing | | Habitat | | | Hydro-Ecology | | | | Reproduction | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Life Stage** | Months | Cue | Substrate | Temp | DO | Stream type | Hydraulic Habitat Unit | Q or Velocity | Depth | Host Traits | Host Fish Species | **Comments** |
| **White heelsplitter,** *Lasmigona complanata* | Spawning | September | | one of the few unionoids that seems to do well in disturbed sediments (Strayer and Jirka 1997) | | | creeks, rivers, reservoirs, lakes and embayments | opportunistic: may exploit marginal areas | Slow | | range of mobile, larger bodied and smaller localized species | common carp, banded killifish, green sunfish, orangespotted sunfish, largemouth bass, white crappie | tolerant of silt, habitat disturbance and impoundment, |
| | Brooding | October-May | | | | | | | | | | | |
| | Glochidia Release | May | | | | | | | | | | | |
| **Eastern floater,** *Pyganodon cataracta* | Spawning | August | | Various substrate types, including deep silt and mud | | | Streams, rivers, ponds and lakes | slow moving reaches | Slow | | range of mobile, larger bodied and smaller localized species | common carp, bluegill, pumpinseed sunfish, yellow perch, three-spined stickleback and white sucker are among suspected hosts | Widely distributed in the Susquehanna basin. Introduced to many man-made ponds, thrives in nutrient rich water, tolerant of deep silt and mud, tolerant of habitat modification and many forms of pollution |
| | Brooding | August-March | | | | | | | | | | | |
| | Glochidia Release | April | | | | | | | | | | | |
| **Cylindrical papershell,** *Anodontoides ferussacianus* | Spawning | June-July | | Various, commonly sand or mud | | | Small streams, creeks and lakes, headwater species | near shore, margins | Slow | Shallow water | range of mobile, larger bodied and smaller localized species | bluegill, black crappie, spotfin shiner, largemouth bass, bluntnose minnow, common shiner, iowa darter, white sucker and the sea lamprey | |
| | Brooding | Early Apr-May | | | | | | | | | | | |
| | Glochidia Release | May | | | | | | | | | | | |

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**Table 9. Aquatic-lotic-** Species that spend most life stages in flowing waters, have specialized stream-dependent feeding habits, and/or other traits (e.g., lungless) that are characteristic of an evolutionary history of instream habitat use

| Common Name, *Scientific name* | Life History Stage | Location during Life Stage A(quatic) or T(errestrial) | Timing | River Type or Location (Habitat preference) | Vegetation and or Substrate (Habitat preference) | Hydraulic Habitat Unit (Habitat preference) | Size, Diet, Home Range, Clutch size (Traits) | Comments |
|---|---|---|---|---|---|---|---|---|
| **Common map turtle,** *Graptemys geographica* | Hibernation | A | Early Winter (late as 1st week Dec)- Early Apr. | | | river bottoms, wedged under submerged logs | | Require high overwinter DO levels, Spends a significant portion of its time basking |
| | Mating | A | Spring and Fall | | | Deep Waters | | |
| | Nesting, Egg Laying and Incubation | T | most nesting in June, can occur May - July; for most, incubation through Fall and Winter | Found on mainstem Susquehanna and Juniata tributary, likely in other large tributaries, Prefer large lakes and rivers (> 50 m wide) | prefer open canopy sites with well drained sandy soils near water; a range of soil types from sandy to coal, to hard-packed clay and gravel mix | | Medium-sized; always feed in water- molluscs, aquatic insects and fish (mostly carrion); clutch of 6 to 20 | |
| | Hatchling Emergence | T | April-May, most found morning following rain (another paper stated Aug-Sept) | | | | | |
| | Adult Growth | A | Peak basking from Apr-June; Oct-Nov, less basking July-Sept | | locations with suitable basking sites (snags or rocks), bask communally 20 m from shore | Prefer slow-flowing sections, generally in water or basking, when found on land they are not far from shore, males move from deep water in spring to shallow water in summer | | |
| **Common musk turtle,** *Sternotherus odoratus* | Hibernation | A | Oct - mid April | | soft mud beneath cover, and near muskrat dens | | | In SC drought study, found to remain in water through drought (did not migrate), although reproduction was significantly impacted |
| | Mating | A | Mostly spring and fall | Most of the Valley and Ridge Province as well as the Piedmont in small streams to large rivers (in large rivers found in backwaters and embayments), rare to find out of water | | River bottom | small bodied; opportunistic carnivore: and insectivore worms, snails, small clams, aquatic insects, crayfish; little known about home range; variable clutch size of 2 to 7 eggs | |
| | Nesting, Egg Laying and Incubation | T | Late May to Early July, Early July-Aug (75 to 82 days incubation) | | | Lay eggs under object or bury under surface debris at the waters edge; maximum distance of 36 ft from waters edge, avg distance of 23 ft (Cagle 1937) | | Float at the surface of the water to absorp heat from the sun, not aerial baskers |
| | Hatchling Emergence | T | Aug-Sept | | | | | |
| | Adult Growth | A | Mature at age 4 | | Grow Basicladia on their shells during basking | Avoid fast currents, feed by walking on the bottom, not swimming, and bask just | | |
| **Northern water snake,** *Nerodia sipedon* | Hibernation | ? | October - early to mid April | | | Use crayfish tunnels, ant mounds and meadow vole tunnels | | emerge earlier if temperatures warmer |
| | Mating | T | Early June | Ubiquitous throughout basin, use lakes, marshes, ponds, slow-and fast moving streams and rivers | | | Known to heard schools of fish and tadpoles to waters edge, primarily fish, also amphibians (frogs), viviparous with a litter of 11 to 36 | |
| | Justation and Parturition | T | Justation 3 to 5 months, Parturition late August to mid Sept of following year? | | | | | |
| | Adult Growth | T/A | | | | Capable of submergence for 1.5 hours, adults use water as retreat/refuge and feeding | | |

**Table 9. Continued**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Queen snake,** *Regina septemvittata* | Hibernation | A or T | mid Oct-late April | Found in the Piedmont region in moderate to fast-flowing streams, creeks and small rivers, (occasionally slow moving streams) | | Muskrat burrows, crayfish burrows and deep cracks in rocky sections of stream, hibernate in congregations | Specialist feeders- almost exclusively crayfish, must be present and abundant; seldom found > 2m from water, skin prone to dessication; bear 4 to 15 young | Dependence on dwindling crayfish may threaten population |
| | Mating | | Likely Spring | | | | | |
| | Justation and Parturition | A/T | Gravid Spring Early to late August, Give birth late summer and early fall | | rocky streams, bulrushes, goldenrods, willows zone, but generally open canopy to allow sunlight on basking sites, must also have ample | | | |
| | Adult Growth | | max life span in wild 11 years | | | moderate to swift current | | |
| **Eastern Hellbender**, *Cryptobranchus alleganiensis* | Breeding and Egg Laying | A | Late August - Early Sept (mating) | Medium sized streams to large rivers, cool-cold waters, 3rd and 4th order streams | create shallow nest depressions under large slabs | nest on river bottom | Very large (giant salamander); Feed almost entirely on crayfish, infrequently | Not found in streams that lack substantial crayfish populations |
| | Egg and Larval Development | A | 60 to 87 days to hatch, | | | | | |
| | Metamorphisis/ Transformation | A | Spend 2 years in larval stage | | gravel or sandy bottom, under large slabs of rock (22 to 40" in diameter) | Prefer fast- flowing waters (likely linked to gas exchange), need high DO | | |
| | Adult | A | mature at estimated 5 to 6 years | | | | | found 8 to 20" deep in French Ck |
| **Northern Dusky Salamander**, *Desmognthus fuscus fuscus* | Breeding and Egg Laying | A | Mating in Spring and Fall, Egg Laying in July | Ubiquitous throughout headwater and small woodland streams (tend to be absent from streams where predatory fish are present) with abundant cover, found to dominate intermittent streams in a NC study | | nesting in stream banks, require flowing water particulary during hibernation | Small size; feeding opportunistic- flies, mayflies, beetles, amphipods and snails; one PA study documents an average of 28 eggs clutch size; home ranges vary by source population from 1.4 to 48.4 sqm | Require flowing water year round (particularly winter), dessication has been documented at a temperature of 26 C |
| | Egg and Larval Development | A | Late Aug - early Oct, temp dependent, 40 to 60 days to larval emergence | | | larvae develop in stream | | Will move to subterranean retreats during cold periods |
| | Metamorphisis/ Transformation | A | End of May to early July of following summer | | streamside cover of vegetation and or medium to large rocks | generally stay within 2 meters of stream bed | | High dependence on stream side vegetation and bank stability (Orser and Shure 1975) |
| | Adult | A/T | | | | | | |
| **Bullfrog,** Rana catesbeiana | Hibernation | A | mid Oct.- mid April (as early as Feb) | | covered with mud and litter | stream or pool bottom | | |
| | Breeding and Egg Laying | A | May-July | Variety of habitats from small ponds to small and Large Rivers, generally slow-moving creeks and streams, in swift streams use backwater habitats, close to shore, present in every county, but native distribution unknown due to State stocking programs | eggs laid in 'rafts' among low emergent vegetation | margins | Large bodied; Most commonly, adults feed on crayfish and other amphibians, occasionally reptiles (box turtles, young water snakes) and mammals; clutch size-6,000-20,000 eggs | |
| | Egg and Larval Development, Metamorphisis | A | Hatch within 3 days; Metamorphisis the summer after hatch | | | | | time to complete metamorphisis largely relies on food availability and length of growing season |
| | Adult | A | | | | | | |

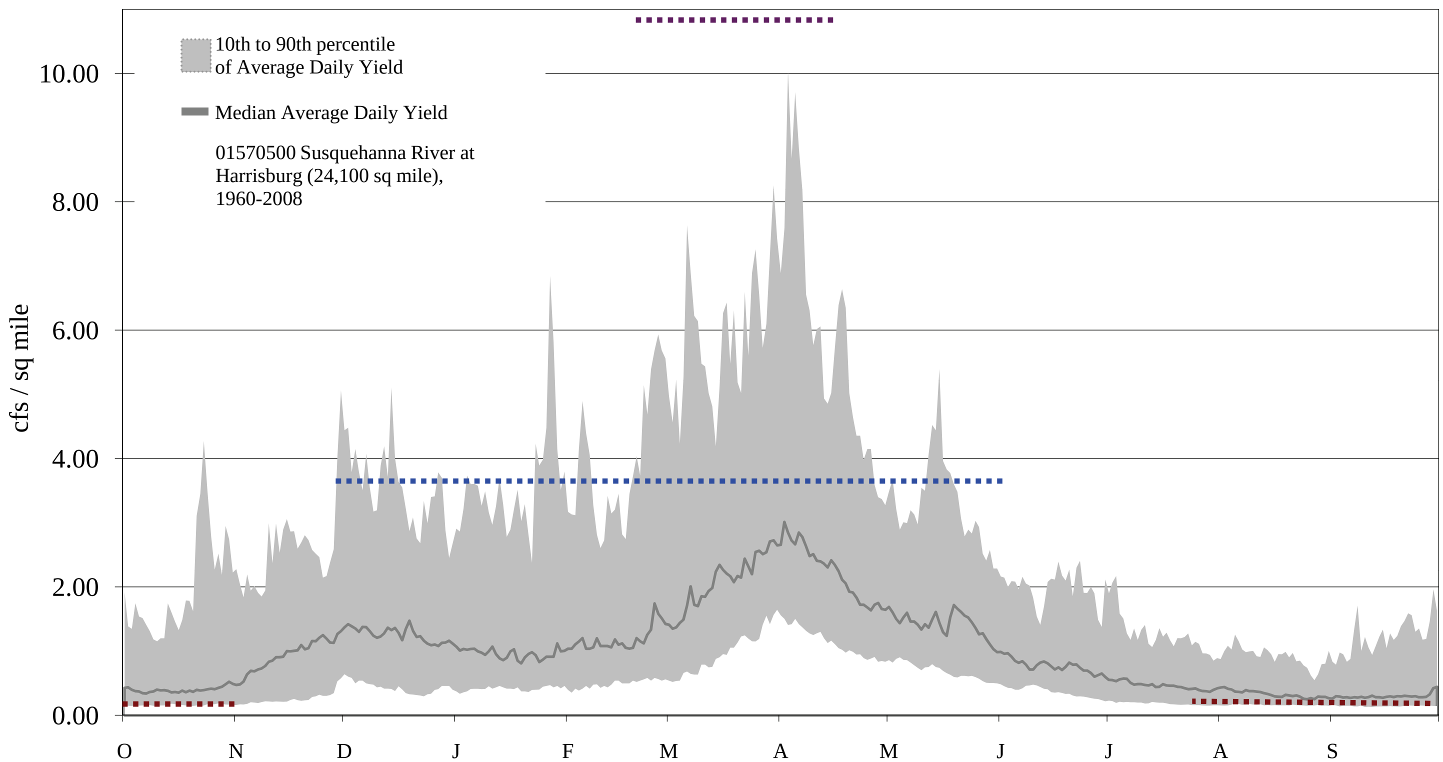
**Table 10. Semi-aquatic-lotic-** Species that rely on flowing waters or habitats within the active channel for a one or more life stages, but may spend part of their life cycle in floodplain or upland environments

| Common Name, *Scientific name* | Life History Stage | Location during Life Stage A(quatic) or T(errestrial) | Timing | Month: O N D J F M A M J J A S | Habitat preference: River Type or Location | Habitat preference: Vegetation and or Substrate | Habitat preference: Hydraulic Habitat Unit | Traits: Size, Diet, Home Range, Clutch size | Comments |
|---|---|---|---|---|---|---|---|---|---|
| **Wood turtle, *Glyptemys insculpta*** | Hibernation | A | Oct - Early April | | Most commonly found in the mountainous areas of the Ridge and Valley, in headwaters (2nd order streams) to medium rivers, associated with streams hosting native brook trout populations | | within cut banks (root wads) and buried in muddy bottoms of slow moving streams, banks and bottoms, root wads, can hibernate in large groups (up to 30 individuals documented in PA) | Small body size; opportunistic omnivores- herbaceous and woody plants, fruits, slugs, worms, incapable of capturing fish, molluscs, tadpoles, dead fish; homerange estimated to be 10.3 acres, noting that travel primarily occurs along river corridorsclutch size typically 5 to 13 eggs and are highly predated | More terrestrial in the summer months, but generally return to water at night, also enter during day during cold snaps and droughts for refuge |
| | Mating | A | Primarily Mid Sept-Oct., other reports have documented spring mating | | | | mate in water, habitat unknown | | Appropriate nesting habitat found to be limiting factor in population viability, late maturity, low fecundity, high adult survival rates, low egg and juvenile survival rates |
| | Nesting, Egg Laying and Incubation | T | Mid June, as early as May, as late as early July; 70 day incubation period | | | use sandy, well drained soils for nesting sites, near the river, usually 1 m above normal water level | eggs laid in depression over a short period in mid-June, females may migrate up to 1 km to find nest site | | |
| | Hatchling Emergence | T | Late Aug -early Sept (early October) | | | hard-bottomed | | | |
| | Adult Growth | T/A | Aquatic in the Spring and Fall, Terrestrial in the Summer, mature between 9 and 20 years, max life span 46 in the wild | prenesting; nesting; prehibernation | | open-canopy riparian thickets (alders), well drained soils, open, **edge species, shrublands** | Found in slow and fast-moving streams, but prefer slower-moving habitat; aquatic activity occurs almost exclusively in flowing water; this species is pollution intolerant | | |
| **Bog Turtle, *Clemmys muhlenbergii*** | Hibernation | A | Begins in late Sept.- mid to late March | | Found in Lower Susquehanna Basin tributaries in Franklin and Cumberland counties and east within spring-fed wetlands, open and slow, small streams or surface seepages | | Stream bottom or may use muskrat dens, in streams they have been found under 8 to 10 inches of water and 1 to 3 inches under the stream bottom (mud) | feeds on primarily insects (catepillars, beetles, caddisfly larvae, earthworms, | extreme habitat specialist |
| | Mating | A/T | Late Apr.- early June | | | | | | habitat requirements from PA A and R < Chase et al 1999 |
| | Nesting, Egg Laying and Incubation | T | Nesting mid May - July, most eggs laid in June, Incubation 45 to 55 days | | | nests constructed in moss or sedge tussocks | | | Talk with Tracy and George |
| | Hatchling Emergence | T | Late August to early Oct | | | | | | |
| | Adult Growth | A/T | and 10, can live more than 40 years | | | abundant low grasses and sedges, relatively open, smooth | requires spring-fed habitats, with wet and dry pockets, shallow and slow waters | | |
| **Eastern Ribbon Snake, *Thamnophis sauritus*** | Hibernation | T/A | Sept-March | | Found in the Piedmont and Ridge and Valley, within a variety of habitats, but must be in proximity to permanent water, either standing or flowing | underground or high ground, or underwater | may migrate to higher elevations for hibernation | Specialized Feeder- preying almost exclusively on amphibians, may also eat small fish; home range of .8 ha in Michigan study, and litter size of 3 to 27 | a partially arboreal species |
| | Mating | T | April and May | | | | | | |
| | Parturition and juvenile growth | T | Partutition August; | | | | | | |
| | Adult Growth | T/A | Mature 2 to 3 years (Michigan) | | | | most prey is captured in water or at waters edge | | |
| **Northern leopard frog, *Rana pipiens*** | Hibernation | A | Oct. -March | | Found in the Appalachian Plateau and Ridge and Valley Province within vegetated margins of ponds, lakes, and slow-flowing rivers and streams, as well as in marshes and swamps | | overwinter at the bottom of streams and lakes | Medium-sized, Terrestrial feeding (insectivore), clutch size 2,000 to 6,000 eggs | * not a true hibernation- quiescent state, temperature dependent, may be earlier or later |
| | Breeding and Egg Laying | A | April | | | | typically vernal habitats, not the same habitats used for overwintering | | |
| | Egg and Larval Development | A | Hatch in 10 days | | | | | | |
| | Metamorphisis/ Transformation | A | Transform by Mid-July | | | | | | |
| | Adult | T | | | | | | | movement precipitation dependent |

**Table 11. Riparian and Floodplain-terrestrial and vernal habitats**- Species that rely on overbank hydrologic processes to influence floodplain habitats, including wetting or refreshing vernal pools, driving vegetative composition, maintaining sediment composition, and substrate

| | | | | | Habitat preference | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|
| **Common Name, *Scientific name*** | **Life History Stage** | **Location during Life Stage A(quatic) or T(errestrial)** | **Timing** | **O N D J F M A M J J A S** | **River Type or Location** | **Vegetation and or Substrate** | **Hydraulic Habitat Unit** | **Size, Diet, Home Range, Clutch size** | |
| **Eastern Hognose snake,** *heterodon platirhinos* | Hibernation | T | Mid Oct- late April early May | | | | | | seek refuge in burrows, either dug, or existing mammal burrows |
| | Mating | T | April or May | | | | | | |
| | Nesting, Egg Laying and Incubation | T | Lay clutch early June-mid July, incubation 60 to 65 days | | Discrete population of the Alleghany front- distributes through the rivers of the ridge and valley province, typically sandy rivers and floodplains | | | Feed on wide variety of animals: specialize for frogs and toads, also salamanders, hatchling turtles, insects; clutch size 4 to 61 eggs | |
| | Hatchling Emergence | T | Late Aug-Sept | | | | | | |
| | Adult Growth | T | Mature at 2 to 3 years, lifespan unknown, up to 11 years in captivity | | | sandy soils for burrowing | grasslands and open forests near water, along sandy rivers and stream bottoms | | |
| **Eastern Gray treefrog**, *hyla versicolor* | Hibernation | T | Oct- early to mid April | | | little known, but likely that they hibernate on land because they are freeze tolerant | | moderate-sized frog; insectivores: terrestrial and aerial, but not much information available | cued by temperature and moisture levels |
| | Breeding and Egg Laying | A | Breeding- Mid May-mid Aug | | Wide but spotty distribution, most common in Southeast and Soutwest PA , an arboreal species of deciduous forest types | | | | in the vicinity of ponds, temporary pools, or roadside ditches |
| | Egg and Larval Development, Metamorphisis | A | | | | | use temporary and permanant bodies of water, woodland pools, ditches, cattle tanks and margins of small ponds and lakes | | |
| | Adult | T | | | | | | | ? Not sure which habitat types/elevation/basin |
| **Fowler's toad,** *Bufo fowleri* | Hibernation | T | October- end of April/beginning of May | | Found in the lowlands of the Ridge and Valley province, primarily an inhabitant of low lying areas with, open, with sandy, gravelly well drained soils (floodplains near streams and rivers) | hibernation sites not found in PA, but likely sand and loose soils of the floodplain | | | Habitat specialist requiring sandy floodplains |
| | Breeding and Egg Laying | A | Mid May- late June, both breeding and laying | | | | Ponds in the floodplain of streams and rivers | | |
| | Egg and Larval Development, Transformation | A | eggs hatch 2 to 3 days after laying, transformation 40 to 55 days | | | | | Insectivores, mostly ants and beetles; Clutch size estimated 8,000 eggs, home range relatively large between 51 and 2500 square meters | |
| | | | mature by July or August the following year | | | | | | |
| | Adult | T | | | | | | | |
| **Marbled Salamander**, *Ambystoma opacum* | Breeding and Egg Laying | T | Sept.-Nov. | | | Upland forests, in vernal depressions, or occasionally in intermittent or ephemeral stream beds | NA | | |
| | Egg and Larval Development | A | Winter and Spring, when vernal pools fill, or during intermittent stream flow | | Upland forests that support vernal ponds, and intermittent stream beds, filling with water during the winter and spring | | NA | Small body-size; Diet of spiders, earthworms, grasshoppers, beetles- **Larvae diet includes microcrustacean zooplankton and aquatic beetles; clutch size ranges from 41 to 200 eggs | |
| | Metamorphisis/ Transformation | A | June-July; about 135 days from | | | Spend most of their time, outside of the reproductive, season in subterranean retreats | NA | | |
| | Adult | T | Spring, Summer and Winter | | | | | | |

# Aquatic and Riparian Communities- Disturbance regimes of Emergent Bed, Herbaceous, Shrub-Scrub, and Forested Communities




**FLOOD**
**(> 2 yr Recurrence)**
Late Feb. to Early April
Flow 10.8 to 16.6 cfs / sq mile
0 to 1 events/ year
0 to 27 days / event

**HIGH PULSE (≥Q10)**
Flow ≥ 3.2 cfs / sq mile
4 to 8 events / year
4 to 6 days / event

**LOW PULSE (≤Q90)**
Flow ≤ .2 cfs / sq mile
1 to 4 events /year
4 to 17 days / event

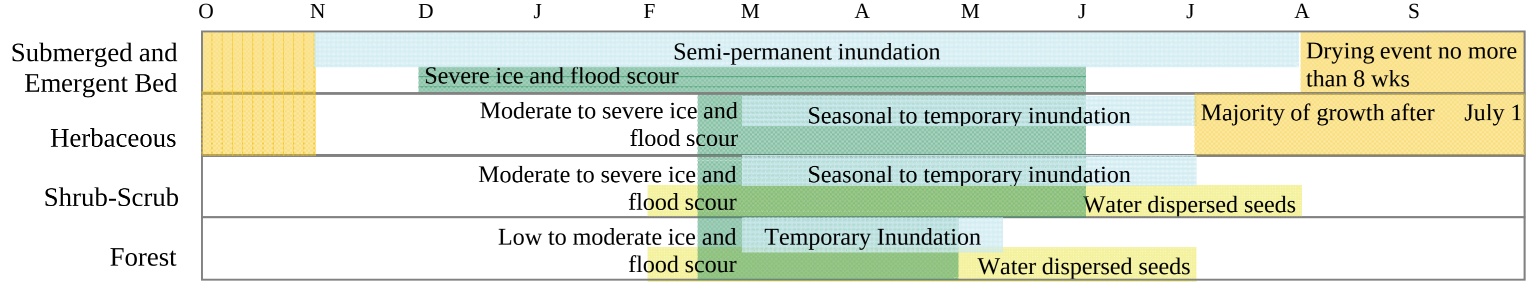



**Table 12** includes a detailed community and life history descriptions

## Table 12: Aquatic, riparian and floodplain communities, life history summaries

| Successional State | Community Types (Perles, S. Podniesinski G., and J. Wagner 2002 and 2004, PNHP 2010) | Landscape Position | | Canopy Dominants | Seed Dispersal/ Establishment | | High Flow conditions (Flood and Ice Scour, and Inundation events) | | | Drought conditions | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Lateral Position | Stream Size (longitudnal) | | Timing and Dispersal | Substrate | magnitude | frequency | duration | magnitude | frequency | duration |
| Emergent Bed | Water Willow Emergent Bed | island heads, edges of bars, terraces and spits | all order streams | water-willow, Justicia americana | new shoots along rhizomes, fragmentation and seed; rhizomes are dormant in winter | variable | subject to severe ice and flood scour | SEMI-PERMANENT (flooded most of the year, may become exposed during dry periods) | | in the summer months, condition rapidly declined after 8 weeks of dessication, and further with a second, subsequent dessication event | | |
| | Lizard's Tail Emergent Bed | island heads, edges of bars, terraces or channels | Juniata drainage and smaller tributaries of the main stem in the Ridge and Valley province | lizard's tail, *Saururus cernuus* | | sand, silt or with cobbles | subject to severe ice and flood scour | SEMI-PERMANENT (lower portions flooded most of the year, entirely submerged by high flow events) | | | | |
| Herbaceous Community | Indian Grass (Willow) Riverine Shrubland | banks, sand and gravel deposits and river islands | North and West Branch and upper portions of the mainstem. | indian grass, *Sorghastrum nutans* | perennial warm-season grass | sand mixed with cobble, rapidly draining soils | moderate to severe ice and flood scour | SEASONAL TO TEMPORARY FLOODING | | drier sites, rapidly draining soils, droughty conditions may prevent establishment of woody vegetation, 70% growth after July 1 | | |
| | Sedge-spotted joe pye weed riverine herbaceous vegetation | Island heads, edges of bars, terraces or channels | smaller tributaries | *Carex trichocarpa, Carex torat, Eupatorium mauclatum* | | cobbles mixed with silt, sand and overlain by muck | subject to moderate flood scour | SEASONAL TO TEMPORARY FLOODING | | | | |
| | Riverine scour community (includes bedrock outcrop community and shoreline and flats community) | island heads, edges of bars, terraces and spits; outcrop community specifically on large river banks | all order streams, with outcrop community on large rivers | sparsely vegetated; Hypericum spp., Osmunda regalis, smart weed (Persicaria spp) and other annuals | | gravel and bedrock | severe ice and flood scour | SEASONAL TO TEMPORARY FLOODING | | | | |
| Scrub/Shrub Community | Speckled Alder - Dogwood Riverine Shrubland | flats within active channels | Upper portion of the West Branch on smaller order streams; Small to Moderate streams; | speckled alder, *Alnus incana ssp. rugosa* | September-April; wind dispersed | cobble substrate | moderate to severe ice and flood scour | SEASONAL TO TEMPORARY FLOODING | | | | |
| | Mixed Hardwood Riverine Shrubland, Silver maple-river birch- Mixed Hardwood shrubland | bars and low terraces, transition community between low floodplain herbaceous and upland floodplain forest, | Sycamore-mixed community on small and intermediate tributaries of the upper mainstem; River birch community occurs on islands of the North and West Branch | See associated floodplain forest | See associated floodplain forest | | moderate to severe ice and flood scour | SEASONAL TO TEMPORARY FLOODING | | | | |
| | Black Willow Slackwater Shrubland | stream and riverbanks, downstream ends and heads of islands where stream velocity is reduced such as back channels and oxbows | Tributaries and Large Rivers | black willow, *Salix nigra* | April -August; water and wind dispersed | establish in very moist, almost flooded exposed soils, deeper soils of silt and loam, | low to moderate to ice and flood scour | SEASONAL TO TEMPORARY FLOODING Inundation period may be longer due to macrotopography, high groundwater, and poor drainage | | seed viability greatly reduced by only a few days of dry conditions. Seedlings growth is dependant upon available moisture throughout the growing season | | |

**Table 12: Continued**

| Successional State | Community Types (Perles, S. Podniesinski G., and J. Wagner 2002 and 2004, PNHP 2010) | Landscape Position | | Canopy Dominants | Seed Dispersal/ Establishment | | High Flow conditions (Flood and Ice Scour, and Inundation events) | | | Drought conditions | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Lateral Position | Stream Size (longitudnal) | | Timing and Dispersal | Substrate | magnitude | frequency | duration | magnitude | frequency | duration |
| Floodplain Forest | Sycamore floodplain forest | floodplains, small islands, low bars and lower terraces, oldest cohorts furthest from active stream channel | intermediate order tributaries to the Susquehanna | American syacamore, *Plantanus occidentalis* | February - May; water dispersed,establishment after flood event | establish in wet alluvium, very well-drained course sand, gravel and cobbles | moderate ice and flood scour | TEMPORARY FLOODING (saturated or inundated for > 2 wks and < growing season), *P. Occidentalis* seedlings will die if inundated > 2 wks | | | | |
| | Sycamore mixed hardwood floodplain forest | low to intermediate elevation islands and terraces (higher terraces as compared to Sycamore Floodplain Forest) | smaller and Intermediate tributaries | river birch, *Betula nigra* | Late Spring to Early Summer, water and wind dispersed | as above- course substrates | low to moderate ice and flood scour | TEMPORARY FLOODING (saturated or inundated <1 wk to 3 mths, typically 7 wks) | | seedlings growth is dependent upon available moisture throughout the growing season | | |
| | Silver maple floodplain forest | well-developed floodplains and islands, low and occasionally high terraces | major tributaries and the mainstem Susq | silver maple, *Acer saccharinum* | April-June; Establishment: after flood event, high flow years | establishment: fine sand and silt, soils with organic matter, moderatley well-drained (scour zones) to poorly drained | low to moderate ice and flood scour | TEMPORARY FLOODING | | | | |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## Appendix 5. Description of Floodplain, Riparian and Aquatic Vegetation Communities

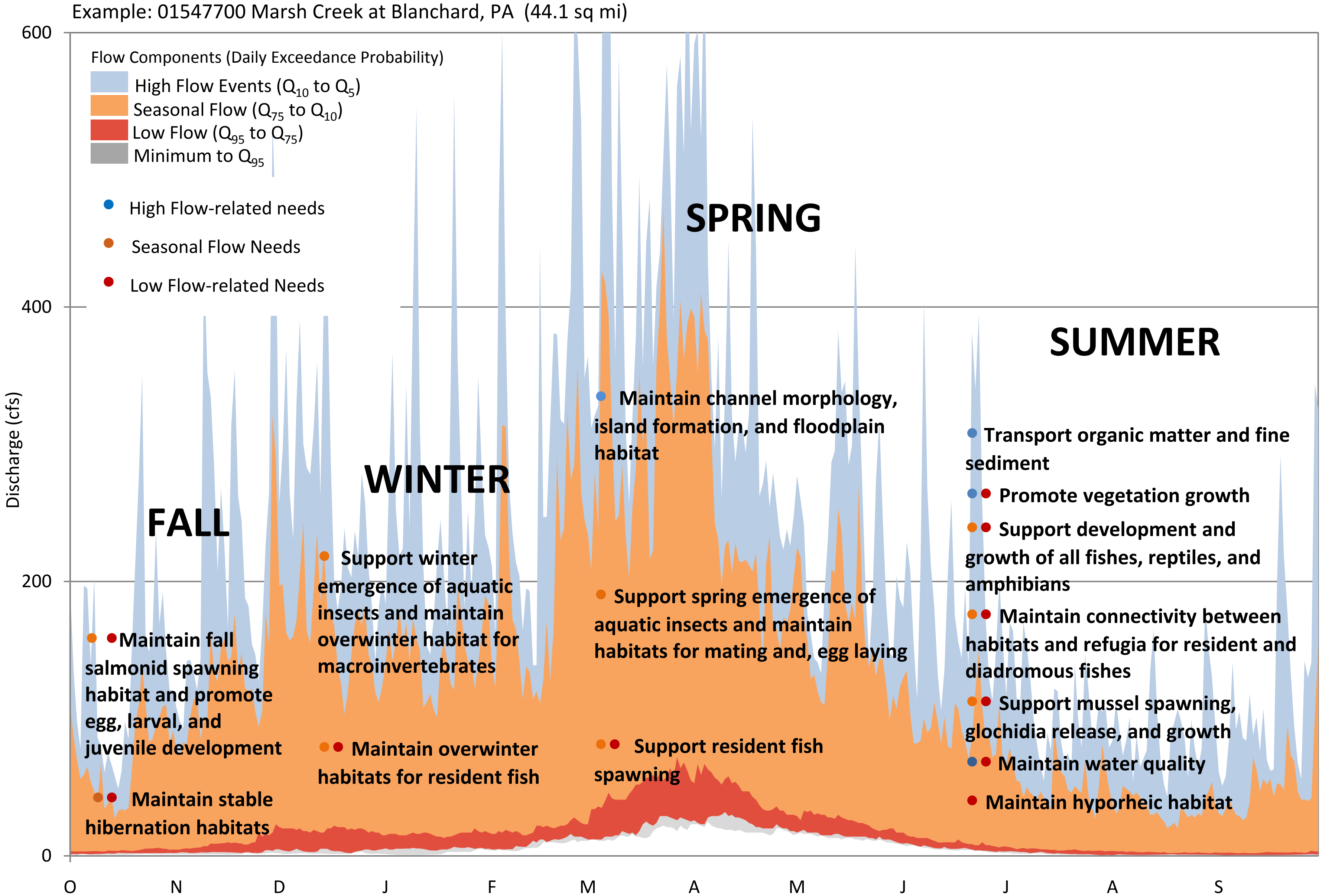
| Community Types (Canopy Dominants) | Landscape Position | Seed Dispersal/Establishment | Flow Disturbance Frequency and Duration (Flood and ice scour, inundation and response to drought) |
|---|---|---|---|
| **Submerged and Emergent Bed** | | | |
| Riverweed *(Podostemum ceratophyllum*) | Stream bed | - Gravel or cobble substrate in moderate to high velocity riffles<br>- Exposure of leaves and/or stem inhibits growth | - Subject to severe ice and flood scour<br>- Permanent inundation (flooded most of the year, may become exposed during drought periods)<br>- Intolerant of long periods of desiccation |
| Water Willow Emergent Bed *(Justicia Americana*) | Island heads, edges of bars, terraces and spits | - New shoots along rhizomes, fragmentation and seed; rhizomes are dormant in winter<br>- Variable substrates | - Subject to severe ice and flood scour<br>- Semi-permanent inundation (flooded most of the year, may become exposed during dry periods)<br>- Intolerant of long periods of desiccation |
| Lizard's Tail Emergent Bed (*Saururus cernuus*) | Island heads, edges of bars, terraces or channels | - Sand, silt or with cobbles | - Subject to severe ice and flood scour<br>- Semi-permanent inundation (lower portions flooded most of the year, entirely submerged by high flow events) |
| **Herbaceous Community** | | | |
| Willow-Indian Grass Riverine Shrubland (*Sorghastrum nutans*) | Banks, sand and gravel deposits and river islands | - Sand mixed with cobble, rapidly draining soils<br>- Drought conditions may prevent establishment of woody vegetation | - Moderate to severe ice and flood scour<br>- Seasonal to temporary flooding |
| **Scrub/Shrub Community** | | | |
| Speckled Alder Riverine Shrubland (*Alnus incana ssp. Rugosa*) | Flats within active channels | - Wind-dispersed during September-April<br>- Cobble substrate | - Moderate to severe ice and flood scour<br>- Seasonal to temporary flooding |

| Community Types (Canopy Dominants) | Landscape Position | Seed Dispersal/Establishment | Flow Disturbance Frequency and Duration (Flood and ice scour, inundation and response to drought) |
|---|---|---|---|
| Sycamore-mixed hardwood, River birch-mixed hardwood, and Silver Maple-mixed hardwood riverine shrublands (See associated floodplain forest) | Bars and low terraces, transition between low floodplain herbaceous and upland floodplain forest | - See associated floodplain forest | - Moderate to severe ice and flood scour<br>- Seasonal to temporary flooding |
| Black Willow - mixed hardwood riverine shrubland (*Salix nigra*) | Stream and riverbanks, downstream ends and heads of islands | - Water and wind dispersed during April -August<br>- Establish in very moist, almost flooded exposed soils<br>- Seedling growth depends upon available moisture throughout growing season | - Moderate to severe ice and flood scour<br>- Seasonal to temporary flooding |
| **Floodplain Forest** | | | |
| Sycamore floodplain forest (*Plantanus occidentalis*) | Floodplains, small islands, low bars and lower terraces, oldest cohorts furthest from active stream channel | - Water-dispersed during February - May<br>- Establish after flood in wet alluvium, very well-drained course sand, gravel and cobbles | - Moderate ice and flood scour<br>- Temporary flooding (saturated or inundated for > 2 wks and < growing season), P. Occidentalis seedlings will die if inundated > 2 wks |
| Sycamore mixed hardwood floodplain forest (*Betula nigra*) | Low to intermediate elevation islands and terraces (higher terraces than Sycamore floodplain forest) | - Water and wind dispersed during late spring to early summer<br>- Seedlings establish in coarse substrates; growth depends upon available moisture throughout the growing season | - Low to moderate ice and flood scour<br>- Temporary flooding (saturated or inundated <1 wk to 3 months, typically 7 wks) |
| Silver maple floodplain forest (*Acer saccharinum*) | Well-developed floodplains and islands, low and occasionally high terraces | - April-June; Establishment: after flood event, high flow years<br>- Establishment on fine sand and silt, soils with organic matter, moderately well-drained (scour zones) to poorly drained | - Low to moderate ice and flood scour<br>- Temporary flooding |

| Community Types (Canopy Dominants) | Landscape Position | Seed Dispersal/Establishment | Flow Disturbance Frequency and Duration (Flood and ice scour, inundation and response to drought) |
|---|---|---|---|
| Silver maple mixed hardwood floodplain forest (*Acer negundo*) | Floodplain depressions, low and upper terraces of major tributaries of the mainstem; young stands on active scour channels | - Wind dispersed from October -Spring<br>- Establishment on moist silt loam, clay loam, | - Low to moderate ice and flood scour<br>- Temporary flooding, long inundation (actually flooded less than 1 wk per year, but may stay inundated for long periods due to high groundwater for much of the growing season) |
| Green Ash, mixed Hardwood Floodplain Forest (*Fraxinus pennsylvanica*) | Old oxbows along the floodplain or depressions behind levees on low terraces | - Wind dispersed, September-winter<br>- Somewhat poorly drained-poorly drained | - Low to moderate flood and ice scour<br>- Temporary flooding, long inundation (actually flooded less than 1 wk per year, but may stay inundated for long periods due to high groundwater for much of the growing season) |

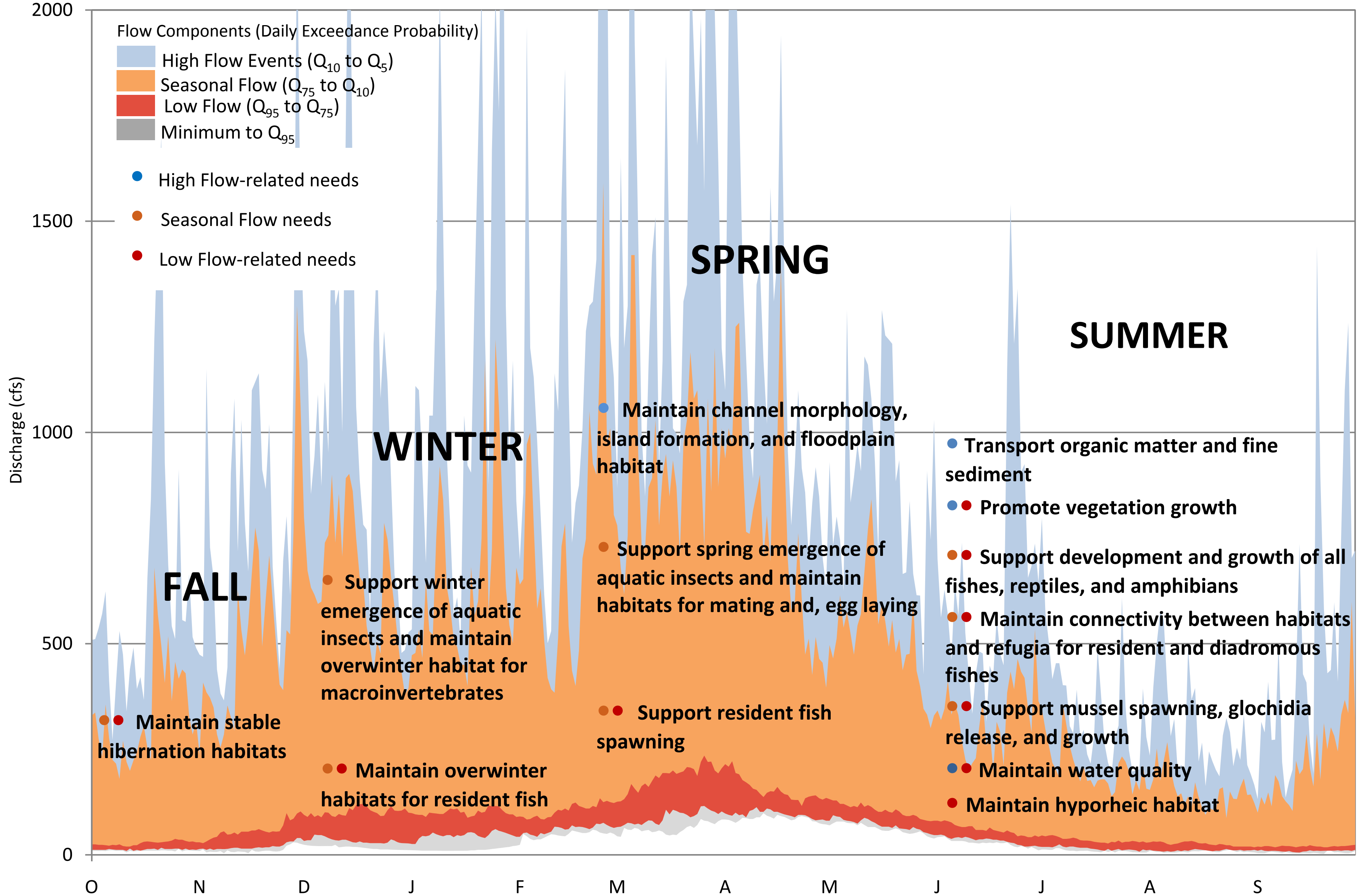
# Appendix 6. Graphs of Flow Needs for Each Major Habitat Type

# Flow Components and Needs: Cold and Cool Headwaters and Small Streams

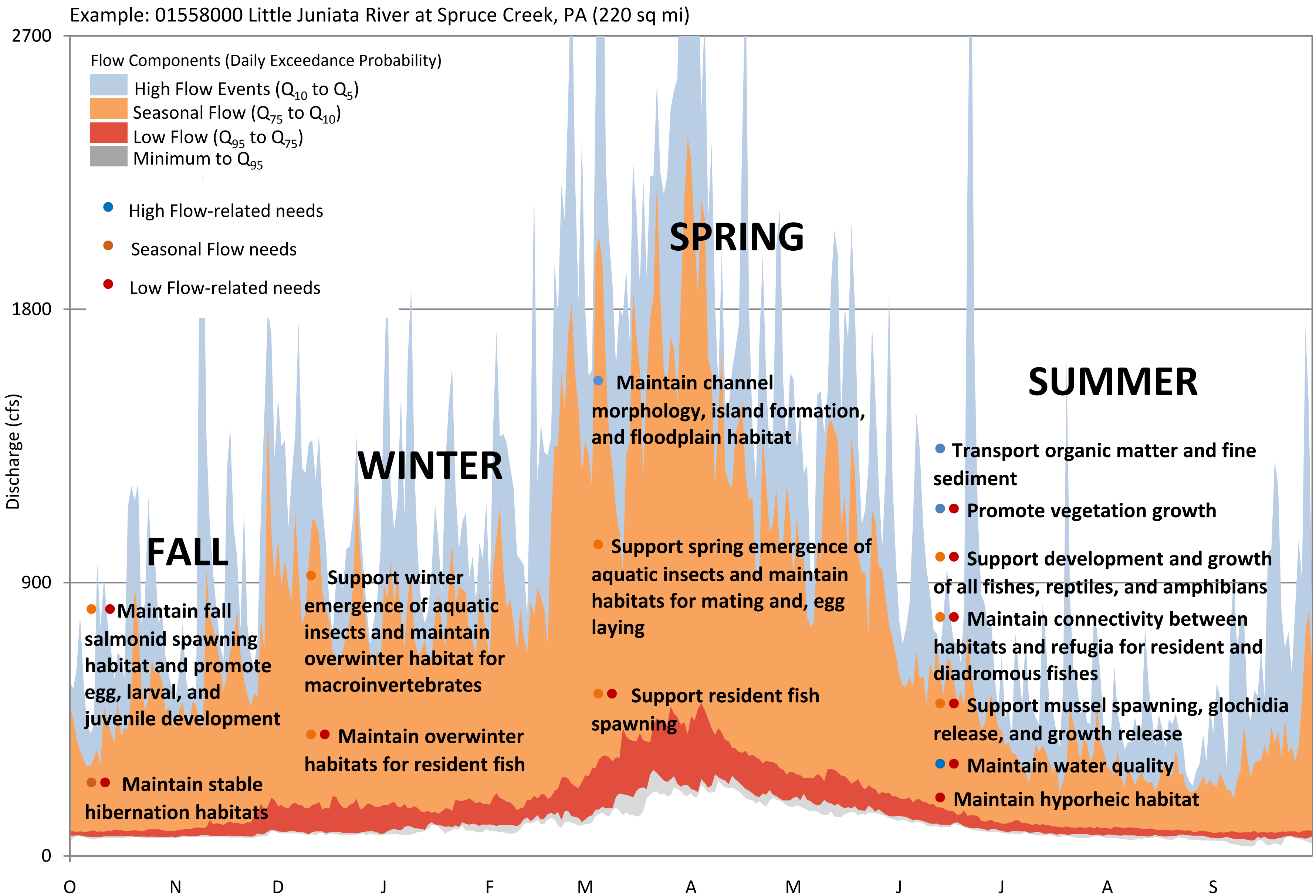


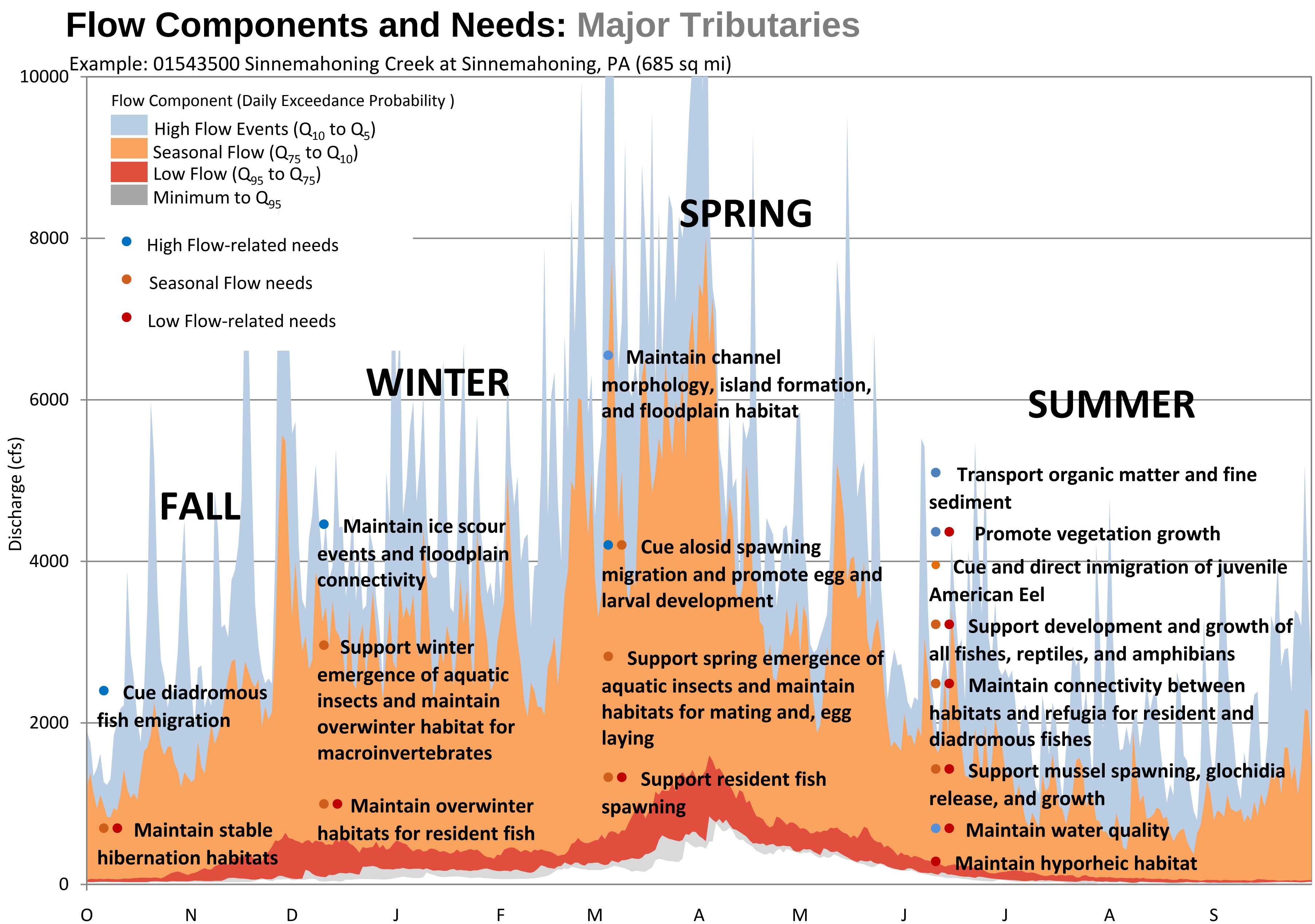
# Flow Components and Needs: Warm Headwaters and Small Streams

Example: 01555500 East Mahantango Creek near Dalmatia, PA (162 sq mi )

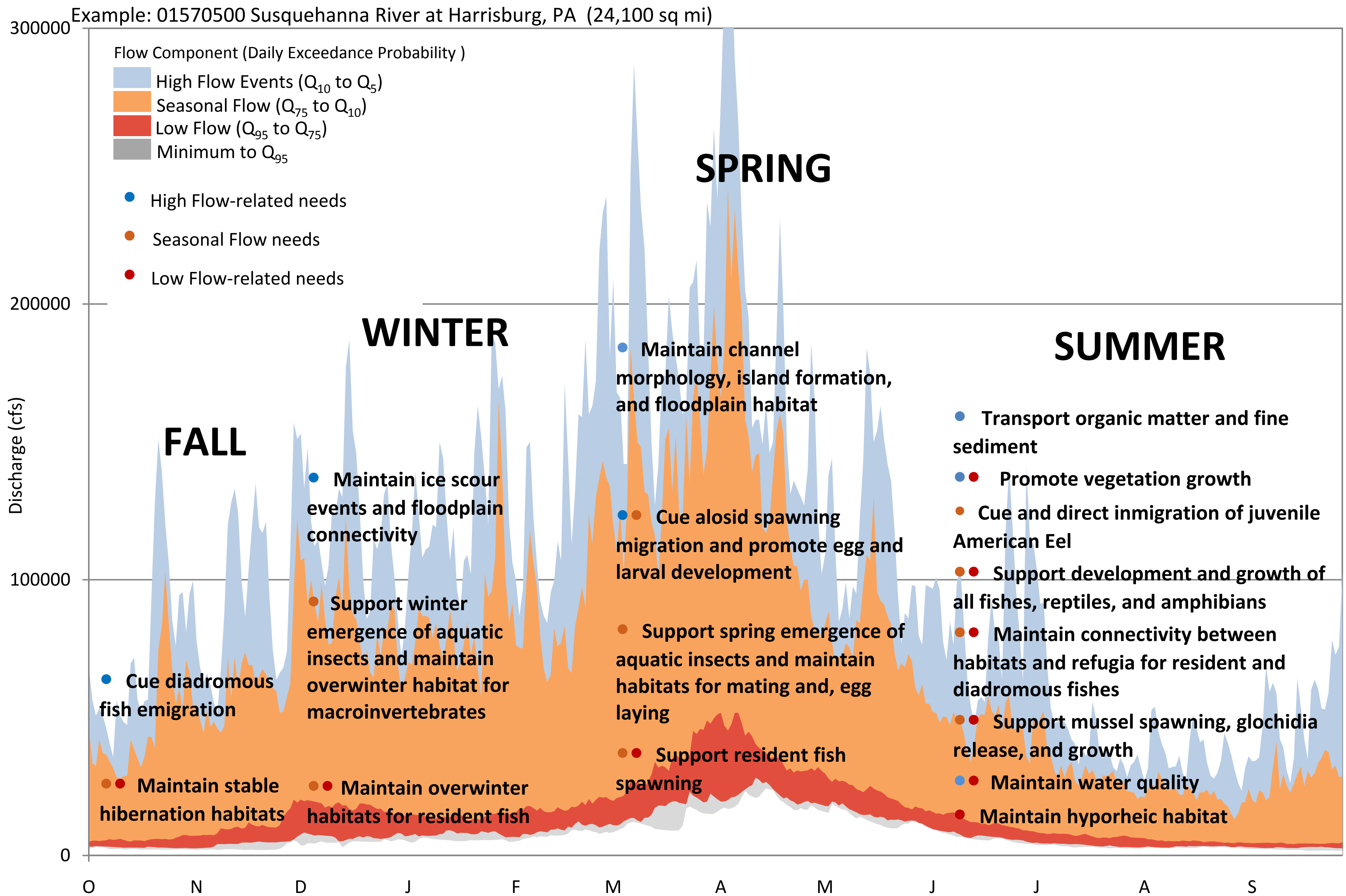


## Flow Components and Needs: High Baseflow Headwaters and Small Streams




Flow Components and Needs: Major Tributaries
Example: 01543500 Sinnemahoning Creek at Sinnemahoning, PA (685 sq mi)
Flow Component (Daily Exceedance Probability )
High Flow Events ($Q_{10}$ to $Q_5$)
Seasonal Flow ($Q_{75}$ to $Q_{10}$)
Low Flow ($Q_{95}$ to $Q_{75}$)
Minimum to $Q_{95}$
High Flow-related needs
Seasonal Flow needs
Low Flow-related needs
Discharge (cfs)
10000
8000
6000
4000
2000
0
O N D J F M A M J J A S
FALL
Cue diadromous fish emigration
Maintain stable hibernation habitats
WINTER
Maintain ice scour events and floodplain connectivity
Support winter emergence of aquatic insects and maintain overwinter habitat for macroinvertebrates
Maintain overwinter habitats for resident fish
SPRING
Maintain channel morphology, island formation, and floodplain habitat
Cue alosid spawning migration and promote egg and larval development
Support spring emergence of aquatic insects and maintain habitats for mating and, egg laying
Support resident fish spawning
SUMMER
Transport organic matter and fine sediment
Promote vegetation growth
Cue and direct inmigration of juvenile American Eel
Support development and growth of all fishes, reptiles, and amphibians
Maintain connectivity between habitats and refugia for resident and diadromous fishes
Support mussel spawning, glochidia release, and growth
Maintain water quality
Maintain hyporheic habitat

# Flow Components and Needs: Mainstem



## Appendix 7: Seasonal Flow Needs, Recommendations, and Supporting Literature and Studies

Flow statistics in this table are defined and described in Section 4 of the main report. Section 5 includes additional explanation of the flow recommendations. This table summarizes relevant literature and studies used to confirm flow need, support the selection of particular flow statistics and/or summarize studies that quantify ecological responses.

| Flow Need | Flow Statistic and Recommendation | Supporting Literature and Studies |
|---|---|---|
| **FALL** | | |
| **Maintain fall salmonid spawning habitat and promote egg, larval, and juvenile development (brook and brown trout) -** fall flows are needed to maintain connectivity to spawning habitats, suitable temperatures and wetted, aerated, and silt-free redds.<br><br>*Cool and coldwater and High baseflow headwaters and small streams* | **Seasonal Flow - Oct-Jun**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range**<br><br>**Low Flow - Oct- Jun**<br><br>Headwaters<br>• No change to **monthly Q75; and**<br>• No change to **monthly low flow range**<br><br>Streams > 50 square miles<br>• No change to **monthly Q95; and**<br>• <10% change to **monthly low flow range** | Eggs and larvae develop through the late fall and early winter and are sensitive to decreased flows that could increase sedimentation, thermal stress or exposure, and increased flows that may cause scour. Juvenile development occurs from March to June, during which they need access to margins and shallows between 0.5-2ft in depth (Raleigh 1982, Denslinger et al. 1998, Hudy et al. 2005, Kocovsky and Carline 2006)<br><br>While temperature is the most limiting factor for suitable habitat, hydraulic conditions and turbidity during baseflow periods (August through December) are also critical for adult growth of trout (Raleigh 1982, Denslinger et al. 1998)<br><br>PA-MD Instream Flow Study predicted a 10% habitat loss for withdrawals of 7 to 8% Average Daily Flow (ADF) on freestone and unglaciated streams, and 10 to 23% ADF in limestone (high baseflow) streams (Denslinger et al. 1998). |
| **Cue diadromous fish emigration -** high flow pulses and seasonal flows needed to cue, direct, and provide access to submerged aquatic vegetation refuge during emigration of juvenile Alosids and adult silver eels.<br><br>*Mainstem and major tributaries* | **High Flow - Sept-Dec**<br><br>• 1 to 5 high flow events > monthly Q10 between Sept-Nov<br><br>**Seasonal Flow – Sept-Dec**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range** | Cues for juvenile Alosid and adult silver eel emigration include precipitation and high flow pulses, temperature decreases of > 1-4 C, and lunar cycle (Hildebrand and Welsh 2005, Greene et al. 2009).<br><br>Freshets (high pulses and flows above mean or median) coupled with lower temperatures initiate juvenile shad outmigration. Outmigration occurs as early as October and as late as December. Once outmigration begins, juvenile shad will continue to move. Outmigration may be inhibited by low flows. High flows or pulses will speed outmigration (M. Hendricks and M. Hartle, personal communication, 2010).<br><br>Lower Susquehanna dams spill during extended high pulses. For juvenile shad, spilling is a safer route than through the turbines (M. Hendricks and M. Hartle, personal communication, 2010).<br><br>Without fall high flow cues, eels delayed outmigration from fall to winter on the Shenandoah River (Eyler et al. 2010). |

| Flow Need | Flow Statistic and Recommendation | Supporting Literature and Studies |
|---|---|---|
| **FALL** | | |
| **Maintain stable hibernation habitat for reptiles, amphibians, and small mammals –** seasonal flows needed during amphibian and reptile hibernation in stream banks and beds, and small mammals nesting in banks.<br><br>*All habitat types: Cool and cold, High Baseflow, and Warm headwaters and small streams; Mainstem and major tributaries* | **Seasonal Flow - Sept-Apr**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range**<br><br>**Low Flow - Sept-Apr**<br><br>Headwaters<br>• No change to **monthly Q75; and**<br>• No change to **monthly low flow range**<br><br>Streams > 50 square miles<br>• No change to **monthly Q95; and**<br>• <10% change to **monthly low flow range** | During hibernation period, map, common musk, and wood turtles need flowing waters (that generally do not freeze) and high DO concentrations (Graham and Forseberg 1991, Crocker et al. 2000, and Greaves 2007).<br><br>Wood turtles only capable of small and slow movements to avoid freezing or poor water quality conditions during overwinter period. (Graham and Forseberg 1991). |

| Flow Need | Flow Statistic and Recommendation | Supporting Literature and Studies |
|---|---|---|
| **WINTER** | | |
| **Maintain overwinter habitats for resident fish –** winter flows needed to a) maintain a range of habitat types including high velocity riffles to low velocity pools, backwaters and stream margins; and b) sustain depths and velocities to moderate freezing air temperatures and minimize formation of anchor ice.<br><br>*All habitat types* | **Seasonal Flow - Dec-Feb**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range**<br><br>**Low Flow - Dec-Feb**<br><br>Headwaters<br>• No change to **monthly Q75; and**<br>• No change to **monthly low flow range**<br><br>Streams > 50 square miles<br>• No change to **monthly Q95; and**<br>• <10% change to **monthly low flow range** | Brook trout migrated (mostly downstream) to winter habitats with low velocities and relatively deep water; surface and subsurface ice can exclude habitats that are available in other seasons. This condition needs to be considered in weighted usable area models (Chisholm 1987).<br><br>Population size for mottled sculpin is regulated by overwinter habitat availability. Juveniles and adults directly compete for refuge (Rashleigh and Grossman 2005).<br><br>Burbot require connectivity to and maintenance of winter spawning habitats in cool to cold headwaters of the Upper Susquehanna. They typically spawn under ice cover (D. Fischer, personal communication, 2009).<br><br>For all riffle-obligate fishes, published observations of habitat and hydraulic needs during the overwinter period are limited, however it is hypothesized that winter baseflows are critical for providing thermal refuge (D. Fischer, personal communication, 2009). |
| **Support winter emergence of aquatic insects and maintain overwinter habitat for macroinvertebrates -** seasonal flows maintain hydraulic habitat and buffer instream temperatures for mussels, crayfish, and aquatic insects<br><br>*All habitat types* | **Seasonal Flow - Nov-Feb**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range** | On a small stream, constant withdrawals through the fall and winter (≥90%) reduced invertebrate density by 51% and richness by 16%. 80% of the altered community was comprised of 'tolerant' species (Rader and Belish 1999).<br><br>Low winter flows have been correlated with anchor ice formation and reduction (Flannigan 1991) or elimination of stonefly taxa (Clifford 1969).<br><br>Reproductive success of long-term brooders may be influenced by overwinter flow magnitude (R. Villella, personal communication, 2010). |
| **Maintain ice scour events and floodplain connectivity -** seasonal high flow pulses maintain geomorphic disturbance patterns, including ice scour and floodplain inundation, and maintain in-channel and floodplain habitat structure and diversity.<br><br>*Mainstem and major tributaries* | **High Flow - Dec-Feb**<br><br>• 1 to 2 **bankfull** events every 2 years | During the winter, high flow events and associated ice scour maintain sites for early successional vegetation (Nilsson 1989, Fike 1999, Podniesinsksi et al. 2002).<br><br>USGS developed regional curves to predict bankfull discharge in NY, PA, and MD. For gages within the Susquehanna Basin, the recurrence interval ranges from 1.1 to 2.1 years (Chaplin 2005, Mulvihill et al. 2005, Westergard et al. 2005). |

| Flow Need | Flow Statistic and Recommendation | Supporting Literature and Studies |
|---|---|---|
| **SPRING** | | |
| **Support resident fish spawning -** maintenance of seasonal flows to support nest construction (nest-building fishes) and rearing and growth of resident and migratory fish.<br><br>*All habitat types* | **Seasonal Flow - Mar-July**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range**<br><br>**Low Flow - Mar-July**<br><br>Headwaters<br>• No change to **monthly Q75; and**<br>• No change to **monthly low flow range**<br><br>Streams > 50 square miles<br>• No change to **monthly Q95; and**<br>• <10% change to **monthly low flow range** | Survival of walleye larvae directly related to discharge; low during years with multiple high flow events during the spring (Mion et al 1998).<br><br>Strongest smallmouth bass year class observed when June flows within 40% of long-term mean (Smith et al. 2005).<br><br>A decrease in the magnitude of median daily flows in spring results in a decrease in the abundance of spring spawners and an increase in summer spawners (Freeman et al. 2001). |
| **Cue alosid spawning migration and promote egg and larval development -** seasonal flows needed to cue spawning migration and provide access to natal spawning streams.<br><br>*Mainstem and major tributaries* | **Seasonal Flow - Mar-June**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range** | Greene et al. 2009, cited above<br><br>Adult migrating shad have strong velocity preferences; they seek moderate flows (around median or mean) and avoid moving in high flows. Spawning migration is cued by seasonal flows in around median. Increased magnitude or frequency of high flow events could delay migration (Bilkovic 2002, M. Hendricks, personal communication, 2010).<br><br>In June 2006, extremely high flows likely negatively impacted juvenile American shad survival (both wild and hatchery) (SRARFC 2008).<br><br>High June mean flow is negatively correlated with shad year-class strength (in addition to temp and precip). High flow conditions reduce larval feeding success and survival (Crecco and Savoy 1984). |

| Flow Need | Flow Statistic and Recommendation | Supporting Literature and Studies |
|---|---|---|
| **SPRING** | | |
| **Support spring emergence of aquatic insects and maintain habitats for mating and, egg laying** – seasonal flows neede to maintain riffle and pool habitats.<br><br>*All habitat types* | **Seasonal Flow - May - June**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range** | Reservoir mitigation releases increased discharge by 6 x (from .7 to 4.3 m3/s) resulting in 36% increase in family richness, up to 119% increase in EPT taxa family richness, and a 13% decrease in tolerant taxa [ May to June surveys] (Bednarek and Hart 2005).<br><br>In small streams, instream flows recommendations developed using IFIM for target benthic fish (sculpin) underestimated habitat loss for macroinvertebrates by up to 25% (Gore et al. 2001). |
| **Maintain channel morphology, island formation, and floodplain habitat -** floods and seasonal high flow pulses are needed to maintain geomorphic disturbance patterns, including bedload transport, island formation, ice scour, floodplain inundation, and maintenance of in-channel and floodplain habitat structure and diversity, and to redistribute alluvium and organic matter.<br><br>*All habitat types* | **High Flow** - Mar - Nov<br><br>Headwaters<br>• 1 to 2 **bankfull** events every 2 years<br><br>Streams > 50 square miles<br>• 1 to 2 **bankfull** events every 3 years<br><br>All habitat types<br>• Maintain magnitude and frequency of **small (5-yr) flood**<br>• Maintain magnitude and frequency of **large (20-year) flood** | Bankfull recurrence intervals from Chaplin 2005, Mulvihill et al. 2005, Westergard et al. 2005, cited above.<br><br>1 in 5 year high flow events are associated with channel maintenance and overbank events (Nanson and Crook 1992, B. Hayes, personal communication, 2009).<br><br>Floods with a recurrence interval of 18 to 20 years are associated with floodplain maintenance and valley formation (Shultz 1999, B. Hayes, personal communication, 2009).<br><br>Spring floods and associated high flow pulses transport bedload material in large river habitats (B. Hayes, personal communication, 2009).<br><br>Floodplain forests of the Susquehanna were surveyed in areas inundated by an estimated range of flows from the Annual Q45 to the Annual Q0.5 (Podniesinski et al. 2002).<br><br>Seeds of riparian trees including American sycamore, river birch and silver maple dependent on high flows for dispersal (Burns and Honkala 1990, Zimmerman 2006).<br><br>An estimated 70% reduction in seasonal high flow pulses results in a -300 to 350% in area of inundated woody vegetation (Bowen et al. 2003).<br><br>Spring high flows and mean annual flows reduced by 25-50% results in riparian encroachment into former channels (Johnson 1994).<br><br>Riparian assemblages in large rivers are particularly sensitive to changes in minimum flow and high flow events (Auble et al. 1994). |

| Flow Need | Flow Statistic and Recommendation | Supporting Literature and Studies |
|---|---|---|
| **SUMMER** | | |
| **Promote/support development and growth of all fishes, reptiles, and amphibians -** Summer and fall flows needed to maintain high velocity riffles, low velocity pools, and backwaters and stream margins.<br><br>*All habitat types* | **Seasonal Flow May-Oct**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range**<br><br>**Low Flow - Mar-July**<br><br>Headwaters<br>• No change to **monthly Q75; and**<br>• No change to **monthly low flow range**<br><br>Streams > 50 square miles<br>• No change to **monthly Q95; and**<br>• <10% change to **monthly low flow range** | In a large river, availability and persistence of shallow-slow water habitats were directly correlated with fish abundance, particularly percids, catostomids and cyprinids (Bowen et al. 1998).<br><br>Reductions of streamflows during this period have had measurable impacts on size of adult brook trout (Hakala and Hartman 2004, Walters and Post 2008)<br><br>On headwater and small streams, a simulated removal of 8% of Aug median (p50), predict 10% shift in fish assemblage; On large rivers removal of 10% in of the Aug median (p50) predict 10% shift in fish assemblage (Zorn et al. 2008).<br><br>Baseflows in a large river were augmented by an estimated 100% under regulated conditions resulting in an estimated 40% reduction of shallow slow water habitat patch size during normal baseflow periods (summer-fall-early winter) (Bowen et al. 2003).<br><br>Young-of-year abundance most correlated with shallow-slow habitat size and persistence. Suitable conditions predicted by statistics including seasonal median daily flow, high pulse magnitude, duration and rate of change (Freeman et al. 2001).<br><br>A comparison of large warmwater streams along a withdrawal index gradient finds a shift in fish assemblages from fluvial specialists to habitat generalists as withdrawals increase above 50% of 7Q10 (Freeman and Marcinek 2006).<br><br>Longitudinal connectivity is important as map turtles migrate to nesting locations. Stream migrations of 1-3 km have been documented on the lower Susquehanna River (Richards and Seigel 2009). |
| **Maintain connectivity between habitats and refugia for resident and diadromous fishes –** resident and diadromous fish need seasonal flows to maintain thermal refugia and maintain connectivity among habitats<br><br>*All habitat types* | **Seasonal Flow - Jun-Oct**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range** | Elimination of longitudinal connectivity (simulated barriers) prevented upstream migration of brook trout and led to extinction of local brook trout populations within 2 to 6 generations. Extinction of source populations increased the probability of metapopulation extinction (Letcher et al. 2007). |

| Flow Need | Flow Statistic and Recommendation | Supporting Literature and Studies |
|---|---|---|
| **SUMMER** | | |
| **Cue and direct inmigration of juvenile American Eel -** seasonal flows are needed to direct upstream migration and provide connectivity between mainstem and tributary habitats<br><br>*Mainstem and major tributaries* | **Seasonal Flow - May-July**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range** | Discharge and velocity influence the rate of upstream migration. Migrating eels may delay migration when velocities are too low or too high (Greene et al. 2009).<br><br>In recent surveys, elvers have been documented reaching the lower mainstem (Conowingo Dam) starting in the late spring (May) through the summer, peaking in June and July (SRAFRC 2009).<br><br>Juveniles have limited swimming ability and difficulty moving long distances against high velocities (Greene et al. 2009). |
| **Support mussel spawning, glochidia release, and growth -** maintenance of seasonal flows and low flows to support spawning, glochidia release, and interaction between mussels and host fish.<br><br>*All habitat types* | **Seasonal Flow - Jun-Sept**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range**<br><br>**Low Flow - Jun-Sept**<br><br>Headwaters<br>• No change to **monthly Q75; and**<br>• No change to **monthly low flow range**<br><br>Streams > 50 square miles<br>• No change to **monthly Q95; and**<br>• <10% change to **monthly low flow range** | Research on the Green River (KY) confirmed that augmented flows during summer months can reduce mussel recruitment (Layzer 2009).<br><br>Increased high flow pulses during low flow season may impact efficiency of spawning and glochidia release, particularly for species with intricate lures (D. Crabtree, personal communication, 2010).<br><br>Individual mussel mortality during drought conditions was associated with two thresholds: velocity < .01 m/s and DO ≤5 mg/L (Johnson et al. 2001).<br><br>In small stream habitat, >50% reduction of median monthly flows in summer months resulted in a 65-85% decrease in mussel density. No live mussels were found on streams that were completely dewatered. In large river habitat, unionid assemblages survive exceptional drought when surface flow connectivity was maintained (Haag and Warren 2008).<br><br>Some mussel species are adapted to low flow conditions in headwater streams but decrease in individual fitness during dry periods has been documented (J. Layzer, personal communication, 2010). |

| Flow Need | Flow Statistic and Recommendation | Supporting Literature and Studies |
|---|---|---|
| **SUMMER** | | |
| **Promote macroinvertebrate growth and insect emergence -** seasonal and low flows needed to maintain depth, velocity, and temperature in riffle and pool habitats.<br><br>*All habitat types* | **Seasonal Flow - Jul-Oct**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range**<br><br>**Low Flow - Jul-Oct**<br><br>Headwaters<br>• No change to **monthly Q75; and**<br>• No change to **monthly low flow range**<br><br>Streams > 50 square miles<br>• No change to **monthly Q95; and**<br>• <10% change to **monthly low flow range** | An experimental withdrawal in headwater streams quantifies response between summer flow and macroinvertebrate density, community composition and available habitat. A threshold seems to occur between summer Q75 and 85 (Walters et al. 2010).<br><br>Macroinvertebrate responses to drought included elimination of taxa groups including free-living caddisflies and stoneflies. Taxa with limited desiccation tolerance were last and fewest to recolonize once rewetted (Boulton 2003).<br><br>An experimental summer flow reduction of 90% resulted in a decrease in macroinvertebrate density including -41% of all macroinvertebrate taxa, -50% EPT taxa, -90% filter feeding insects, -48% grazing insects (Wills et al. 2006).<br><br>An experimental summer flow reduction of 90% of summer discharge resulted in -31% wetted width, -57% invertebrate density, and -26% density of EPT taxa (Dewson et al. 2007b).<br><br>Multiple alterations including 73% decrease in median summer flow resulted in statistically significant decreases in macroinvertebrate taxa, total number of sensitive taxa, and increases in tolerant taxa (Nichols et al. 2006).<br><br>Rapid wetting and drying of stream margins led to a decrease of total available energy, biomass, and community shifts. Varial zone benthic biomass was 33% of persistent habitat biomass (Blinn et al. 1995).<br><br>Studies have documented reduced carapace length for crayfish exposed to low flow conditions (Taylor 1982, Acosta and Perry 2001).<br><br>Crayfish are susceptible to increased predation during low flow conditions (Flinders 2003, Flinders and Magoulick 2007). |

| Flow Need | Flow Statistic and Recommendation | Supporting Literature and Studies |
|---|---|---|
| **SUMMER** | | |
| **Promote vegetation growth –** seasonal flows and high flow pulses needed to sustain inundation frequencies, maintain substrate size and soil moisture, and deter establishment of non-native vegetation.<br><br>*All habitat types* | **High Flow - May-Sept**<br><br>• 2 to 8 high flow events > Q10<br><br>**Seasonal Flow - May-Sept**<br><br>• **Monthly median** between 45th and 55th percentile; **and**<br>• Less than 20% change to **monthly range**<br><br>**Low Flow - May-Sept**<br><br>Headwaters<br>• No change to **monthly Q75; and**<br>• No change to **monthly low flow range**<br><br>Streams > 50 square miles<br>• No change to **monthly Q95; and**<br>• <10% change to **monthly low flow range** | Podniesinksi et al. 2002, cited above.<br><br>On a large river habitat, riparian assemblages are particularly sensitive to changes in minimum flow and high flow (magnitude, freq, duration) events (Auble et al. 1994).<br><br>On Aughwick Creek, loss of upright branches and leaves was associated with a 5-day duration of 15 cfs (July Q80 or Aug Q60). Plant bases began to be exposed at streamflows of 10 cfs or less (July Q90 or Aug Q77). Although this disturbance stunted total seasonal growth, it was followed by a second period of growth occurring from September to October when average hydrologic conditions resumed (Munch 1993) |
| **Maintain hyporheic habitat –** connectivity between surface and groundwater maintains hyporheic habitat within the channels, which provides provide refugia for aquatic invertebrates during drought conditions and for seasonal temperature regulation.<br><br>*All habitat types* | **Low Flow - Jun-Oct**<br><br>Headwaters<br>• No change to **monthly Q75; and**<br>• No change to **monthly low flow range**<br><br>Streams > 50 square miles<br>• No change to **monthly Q95; and**<br>• <10% change to **monthly low flow range** | Exchange between surface water and hyporheic zone occurs in response to variations in discharge, bed topography and transmissivity. Upwelling provides stream with nutrients and downwelling provides DO and organic matter to hyporheos. This zone is also refuge to early instars and stream invertebrates during extreme conditions including drought (Boulton et al. 1998).<br><br>Crayfish were found in the hyporheic zone (within 30 cm below streambed) during seasonal summer drying; they did not migrate downstream to avoid desiccation. Hyporheic burrows served as refuge for other invertebrates (DiStefano 2009). |
| **Transport organic matter and fine sediment -** seasonal high flow pulses needed to flush fine sediment and to transport and breakdown leaf litter (CPOM).<br><br>*All habitat types* | **High Flow - Jun-Nov**<br><br>• 2 to 8 high flow events > Q10 | Experimental diversion 80% of summer flows demonstrates need for high flow pulses during summer months to transport and breakdown coarse particulate organic matter (Dewson et al. 2007b).<br><br>Summer precipitation and associated high flow events flush interstitial fine sediments (sands and silt) from stream bed (B. Hayes, personal communication, 2009). |

| Flow Need | Flow Statistic and Recommendation | Supporting Literature and Studies |
|---|---|---|
| **SUMMER** | | |
| **Maintain water quality - m**aintenance of seasonal low flows needed to provide habitable water quality including temperature and dissolved oxygen in mainstem and backwater habitats, maintenance of assimilative conditions below wastewater discharges and minimize local and downstream impacts of AMD discharges.<br><br>*All habitat types* | **High Flow – July -Nov**<br><br>• 2 to 8 high flow events > Q10<br><br>**Low Flow - July-Oct**<br><br>Headwaters<br>• No change to **monthly Q75; and**<br>• No change to **monthly low flow range**<br><br>Streams > 50 square miles<br>• No change to **monthly Q95; and**<br>• <10% change to **monthly low flow range** | High flow events in Susquehanna and major tributaries decrease temperatures and increase DO during summer months (Chaplin et al. 2009 and USGS unpublished data).<br><br>In late summer/early fall of 2008, the Large River Assessment Project sampled 16 points along the Susquehanna mainstem and found that 93% of water quality parameters met standards. Only one sample did not meet temperature standards. All samples met state water quality standard for DO (> 4 mg/L). Streamflow during those months ranged from the monthly Q50 to Q70 (SRBC 2009 and USGS unpublished data).<br><br>An instantaneous minimum DO of 5.0 mg/L and a 7-day average minimum of 6.0 mg/L are recommended to protect early life stages of fishes (US EPA 1986, Chaplin et al. 2009, Greene et al. 2009).<br><br>Assimilative capacity is calculated using the 7-day, 1 in 10 year, low flow event. On the Lower Susquehanna this translates to the monthly Q99 for Jul and Aug and the monthly Q96 for Sept and Oct (USGS unpublished data). |
| **Provide abundant food sources and maintain feeding and nesting habitat for birds and mammals**<br><br>*All habitat types* | **Seasonal Flow - Jun-Oct**<br><br>• **Monthly median** between $45^{th}$ and $55^{th}$ percentile; **and**<br>• Less than 20% change to **monthly range** | Low flows can reduce aquatic prey availability for birds and create land bridges between mainland and island habitats, introducing predators which may threaten rookeries and breeding success (Brauning 1992, PGC and PFBC 2005).<br><br>Small mammals including the northern water shrew and many bat species require continuous localized access to an abundance of aquatic insects (Merritt 1987, PNHP 2009) |

## Appendix 8. List of Index Gages

| Habitat Type | Gage # | Stream Name | Drainage Area |
|---|---|---|---|
| Cold Headwater and Small Stream | 01542810 | Waldy Run near Emporium, PA | 5.2 |
| | 01549780 | Larrys Creek at Cogan House, PA | 6.8 |
| | 01517000 | Elk Run near Mainesburg, PA | 10.2 |
| | 01516500 | Corey Creek near Mainesburg, PA | 12.2 |
| | 01567500 | Bixler Run near Loysville, PA | 15.0 |
| | 01552500 | Muncy Creek near Sonestown, PA | 23.8 |
| | 01533500 | North Branch Mehoopany Creek near Lovelton, PA | 35.2 |
| | 01549500 | Blockhouse Creek near English Center, PA | 37.7 |
| | 01547700 | Marsh Creek at Blanchard, PA | 44.1 |
| | 01557500 | Bald Eagle Creek at Tyrone, PA | 44.1 |
| | 01545600 | Young Womans Creek near Renovo, PA | 46.2 |
| | 01518500 | Crooked Creek at Tioga, PA | 122.0 |
| | 01544500 | Kettle Creek at Cross Fork, PA | 136.0 |
| | 01550000 | Lycoming Creek near Trout Run, PA | 173.0 |
| | 01514000 | Owego Creek Near Owego, NY | 185.0 |
| | 01564500 | Aughwick Creek near Three Springs, PA | 205.0 |
| High Baseflow Headwater and Small Streams | 01578400 | Bowery Run near Quarryville, PA | 6.0 |
| | 01565700 | Little Lost Creek at Oakland Mills, PA | 6.5 |
| | 01547100 | Spring Creek at Milesburg, PA | 142.0 |
| | 01547950 | Beech Creek at Monument, PA | 152.0 |
| | 01565000 | Kishacoquillas Creek at Reedsville, PA | 164.0 |
| | 01571500 | Yellow Breeches Creek near Camp Hill, PA | 216.0 |
| | 01558000 | Little Juniata River at Spruce Creek, PA | 220.0 |
| | 01547200 | Bald Eagle Creek bl Spring Creek at Milesburg, PA | 265.0 |
| | 01555000 | Penns Creek at Penns Creek, PA | 301.0 |
| Warm Headwater and Small Streams | 01559700 | Sulphur Springs Creek near Manns Choice, PA | 5.3 |
| | 01574500 | Codorus Creek at Spring Grove, PA | 75.5 |
| | 01518862 | Cowanesque River at Westfield, PA | 90.6 |
| | 01555500 | East Mahantango Creek near Dalmatia, PA | 162.0 |
| | 01560000 | Dunning Creek at Belden, PA | 172.0 |
| Mainstem Tributaries | 01568000 | Sherman Creek at Shermans Dale, PA | 207.0 |
| | 01532000 | Towanda Creek near Monroeton, PA | 215.0 |
| | 01539000 | Fishing Creek near Bloomsburg, PA | 274.0 |
| | 01534000 | Tunkhannock Creek near Tunkhannock, PA | 383.0 |
| | 01570000 | Conodoguinet Creek near Hogestown, PA | 470.0 |
| | 01576754 | Conestoga River at Conestoga, PA | 470.0 |
| Upper Susquehanna Major Tributaries | 01525500 | Canisteo River at West Cameron, NY | 340.0 |
| | 01502500 | Unadilla River at Rockdayle, NY | 520.0 |
| Chemung Major Tributaries | 01520000 | Cowanesque River near Lawrenceville, PA | 298.0 |

| **Habitat Type** | **Gage #** | **Stream Name** | **Drainage Area** |
|---|---|---|---|
| West Branch Major Tributaries | 01543000 | Driftwood Br Sinnemahoning Cr at Sterling Run, PA | 272.0 |
| | 01541000 | West Branch Susquehanna River at Bower, PA | 315.0 |
| | 01552000 | Loyalsock Creek at Loyalsockville, PA | 435.0 |
| | 01548005 | Bald Eagle Creek near Beech Creek Station, PA | 562.0 |
| | 01548500 | Pine Creek at Cedar Run, PA | 604.0 |
| | 01543500 | Sinnemahoning Creek at Sinnemahoning, PA | 685.0 |
| | 01549700 | Pine Creek bl L Pine Creek near Waterville, PA | 944.0 |
| | 01542500 | WB Susquehanna River at Karthaus, Pa. | 1462.0 |
| Juniata Major Tributaries | 01566000 | Tuscarora Creek near Port Royal, PA | 214.0 |
| | 01556000 | Frankstown Br Juniata River at Williamsburg, PA | 291.0 |
| | 01562000 | Raystown Branch Juniata River at Saxton, PA | 756.0 |
| | 01559000 | Juniata River at Huntingdon, PA | 816.0 |

## Appendix 9. Summary of Water Withdrawal Scenarios and Impacts on Flow Statistics

To better understand how existing or proposed withdrawals affect flow statistics, we worked with SRBC to develop hypothetical water withdrawal scenarios and analyze them in context of the draft flow recommendations. Eight scenarios represent water withdrawals from various sectors, including shale gas development, golf course irrigation, public water supply, and nuclear power generation. For each scenario, SRBC provided a pre-withdrawal daily time series for WY1960-2008, a post-withdrawal scenario (created by subtracting the quantity withdrawn over the same time period) and a post-withdrawal scenario with pass-by conditions imposed, if applicable.

Table A9.1 lists hypothetical water withdrawal scenarios. Each scenario includes five descriptors that help determine which flow recommendations are applicable and how pass-by flows would be determined under existing guidance. These elements include (a) major habitat type; (b) designated use; (c) drainage area; (d) volume withdrawn and schedule (if variable); and (e) other characteristics of the withdrawal, including options for preventing impacts to low flow conditions.

**Table A9.1 Descriptions of hypothetical water withdrawal scenarios**

| Scenario | Description |
|---|---|
| Scenario 1 | Marcellus shale gas industry variable surface water withdrawal from extreme headwater tributary to Sugar Creek<br>a) Cold and Cool Headwaters and Small Streams<br>b) Trout Stocked Fishery<br>c) Drainage Area = 1.7 sq mi<br>d) Withdrawal (variable) = 10% of daily flow, not to exceed 1.000 mgd<br>e) Interruptible withdrawal = build storage |
| Scenario 2 | Marcellus shale gas industry surface water withdrawal from upper South Branch Sugar Creek<br>a) Cold and Cool Headwaters and Small Streams<br>b) Trout Stocked Fishery<br>c) Drainage Area = 3.5 sq mi<br>d) Withdrawal = 0.9 mgd<br>e) Interruptible withdrawal = build storage |

| Scenario | Description |
|---|---|
| Scenario 3 | Golf course surface water withdrawal from Honey Run<br><br>a) Cold and Cool Headwaters and Small Streams<br>b) Trout Stocked Fishery<br>c) Drainage Area = 3.6 sq mi<br>d) Withdrawal = 0.382 mgd<br>e) e. Interruptible withdrawal = secure conjunctive/alternative sources |
| Scenario 4 | Marcellus shale gas industry surface water withdrawal from Young Womans Creek<br><br>a) Cold and Cool Headwaters and Small Streams<br>b) Exceptional Value<br>c) Drainage Area = 49.9 sq mi<br>d) Withdrawal = 1.6 mgd<br>e) Interruptible withdrawal = build storage |
| Scenario 5 | Public water supply surface water withdrawal/diversion from Octoraro Creek/Reservoir<br><br>a) Major Tributaries<br>b) Warmwater Fishery<br>c) Drainage Area = 139 sq mi<br>d) Withdrawal = 30.000 mgd<br>e) Grandfathered source/diversion |
| Scenario 6 | Marcellus shale gas industry cumulative surface water withdrawal from Sugar Creek watershed<br><br>a) Cold and Cool Headwaters and Small Streams<br>b) Trout Stocked Fishery<br>c) Drainage Area = 188 sq mi<br>d) Withdrawal (cumulative) = 5.350 mgd<br>e) Interruptible withdrawals = build storage |
| Scenario 7 | Public water supply surface water withdrawal from lower Conestoga River<br><br>a) Major Tributaries<br>b) Warmwater Fishery<br>c) Drainage Area = 320 sq mi<br>d) Withdrawal = 12 mgd<br>e) Interruptible withdrawal = secure conjunctive/alternative sources |

| Scenario | Description |
|---|---|
| Scenario 8 | Nuclear power facility cooling water surface water withdrawal from middle Susquehanna River<br><br>a) Mainstem Rivers<br>b) Warmwater Fishery<br>c) Drainage Area = 10,253 sq mi<br>d) Withdrawal = 44 mgd<br>e) Uninterruptable withdrawal = provide mitigation |

We used the IHA and a flow duration curve calculator to compare the pre- and post- withdrawal values of six flow statistics: monthly Q10, monthly median (Q50), monthly range (change in area under monthly flow duration curve between Q75 and Q10); low flow range (change in area under monthly flow duration curve between Q75 and Q99); monthly Q75 (streams <50 square miles) and monthly Q95 (streams and rivers > 50 square miles).

Table A9.2 shows the changes to each flow statistic. The flow recommendation for each statistic is listed in Table 5.1 of this report and also at the top of each column in Table A9.2. We color-coded the results to illustrate how various scenarios affect each flow statistic:

- For monthly Q10, monthly range, and monthly low flow range, changes are expressed as percent change to flow statistic: <10% (green); 10-20% (yellow); 20-50% (red); and >50% (black). For monthly range, the recommendation is <20% change to the area under this portion of the curve, so both green and yellow indicate that the recommendation was met. For monthly Q10 and monthly low flow range, the recommendation is <10% change, so only green indicates that the recommendation was met.
- For monthly median, change is expressed as within (green) or outside (black) the range between the pre-withdrawal 45$^{th}$ and 55$^{th}$ percentiles of the annual monthly medians during WY 1960-2008.
- For monthly Q75 and Q95, the flow recommendation is no change to the pre-withdrawal value. The table indicates if the withdrawal changed (black) or did not change (green) the value. Monthly Q75 is used for headwaters (<50 mi$^2$) and monthly Q95 for all other streams and rivers.

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- Green: Less than 10% change OR Within if the alternative is Within/Outside of recommendation
- Yellow: 10 to 20% change
- Red: 20 to 50% change
- Black: more than 50% change OR Outside if the alternative is Within/Outside of recommendation
- (shaded) Passby Alternative
- (shaded purple) Alternative results in Augmentation

| | | | High Flows | Seasonal Median | Seasonal Range | Low Flow Range | | Low Flow Magnitude | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Statistic** | **Monthly Q10** | **Monthly Median** Median of Monthly Medians | **Monthly Range (Q75 to Q10)** | **Monthly Q75 to Q99**: Headwaters < 50 sqmi | **Monthly Q75 to Q99:** Sheds > 50 sqmi | **Monthly Q75** Headwaters < 50 sqmi | **Monthly Q95** Sheds > 50 sq mi |
| | | **Flow Recommendation** | ≤ 10% change to Q10 | Between the 45th and 55th Percentiles | ≤ 20% change to area under curve between Q10 and Q75 | No Change | ≤ 10% change to area under curve between Q75 and Q99 | No Change | No Change |
| | Scenarios | **Month** | % change to Q10 | Within/Outside | % change to area | Within/Outside | % change to area | Within/Outside | Within/Outside |
| **Scenario 1** | Headwater 1.7 sqm 10% daily flows withdrawal - no min | **Oct** | Yellow | Green | Yellow | Black | | Green | |
| | | **Nov** | Green | Black | Yellow | Black | | Black | |
| | | **Dec** | Green | Green | Yellow | Black | | Green | |
| | | **Jan** | Yellow | Green | Green | Black | | Black | |
| | | **Feb** | Green | Green | Green | Black | | Green | |
| | | **Mar** | Yellow | Black | Yellow | Black | | Black | |
| | | **Apr** | Yellow | Black | Green | Black | | Black | |
| | | **May** | Yellow | Green | Green | Black | | Green | |
| | | **Jun** | Yellow | Black | Green | Black | | Green | |
| | | **Jul** | Green | Black | Yellow | Black | | Green | |
| | | **Aug** | Green | Green | Yellow | Green | | Green | |
| | | **Sep** | Yellow | Green | Yellow | Black | | Black | |
| | Headwater 1.7 sqm 10% daily flows 20% ADF passby | **Oct** | Yellow | Green | Green | Green | | Green | |
| | | **Nov** | Green | Black | Green | Green | | Green | |
| | | **Dec** | Green | Green | Yellow | Black | | Green | |
| | | **Jan** | Yellow | Green | Green | Black | | Black | |
| | | **Feb** | Green | Green | Green | Black | | Green | |
| | | **Mar** | Yellow | Black | Yellow | Black | | Black | |
| | | **Apr** | Yellow | Black | Green | Black | | Black | |
| | | **May** | Yellow | Green | Green | Black | | Green | |
| | | **Jun** | Yellow | Black | Green | Green | | Green | |
| | | **Jul** | Green | Green | Green | Green | | Green | |
| | | **Aug** | Green | Green | Green | Green | | Green | |
| | | **Sep** | Yellow | Green | Green | Green | | Green | |
| **Scenario 2** | Headwater 3.5 sqm .9mgd withdrawal - no min | **Oct** | Red | Black | Black | Black | | Black | |
| | | **Nov** | Red | Black | Black | Black | | Black | |
| | | **Dec** | Yellow | Black | Red | Black | | Black | |
| | | **Jan** | Yellow | Black | Black | Black | | Black | |
| | | **Feb** | Yellow | Black | Red | Black | | Black | |
| | | **Mar** | Green | Black | Red | Black | | Black | |
| | | **Apr** | Green | Black | Red | Black | | Black | |
| | | **May** | Yellow | Black | Red | Black | | Black | |
| | | **Jun** | Red | Black | Black | Black | | Black | |
| | | **Jul** | Black | Black | Black | Black | | Black | |
| | | **Aug** | Black | Black | Black | Black | | Black | |
| | | **Sep** | Black | Black | Black | Black | | Black | |
| | Headwater 3.5 sqm .9mgd 20% ADF passby | **Oct** | Red | Green | Red | Green | | Green | |
| | | **Nov** | Red | Black | Red | Green | | Green | |
| | | **Dec** | Yellow | Black | Red | Black | | Black | |
| | | **Jan** | Yellow | Black | Red | Red | | Black | |
| | | **Feb** | Yellow | Black | Red | Black | | Black | |
| | | **Mar** | Green | Black | Red | Black | | Black | |
| | | **Apr** | Green | Black | Red | Black | | Black | |
| | | **May** | Yellow | Black | Red | Black | | Black | |
| | | **Jun** | Red | Green | Red | Green | | Green | |
| | | **Jul** | Black | Green | Yellow | Green | | Green | |
| | | **Aug** | Red | Green | Green | Green | | Green | |
| | | **Sep** | Black | Green | Yellow | Green | | Green | |
| **Scenario 3** | Headwater 3.6 sqm .382 mgd withdrawal - no min | **Oct** | Yellow | Black | Red | Black | | Black | |
| | | **Nov** | Green | Black | Red | Black | | Black | |
| | | **Dec** | Green | Black | Yellow | Black | | Black | |
| | | **Jan** | Green | Black | Yellow | Black | | Black | |
| | | **Feb** | Green | Black | Yellow | Black | | Black | |
| | | **Mar** | Green | Black | Green | Black | | Black | |
| | | **Apr** | Green | Black | Yellow | Black | | Black | |
| | | **May** | Green | Black | Yellow | Black | | Black | |
| | | **Jun** | Green | Black | Red | Black | | Black | |
| | | **Jul** | Yellow | Black | Red | Black | | Black | |
| | | **Aug** | Red | Black | Black | Black | | Black | |
| | | **Sep** | Yellow | Black | Black | Black | | Black | |
| | Headwater 3.6 sqm .382 mgd 20% ADF passby | **Oct** | Yellow | Green | Yellow | Green | | Green | |
| | | **Nov** | Green | Black | Yellow | Green | | Green | |
| | | **Dec** | Green | Black | Yellow | Black | | Black | |
| | | **Jan** | Green | Black | Yellow | Black | | Black | |
| | | **Feb** | Green | Black | Yellow | Black | | Black | |
| | | **Mar** | Green | Black | Green | Black | | Black | |
| | | **Apr** | Green | Black | Yellow | Black | | Black | |
| | | **May** | Green | Black | Yellow | Black | | Black | |
| | | **Jun** | Green | Black | Red | Green | | Green | |
| | | **Jul** | Yellow | Green | Red | Green | | Green | |
| | | **Aug** | Red | Green | Yellow | Green | | Green | |
| | | **Sep** | Yellow | Green | Yellow | Green | | Green | |

| | | | High Flows | Seasonal Median | Seasonal Range | Low Flow Range | | Low Flow Magnitude | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Statistic** | **Monthly Q10** | **Monthly Median** Median of Monthly Medians | **Monthly Range (Q75 to Q10)** | **Monthly Q75 to Q99**: Headwaters < 50 sqmi | **Monthly Q75 to Q99:** Sheds > 50 sqmi | **Monthly Q75** Headwaters < 50 sqmi | **Monthly Q95** Sheds > 50 sq mi |
| | | **Flow Recommendation** | ≤ 10% change to Q10 | Between the 45th and 55th Percentiles | ≤ 20% change to area under curve between Q10 and Q75 | No Change | ≤ 10% change to area under curve between Q75 and Q99 | No Change | No Change |
| | Scenarios | **Month** | % change to Q10 | Within/Outside | % change to area | Within/Outside | % change to area | Within/Outside | Within/Outside |
| **Scenario 4** | Headwater | **Oct** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | 49.9sqm | **Nov** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | 1.6 mgd | **Dec** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | withdrawal - no min | **Jan** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | | **Feb** | 🟢 | ⚫ | 🟢 | ⚫ | | ⚫ | |
| | | **Mar** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | | **Apr** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | | **May** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | | **Jun** | 🟢 | ⚫ | 🟢 | ⚫ | | ⚫ | |
| | | **Jul** | 🟢 | ⚫ | 🟢 | ⚫ | | ⚫ | |
| | | **Aug** | 🟢 | ⚫ | 🟢 | ⚫ | | ⚫ | |
| | | **Sep** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | Headwater | **Oct** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | 49.9 sqm | **Nov** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | 1.6 mgd | **Dec** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | 4% ADF Passby (IFIM) | **Jan** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | | **Feb** | 🟢 | ⚫ | 🟢 | ⚫ | | ⚫ | |
| | | **Mar** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | | **Apr** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | | **May** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| | | **Jun** | 🟢 | ⚫ | 🟢 | ⚫ | | ⚫ | |
| | | **Jul** | 🟢 | ⚫ | 🟢 | ⚫ | | ⚫ | |
| | | **Aug** | 🟢 | ⚫ | 🟢 | ⚫ | | ⚫ | |
| | | **Sep** | 🟢 | 🟢 | 🟢 | ⚫ | | ⚫ | |
| **Scenario 5** | Headwater | **Oct** | 🔴 | ⚫ | ⚫ | | ⚫ | | ⚫ |
| | 139 sqm | **Nov** | 🟡 | ⚫ | 🔴 | | ⚫ | | ⚫ |
| | 30 mgd | **Dec** | 🟡 | ⚫ | 🔴 | | ⚫ | | ⚫ |
| | withdrawal - no min | **Jan** | 🟡 | ⚫ | 🔴 | | ⚫ | | ⚫ |
| | | **Feb** | 🟡 | ⚫ | 🔴 | | ⚫ | | ⚫ |
| | | **Mar** | 🟢 | ⚫ | 🟡 | | 🔴 | | ⚫ |
| | | **Apr** | 🟢 | ⚫ | 🟡 | | 🔴 | | ⚫ |
| | | **May** | 🟡 | ⚫ | 🔴 | | ⚫ | | ⚫ |
| | | **Jun** | 🟡 | ⚫ | 🔴 | | ⚫ | | ⚫ |
| | | **Jul** | 🟡 | ⚫ | 🔴 | | ⚫ | | ⚫ |
| | | **Aug** | 🔴 | ⚫ | ⚫ | | ⚫ | | ⚫ |
| | | **Sep** | 🔴 | ⚫ | ⚫ | | ⚫ | | ⚫ |
| | Headwater | **Oct** | 🟢 | ⚫ | 🔴 | | 🟡 | | ⚫ |
| | 139 sqm | **Nov** | 🟢 | ⚫ | 🟡 | | 🔴 | | ⚫ |
| | 30mgd | **Dec** | 🟢 | ⚫ | 🟡 | | 🔴 | | ⚫ |
| | 27 cfs release | **Jan** | 🟢 | ⚫ | 🟢 | | 🔴 | | ⚫ |
| | | **Feb** | 🟢 | ⚫ | 🟢 | | 🔴 | | ⚫ |
| | | **Mar** | 🟢 | ⚫ | 🟢 | | 🟡 | | ⚫ |
| | | **Apr** | 🟢 | 🟢 | 🟢 | | 🟡 | | ⚫ |
| | | **May** | 🟢 | ⚫ | 🟡 | | 🔴 | | ⚫ |
| | | **Jun** | 🟢 | ⚫ | 🟡 | | 🔴 | | ⚫ |
| | | **Jul** | 🟢 | ⚫ | 🟡 | | 🔴 | | ⚫ |
| | | **Aug** | 🟡 | ⚫ | 🔴 | | 🟡 | | ⚫ |
| | | **Sep** | 🟡 | ⚫ | 🔴 | | 🟢 | | ⚫ |
| **Scenario 6** | Headwater | **Oct** | 🟢 | 🟢 | 🟢 | | ⚫ | | ⚫ |
| | 188 sqm | **Nov** | 🟢 | 🟢 | 🟢 | | 🔴 | | ⚫ |
| | 5.35 mgd | **Dec** | 🟢 | 🟢 | 🟢 | | 🟡 | | ⚫ |
| | withdrawal - no min | **Jan** | 🟢 | ⚫ | 🟢 | | 🟡 | | ⚫ |
| | | **Feb** | 🟢 | 🟢 | 🟢 | | 🟡 | | ⚫ |
| | | **Mar** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Apr** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **May** | 🟢 | 🟢 | 🟢 | | 🟡 | | ⚫ |
| | | **Jun** | 🟢 | ⚫ | 🟢 | | 🔴 | | ⚫ |
| | | **Jul** | 🟢 | ⚫ | 🟡 | | ⚫ | | ⚫ |
| | | **Aug** | 🟢 | ⚫ | 🔴 | | ⚫ | | ⚫ |
| | | **Sep** | 🟢 | ⚫ | 🔴 | | ⚫ | | ⚫ |
| | Headwater | **Oct** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |
| | 188 sqm | **Nov** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |
| | 5.35 mgd | **Dec** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |
| | 20% ADF passby | **Jan** | 🟢 | ⚫ | 🟢 | | 🟢 | | 🟢 |
| | | **Feb** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |
| | | **Mar** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Apr** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **May** | 🟢 | 🟢 | 🟢 | | 🟡 | | ⚫ |
| | | **Jun** | 🟢 | ⚫ | 🟢 | | 🟢 | | 🟢 |
| | | **Jul** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |
| | | **Aug** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |
| | | **Sep** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |

| | | | High Flows | Seasonal Median | Seasonal Range | Low Flow Range | | Low Flow Magnitude | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Statistic** | **Monthly Q10** | **Monthly Median** Median of Monthly Medians | **Monthly Range (Q75 to Q10)** | **Monthly Q75 to Q99**: Headwaters < 50 sqmi | **Monthly Q75 to Q99:** Sheds > 50 sqmi | **Monthly Q75** Headwaters < 50 sqmi | **Monthly Q95** Sheds > 50 sq mi |
| | | **Flow Recommendation** | ≤ 10% change to Q10 | Between the 45th and 55th Percentiles | ≤ 20% change to area under curve between Q10 and Q75 | No Change | ≤ 10% change to area under curve between Q75 and Q99 | No Change | No Change |
| | Scenarios | **Month** | % change to Q10 | Within/Outside | % change to area | Within/Outside | % change to area | Within/Outside | Within/Outside |
| **Scenario 7** | Major Trib | **Oct** | 🟢 | ⚫ | 🟢 | | 🔴 | | ⚫ |
| | 320 sqm | **Nov** | 🟢 | ⚫ | 🟢 | | 🔴 | | ⚫ |
| | 12 mgd | **Dec** | 🟢 | 🟢 | 🟢 | | 🟡 | | ⚫ |
| | withdrawal - no min | **Jan** | 🟢 | 🟢 | 🟢 | | 🟡 | | ⚫ |
| | | **Feb** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Mar** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Apr** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **May** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Jun** | 🟢 | 🟢 | 🟢 | | 🟡 | | ⚫ |
| | | **Jul** | 🟢 | ⚫ | 🟢 | | 🔴 | | ⚫ |
| | | **Aug** | 🟢 | ⚫ | 🟢 | | 🔴 | | ⚫ |
| | | **Sep** | 🟢 | ⚫ | 🟡 | | 🔴 | | ⚫ |
| | Major Trib | **Oct** | 🟢 | ⚫ | 🟢 | | 🟢 | | 🟢 |
| | 320 sqm | **Nov** | 🟢 | ⚫ | 🟢 | | 🟡 | | 🟢 |
| | 12 mgd | **Dec** | 🟢 | 🟢 | 🟢 | | 🟡 | | 🟢 |
| | 20% ADF passby | **Jan** | 🟢 | 🟢 | 🟢 | | 🟡 | | ⚫ |
| | | **Feb** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Mar** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Apr** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **May** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Jun** | 🟢 | 🟢 | 🟢 | | 🟡 | | ⚫ |
| | | **Jul** | 🟢 | ⚫ | 🟢 | | 🟡 | | 🟢 |
| | | **Aug** | 🟢 | ⚫ | 🟢 | | 🟢 | | 🟢 |
| | | Sep | 🟢 | ⚫ | 🟡 | | 🟢 | | 🟢 |
| **Scenario 8** | Mainstem | **Oct** | 🟢 | ⚫ | 🟢 | | 🟢 | | ⚫ |
| | 10,253 sqm | **Nov** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | 44 mgd | **Dec** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | withdrawal - no min | **Jan** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Feb** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Mar** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Apr** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **May** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Jun** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Jul** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Aug** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Sep** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | Mainstem | **Oct** | 🟢 | ⚫ | 🟢 | | 🟢 | | 🟢 |
| | 10,253 sqm | **Nov** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |
| | 44 mgd | **Dec** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | 20% ADF passby | **Jan** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Feb** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Mar** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Apr** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **May** | 🟢 | 🟢 | 🟢 | | 🟢 | | ⚫ |
| | | **Jun** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |
| | | **Jul** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |
| | | **Aug** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |
| | | **Sep** | 🟢 | 🟢 | 🟢 | | 🟢 | | 🟢 |