Provisional Adaptive Management and Monitoring Plan for the Allegheny River

Submitted by The Nature Conservancy

PROVISIONAL ADAPTIVE MANAGEMENT AND MONITORING PLAN FOR THE ALLEGHENY RIVER

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Report prepared by The Nature Conservancy

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EXECUTIVE SUMMARY

This Provisional Adaptive Management and Monitoring Plan (AMMP) is developed by The Nature Conservancy in partnership with the U.S. Army Corps of Engineers, Pittsburgh District through the Sustainable Rivers Program. It builds on previous studies completed by The Nature Conservancy in 2013, 2015, 2017, 2018, and 2019, notably the Provisional Ecosystem Flow Recommendations developed for the Allegheny River and Kinzua Dam in 2017 and a stakeholder workshop, held in September 2020. This document provides a foundational outline for the development of a full AMMP anticipated to be finalized in partnership with the U.S. Army Corps of Engineers, Pittsburgh District, U.S. Geological Survey, and other federal, state, and conservation partners.

The Provisional Ecosystem Flow Recommendations for Kinzua Dam developed in 2017 are intended to improve streamflow conditions and riverine habitat by restoring key components of the natural flow regime. They were developed by comparing estimated natural flows to managed post-dam streamflow and identifying the hydrogeomorphic and vegetation conditions that support key aquatic and riparian communities and riverine processes. The recommendations were developed for specific river segments and are composed of multiple, seasonally varying environmental flow components, including high, seasonal, and low flows. Each ecosystem flow component has distinct streamflow targets and ecological goals associated with it.

While the Provisional Recommendations were made using the best available knowledge of streamflow and ecological relationships, the AMMP is necessary to determine if the implemented flows result in the anticipated ecosystem response (Higgins, Konrad, Warner, & Hickey, 2011). Monitoring will support refinements to the flow recommendations while ensuring that negative impacts to other dam operations are not occurring. The AMMP will explore operational opportunities and constraints, the potential trade-offs of implementation between downstream river needs and the upstream reservoir, and evaluate future conditions through the lens of a changing climate and in light of ecosystem changes that have occurred after more than half a century of flow regulation.

The AMMP seeks to improve the practice of conservation by working with practitioners to develop and communicate tested knowledge about what works, what does not work, and why. Sound guiding principles will develop clear and practical measures of conservation success. The AMMP will:

- Define ecosystem flow recommendations
- Define a system for monitoring the degree to which the ecosystem flow is implemented
- Recommend management and monitor approaches that evaluate short term responses and long-term trends reflecting the implementation of ecosystem flow recommendations

As a “living document,” the final AMMP will provide a flexible framework allowing for future updates, changes, or adjustments. The United States Army Corps of Engineers, Pittsburgh District in partnership with a core team of defined practitioners will share responsibility for updating the document, using the document as a vehicle for adaptive management, monitoring, and decision support. A system should be created with a defined process for tracking changes and making decisions, ensuring changes are made systematically and consistently integrated into flow management decisions while being accurately and efficiently communicated with District leadership and partners.

TABLE OF CONTENTS

Acknowledgements i

Executive Summary ii

Introduction 1

The Sustainable Rivers Program 1

The Study Area 1

Basin Characteristics 2

Provisional Ecosystem Flow Recommendations for Kinzua Dam 5

The Development of Provisional Ecosystem Flow Recommendations (2017) 5

A Review of the Provisional Ecosystem Flow Recommendations (2020) 13

Guiding Principles for the Kinzua Dam-Allegheny River Adaptive Management and Monitoring Plan 16

Monitoring Scales 16

Monitoring Locations 16

Existing Monitoring Sites and Data 17

Monitor Indicators 18

Monitoring Design 19

Adapting to a Changing Climate 19

An Outline for the Kinzua Dam-Allegheny River Adaptive Management and Monitoring Plan 20

Monitoring the Implementation of Ecosystem Flow Recommendations 22

Monitoring Validation Flows 23

Goal 1. Restore Bankfull Flows to Support Dynamic Geomorphological Processes 25

Goal 2. Restore Spring Pulses to Support Spring Spawning Cues and Habitat 29

Goal 3. Restore Spring Baseflows to Support Spawning and Rearing 32

Goal 4. Restore Summer Baseflows to Support Species Growth 35

Goal 5. Maintain Late Fall and Winter Flows to Support Fall Spawning and Overwintering 39

Conclusions 42

Bibliography 43

Appendix A. Allegheny River Tributaries 47

Appendix B. Allegheny River Flow-Sensitive Species Groups 48

Appendix C. Floodplain and Aquatic Vegetation Conceptual Ecological Models 52

Appendix D. Freshwater Mussel Conceptual Ecological Models 53

LIST OF FIGURES

Figure 1. Study Reaches. 1

Figure 2. Allegheny River Annual Hydrograph illustrating Flow Components and Ecosystem Flow Needs. 7

Figure 3. Flow-Ecology Diagram for the Allegheny River. 8

Figure 4. Allegheny River Provisional Ecosystem Flow Recommendations Hydrograph. 10

LIST OF TABLES

Table 1. Study Reaches. 2

Table 2. Monthly Median Streamflow Comparison with and without Kinzua Dam. 9

Table 3. Allegheny River Provisional Ecosystem Flow Recommendations. 11

Table 4. Ecosystem Flow Restoration Opportunities. 12

Table 5. Study Reach Key Characteristics. 17

INTRODUCTION

THE SUSTAINABLE RIVERS PROGRAM

In 2002, The Nature Conservancy (The Conservancy) in partnership with the United States Army Corps of Engineers (USACE)—the largest water manager in the nation—launched a collaborative effort to find more sustainable ways to manage river infrastructure that maximizes benefits for people and nature. First known as the Sustainable River Project (SRP), this work expanded to eight rivers at 36 sites across the nation by 2015. In 2017, the USACE recognized the SRP as a “Program” that included, by 2019, 66 federal dams on 16 rivers in 15 states. The SRP focuses on determining unique flow requirements for rivers and then creating operating plans for dams that achieve environmental flows—scientific prescriptions for the timing, quantity, and quality of water flow that must occur downstream and upstream of dams to revive and sustain critical ecological functions and habitat for species.

Since 2013, The Conservancy and the USACE Pittsburgh District (the District) have worked cooperatively to advance the SRP in the upper Ohio Basin. Key outcomes from this work include an extensive review of literature documenting flow-sensitive species occurring in the basin and their associated life-history needs, an evaluation of the degree of flow alteration conducted for eight Allegheny and Monongahela Basin dams, and ecosystem flow recommendations developed for three dams including Kinzua, Clarion, and Youghiogheny Lake Dams. This AMMP will develop a plan for Kinzua Dam and the Allegheny River and serve as a pilot for the development of future AMMPs for additional upper Ohio Basin dams.

THE STUDY AREA

After leaving Allegheny Reservoir through Kinzua Dam, the Allegheny River flows southwest for 198 miles, along or through eight counties. During its course downstream of Kinzua Dam, approximately 126 miles of the Allegheny River remains free-flowing, 82 miles of which are designated for inclusion in the National Wild and Scenic Rivers System. The remaining 72 miles of the Allegheny are regulated by a series of fixed-crest, low head, run of river navigation dams before reaching its confluence with the Monongahela River in Pittsburgh. The impacts of flow releases from Kinzua Dam decrease with downstream distance from the dam but are still realized at East Brady, approximately 126 miles downstream of Kinzua Dam.

In 2015, the *Ecological Flow Study for the Allegheny River* assessed the impacts of reservoir operations on reach-specific habitats and river processes for French Creek, and the Tionesta, Clarion, and Allegheny Rivers (The Nature Conservancy, 2015). The study area was divided into 14 geographically distinct reaches that account for the variability across the regulated portions of the upper Allegheny Basin. These reaches were defined based on locations of major confluences, ecological values, flow targets (to meet existing management objectives), and potential influences of both the District and non-federal reservoirs (Table 1, Figure 1). Kinzua Dam releases are made to support water quality and biological conditions at two downstream stream gages located at Natrona and West Hickory, respectively.

The geographic scope of SRP efforts on the Allegheny River has focused on Kinzua Dam to lock and dam (L/D) 9 on the Allegheny River below the Clarion River confluence, which spans Reaches A1-A7. The presence of L/D 9 changes the depth and velocity of the Allegheny mainstem, creating a 10-mile long, slow-moving pool, upstream of the L/D. Reaches A1-A5 which are most impacted by releases from Kinzua Dam are the focus of the AMMP and are defined as the Study Area (Table 1, Figure 1).

The Study Area of the river is characterized as unbraided, but some reaches (downstream of Franklin) are highly meandering, with a slightly entrenched river channel confined within a relatively narrow, steep-walled, and moderately incised valley. Deep pools (> 25 feet) occasionally occur at historic commercial sand and gravel dredging locations near Franklin, Oil City, Tionesta, Starbrick, Mead Island, and Warren (Pennsylvania Fish and Boat Commission, 2011; Mayer, 1972).

TABLE 1. STUDY REACHES.
Description of reaches for the upper Allegheny River. Reservoirs and reaches are illustrated in Figure 1. The Study Area is defined as Reaches A1-A5.

Study Reach	Reach Extent	Reach Description
A1	Kinzua Dam to Conewango Creek confluence **9 RM**	Influenced by Kinzua Dam; authorized purposes include flood control, water quality management, hydropower, fish & wildlife, & recreation
A2	Conewango to Tionesta Creek confluence **38 RM**	Influenced by Kinzua Dam & Conewango Creek
A3	Tionesta Creek to Oil Creek confluence **19 RM**	Influenced by Kinzua & Tionesta Dams
A4	Oil Creek to French Creek confluence **8 RM**	Influenced by Kinzua & Tionesta Dams & Oil Creek
A5	French Creek to Sandy Creek confluence **10 RM**	Influenced by Kinzua, Tionesta, Union & Woodcock Creek Dams
A6	Sandy Creek to Clarion River confluence **29 RM**	Influenced by Lake Wilhelm on Sandy Creek owned & operated by State of PA
A7	Clarion River confluence to L/D 9 **11 RM**	Influenced by East Branch Clarion Lake and Piney Dam

FIGURE 1. STUDY REACHES.
The 2015 Ecological Flow Study for the upper Allegheny River defined 14 study reaches for the upper Ohio Basin. The Study Area for the AMMP is defined as Reaches A1-A5.

BASIN CHARACTERISTICS

PHYSIOGRAPHY

The Study Area occurs in the Teays – Old Ohio freshwater ecoregion (Hales, n.d.; Abell, et al., 2000) while spanning the Unglaciated High Allegheny and Pittsburgh Low Plateau terrestrial ecoregions. Before advancing glaciers blocked their flows, many of the rivers in the eastern part of the region, including the Allegheny and Monongahela, flowed northward into the Laurentian system that today is composed of the St. Lawrence River and its tributaries. Consequently, fishes that had been confined to the Hudson Bay and Laurentian system were displaced into the Old Ohio during glaciation. Due to ancestral connections to multiple Basins, this freshwater ecoregion is considered globally outstanding for its' extraordinary species richness (Abell, et al., 2000), especially fishes and freshwater mussels (Ortmann, 1919; Lachner, 1956; Bier, 1994). Many of the glacial deposits have high calcium content, which is important for buffering water quality and supporting freshwater mussels. Reaches of the Allegheny River flow over glacial outwash as thick as 80 feet (Ventorini, 2011).

The Unglaciated High Allegheny Plateau is a deeply dissected highland composed of plateau remnants, rounded hills, low mountains, and narrow valleys. It is characterized by extensive forests, a short growing season, nutrient-poor residual soils, high local relief, nearly horizontal strata, resistant rock, humid climate with long winters, and oil wells. Overall, the High Allegheny Plateau is very rugged with steep valley sides, entrenched streams, high-gradient channels, and many waterfalls. Its southwestern boundary with the Pittsburgh Low Plateau is drawn where elevation, forest density, and soil changes. The Pittsburgh Low Plateau has lower elevations, less woodland density, and different soils. The terrestrial ecoregions align with the physiographic sections occurring in the Basin which include the High Plateau (from Kinzua Dam to Kennerdell) and Pittsburgh Low Plateau Sections of the Appalachian Plateaus Province (Sevon, 2000; Cushing, Cummins, & Minshall, 2006). Streams and rivers originating in these ecoregions (and physiographic sections) tend to exhibit flashy hydrology due to high local relief and narrow, discontinuous valleys (Pennsylvania Fish and Boat Commission, 2011).

CLIMATE

The upper Ohio Basin is in the humid continental climatic region which is characterized by four distinct seasons with large seasonal temperature differences and precipitation distributed throughout the year. Temperatures are lowest in the High Plateau and Allegheny Mountain Sections, where they range from an average annual minimum of 9°F to an average maximum of 75°F. These sections are dominated by cool-cold headwaters and creeks.

Across the Basin, average annual precipitation ranges from 34 to 53 inches per year. Precipitation and temperature data records from 1952 show a slight warming trend in the Basin with slight increases in annual precipitation which occur during the early fall season (Drum, et al., 2017). Weather in the region is influenced by the northern hemisphere polar jet stream that crosses the basin and the many high- and low-pressure systems that follow this jet stream.

HYDROLOGY

Major watersheds contributing to the Study Area include Conewango, Brokenstraw, and French Creek from the west; Tionesta Creek and the Clarion River from the east (see Appendix A for a more complete list of tributaries.

From the headwaters to the mainstem, streamflow magnitude varies seasonally with the lowest baseflows occurring from late summer through early fall (July through October). Evapotranspiration rates are highest during these months and precipitation is relatively low compared to the winter and spring seasons. Baseflows are moderate in the winter months and highest during spring, particularly in March and April, when they are close to ten times the magnitude of flows during the late summer and fall. During winter and spring, soils are generally saturated or frozen, resulting in higher run-off ratios during precipitation.

FLOOD AND DROUGHT HISTORY

Seasonal baseflow patterns are generally consistent, but extreme conditions can occur in any season. Hydrologic conditions can vary within years; floods and droughts can occur in the same year. The flood of record, known as the Saint Patrick's Day flood of 1936, was estimated to be a 500-year event. The flood peaked at a discharge of 574,000 cfs and 21 feet above flood stage. It was considered the worst natural disaster in western Pennsylvania history and prompted the Flood Control Act of 1936 (Ventorini, 2011). In response, over the following decades, the USACE constructed 16 flood control projects on several major upper Ohio Basin tributaries, tempering the magnitude of floods in the Basin.

Droughts and subsequent low flow conditions occurred in 1934, 1939, 1957, 1958, 1964, 1988, and 1991 (U.S. Geological Survey, 2012; Greene & Weber, 1993). The lowest flow recorded on the Ohio River at Sewickley was 2,100 cfs on September 4, 1957. Since the mid-1900s, low flow conditions on major tributaries and the mainstem have been augmented by reservoir releases and the operation of navigational L/Ds.

IMPACTS TO WATER QUALITY

In response to resource extraction, industrial development, land-use conversion and associated water quality impacts, many of the Basin's flora and fauna have experienced drastic reductions in range and abundance, and in some cases, have been extirpated (Ortmann, The destruction of the fresh-water fauna in western Pennsylvania, 1909; Lachner, 1956; Yoder, et al., 2005). In 1909, when Ortmann described biological conditions in the upper Ohio Basin, many tributaries were unfit to support native freshwater fauna, but some streams maintained adequate aquatic habitat, serving as refuges for the region's biodiversity. With improvements in water quality over the last few decades, these source populations have begun to recolonize formerly extirpated ranges (Koryak, Bonislawsky, Locy, & Porter, 2009).

Land-use conversion and several types of resource extraction – including logging, mining, and oil and gas development – have influenced the hydrology and quality of habitat in the region. From the time of settlement, logging was a significant part of the region's economy with demands driven by shipbuilding timbers, fuel, construction materials, and eventually pulp production. Large clear-cuts and land clearing resulted in erosion, decreases in bank stability, reduced shading, and increases in stream temperatures. The state's most expansive and productive bituminous coal and oil and gas formations are located in western Pennsylvania (Pennsylvania Department of Environmental Protection (PADEP), 2009). The development of these formations had a significant impact on water quality and ground and surface water hydrology in the Basin. This development has also resulted in acid mine drainage, which is the most common water quality impairment in western Pennsylvania.

To restore water quality in the Ohio River and its major tributaries, the Ohio River Valley Water Sanitation Commission (ORSANCO) was established in 1948 and ORSANCO began implementing water quality remediation and monitoring programs. In a recent summary of trends, ORSANCO reported that water quality and overall fish community health have improved over the last 40 years. The percent of pollution tolerant individuals have decreased, and native and intolerant species have increased (Thomas, Emery, & McCormick, 2005; Ohio River Valley Water Sanitation Commission, 2010). Although water quality and aquatic habitat conditions have greatly improved, mining, shale gas drilling, industrial discharges, combined sewer overflows, and emerging contaminants continue to threaten the condition, connectivity, and recovery potential of the freshwater ecosystem.

PROVISIONAL ECOSYSTEM FLOW RECOMMENDATIONS FOR KINZUA DAM

THE DEVELOPMENT OF PROVISIONAL ECOSYSTEM FLOW RECOMMENDATIONS (2017)

In 2013, the *Ecosystem Flow Recommendations for the Upper Ohio River Basin in Western Pennsylvania* study identified flow-sensitive taxa and their flow needs per season. Through a series of four workshops[1] coupled with a synthesis of over 150 pertinent publications and reports, flow hypotheses for groups of species, including fish, mussels, aquatic insects, reptiles, amphibians, birds, mammals, and vegetation, that are expected to be sensitive to changes in the flow regime, were developed. Flow management impacts to water quality, floodplain, and channel maintenance were also explored. Key life history requirements for each species group were then overlain on representative streamflow hydrographs to determine the relationships between species groups and seasonal and interannual streamflow patterns (Figure 2, Figure 3). This "bottom-up" approach confirmed the importance of high, seasonal, and low flows throughout the year and of natural variability among years.

In 2015, the *Ecological Flow Study for the Upper Allegheny River* study then compared estimated baseline (defined as streamflow without the influence of reservoir operations) and current flows (defined as streamflow conditions with operations) to identify the flow components that are altered by current operations (The Nature Conservancy, 2015). Current operations of Kinzua Dam have reduced the magnitude and frequency of bankfull events, small floods, and high flow pulses, reduced the magnitude of spring baseflows, elevated the magnitude of summer and fall baseflows, and altered winter flows (Table 2). Seasonal impacts are summarized below:

- **Spring** (March, April, May). During March and April, current monthly medians are lower than the baseline conditions.
- **Summer** (June, July, August, September). During summer months, median flows, particularly during July, August, and September, are significantly higher than baseline conditions.
- **Fall** (Oct, Nov). During October and November, monthly median flows are similar to the summer flows and significantly higher than baseline conditions.
- **Winter** (Dec, Jan, Feb). In general, alteration during the winter months is less than during the fall and summer; however, monthly medians are higher than the baseline.

[1] Technical experts in the disciplines of biology, water quality, and hydrology, were engaged from Pennsylvania Department of Environmental Protection, Pennsylvania Fish & Boat Commission, U.S. Geological Survey, U.S. Fish & Wildlife Service, U.S. Environmental Protection Agency, USACE, ORSANCO, and Western Pennsylvania Conservancy.

- **High Flows**. The frequency and magnitude of high flow pulses including 1- and 3-day high flow events have been reduced. Bankfull floods were also eliminated below Kinzua Dam.
- **Low Flows.** The magnitude of low flow pulses has increased. The timing of low flows has also changed. Under baseline conditions, low flows primarily occurred between July through October whereas low flows now occur throughout the year, even during the spring, which under baseline conditions was typically the highest flow season.

In 2017, the *Provisional Ecosystem Flow Recommendations for Allegheny and Clarion Rivers* study assessed flows on daily and monthly time-steps to refine estimates of hydrologic alteration and develop more specific flow recommendations in a form that may be operationalized (The Nature Conservancy, 2017). Recommendations for five target flow components including spring bankfull, spring pulse, and seasonal baseflows were developed for the Allegheny River from Kinzua Dam to the Clarion River confluence. Depending on the flow component, the Provisional Recommendation is presented as either (a) a range of flows (in cfs) or (b) the frequency and duration of events (either in events or days) above a specified magnitude (Figure 4, Table *3*).

The Provisional Recommendations are intended to improve streamflow conditions and the availability and quality of habitat for riverine and floodplain species by restoring key components of the flow regime that are anticipated to have the greatest influence and ecological benefit. Table 4 illustrates ecosystem needs and impacts on the natural flow components.

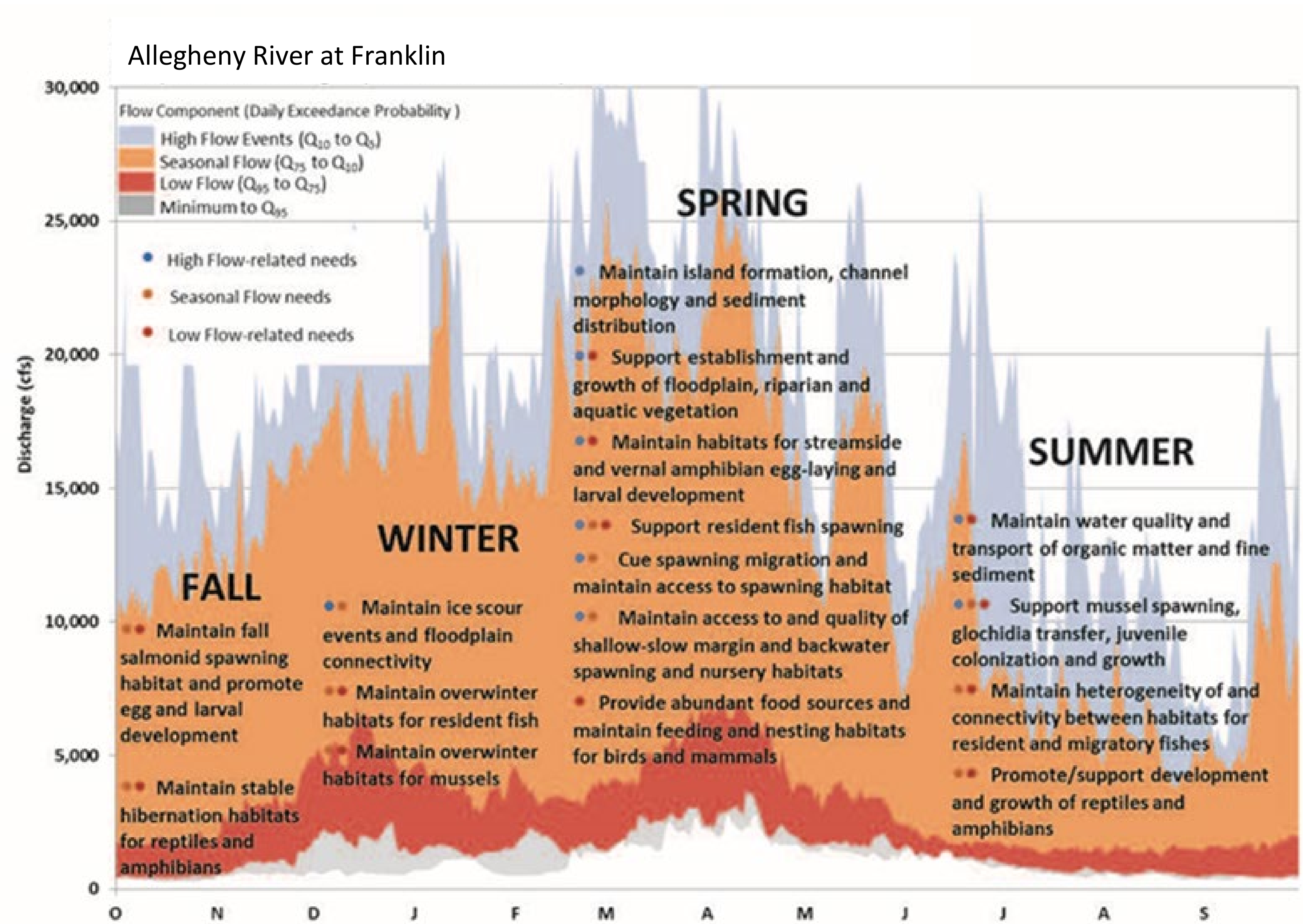

FIGURE 2. ALLEGHENY RIVER ANNUAL HYDROGRAPH ILLUSTRATING FLOW COMPONENTS AND ECOSYSTEM FLOW NEEDS. Figure summarizes flow needs in each season and indicates whether these needs are related to high, seasonal, or low streamflow components (DePhilip & Moberg, 2013).

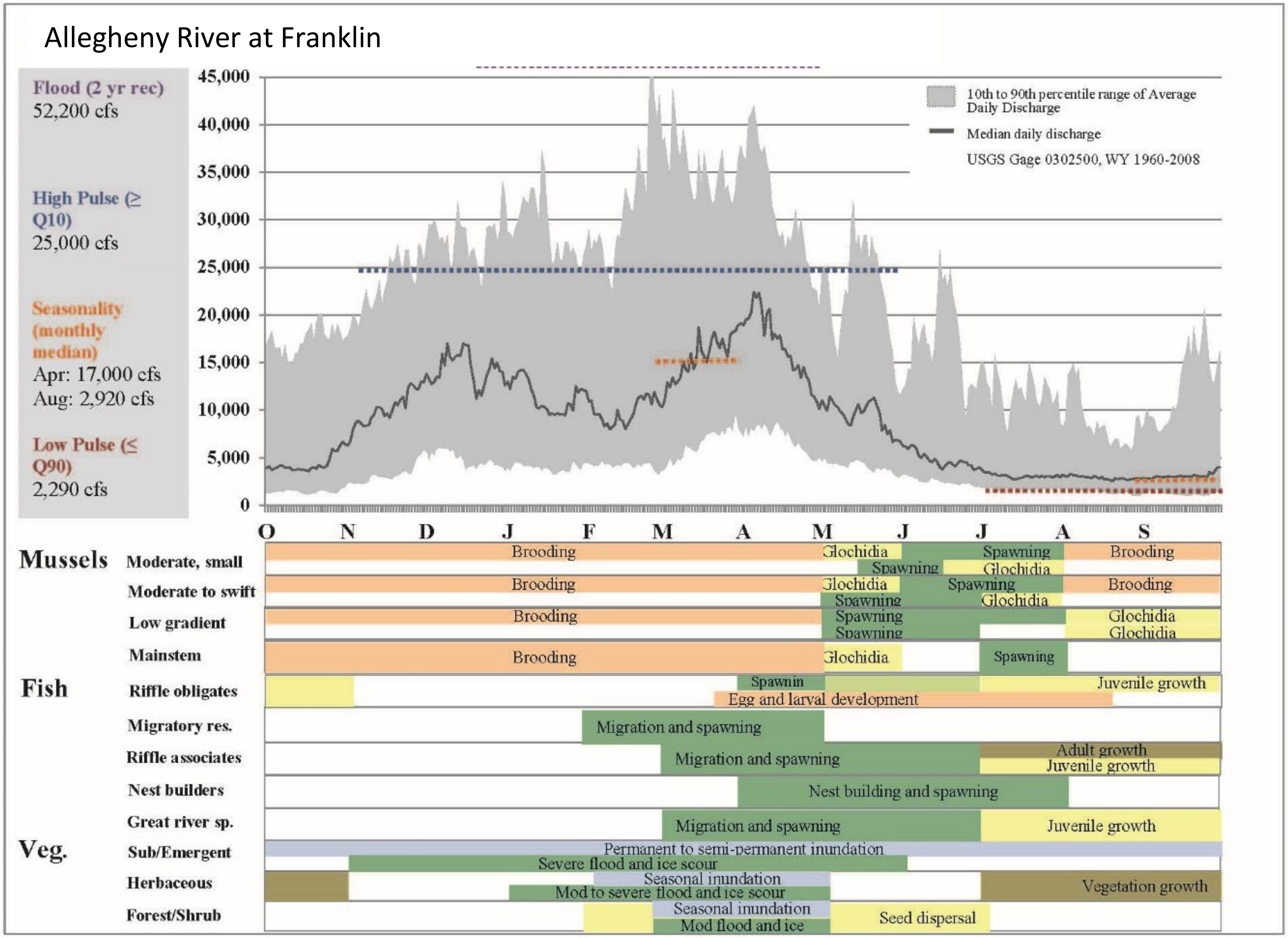

FIGURE 3. FLOW-ECOLOGY DIAGRAM FOR THE ALLEGHENY RIVER.

Figure illustrates critical life stages for flow-sensitive taxa groups during an annualized hydrograph for the Allegheny River at the Franklin U.S. Geological Survey stream gage (DePhilip & Moberg, 2013).

TABLE 2. Monthly Median Streamflow Comparison with and without Kinzua Dam. This table illustrates differences between the existing and recommended monthly median flows between 1965 to 2013. Values within 15% of the recommended values are shown as (-).

REACH	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MARCH**	**APRIL**	**MAY**	**JUNE**	**JULY**	**AUG**	**SEPT**
A1	+92%	+24%	+45%	+33%	-	-40%	-17%	-	-	+45%	+86%	+145%
A2	+48%	-	+35%	+35%	-	-23%	-	-	-	+33%	+55%	+96%
A3	+43%	-	+30%	+32%	-	-16%	-	-	-	+24%	+48%	+87%
A4	+41%	-	+25%	+30%	-	-	-	-	-	+28%	+50%	+78%
A5	+56%	-	+18%	-	+16%	-17%	-	-	-	+28%	+52%	+89%
A6	+34%	-	-	-	-18%	-36%	-19%	-	-	+20%	+43%	+74%
A7	+41%	-	+27%	+22%	+19%	-	-	+30%	+37%	+23%	+53%	+88%

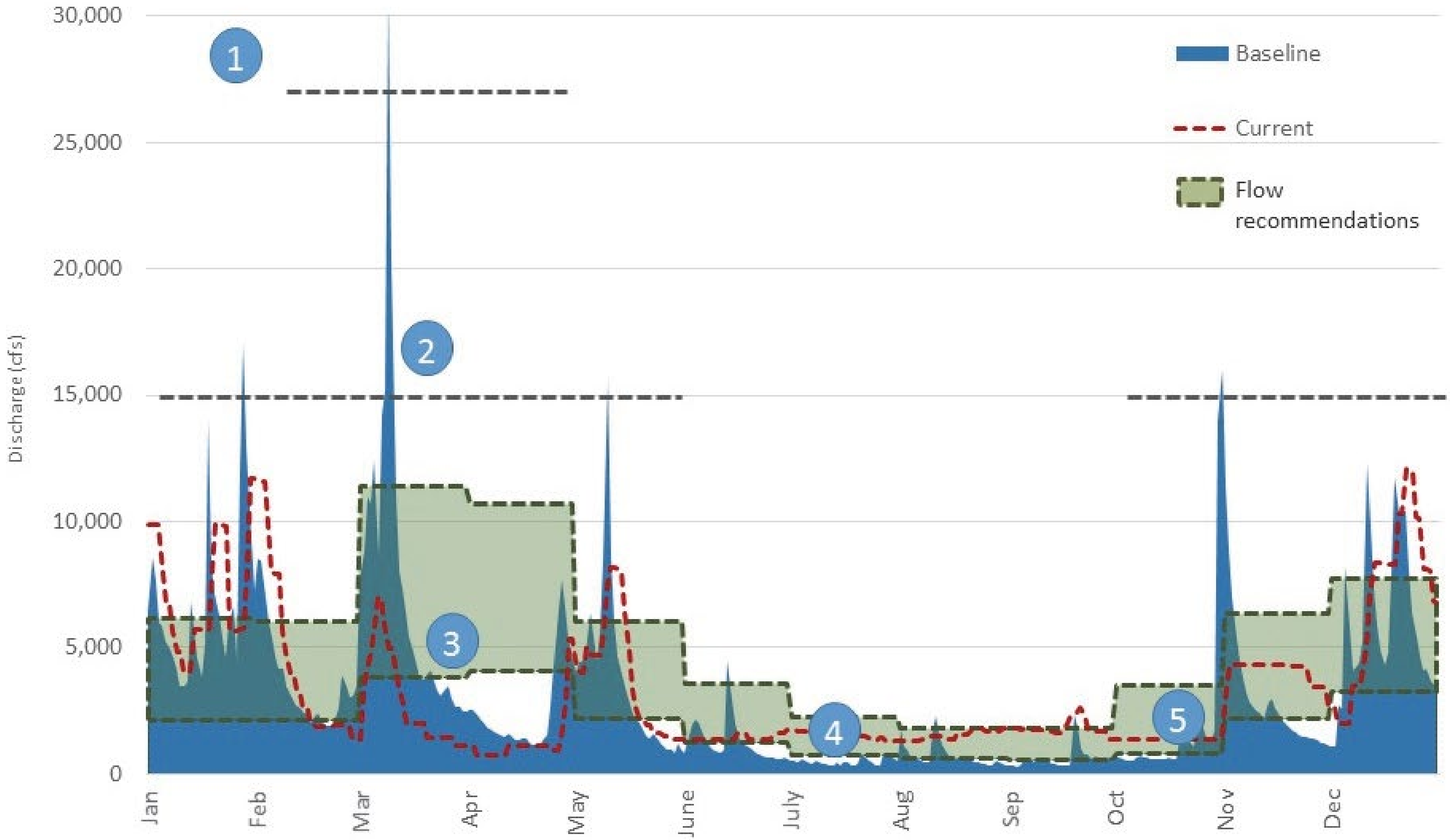

FIGURE 4. ALLEGHENY RIVER PROVISIONAL ECOSYSTEM FLOW RECOMMENDATIONS HYDROGRAPH.
Provisional Recommendations (dashed green lines and shading) for Allegheny River below Kinzua Dam including bankfull and spring pulse events (1, 2) and seasonal baseflows in spring, summer, fall and winter (3, 4, 5). See Table 4 for detailed recommendations for each of the five flow components (The Nature Conservancy, 2017).

TABLE 5. ALLEGHENY RIVER PROVISIONAL ECOSYSTEM FLOW RECOMMENDATIONS.

The following table illustrates the Provisional Ecosystem Flow Recommendations for the Allegheny River from Kinzua Dam and at Franklin (The Nature Conservancy, 2017).

SPRING			
1	**Restore bankfull flood frequency and magnitude (Annual, and Mar, Apr)**	**Below Kinzua Dam:** release a bankfull event approximately every 2 - 5 years (estimated bankfull below Kinzua Dam: 27,000 cfs), 7-day duration[1]	**At Franklin:** Release a bankfull event approximately every 2 - 5 years. Discharge should approach 100,000 cfs
2	**Restore high flow pulses during spring (pulse defined as Mar- April Q_{10}[2])**	**Below Kinzua Dam:** Release 1-3 events each year >15,000 cfs, 3-day duration, during spring for channel maintenance, habitat availability, and seed dispersal	**At Franklin:** 1-3 events each year > 38,000 cfs
3	**Restore magnitude and timing (Seasonality of spring baseflows (Mar, Apr, May)**	Approximately 50% of daily flows in Mar, Apr, and May should be within the range defined by the monthly Q_{25} and Q_{75}: **Below Kinzua Dam:** Mar: 3,200 - 9500 cfs Apr: 3,400 - 8900 cfs May: 1,800 - 5,000 cfs	**At Franklin:** Mar: 9,600 - 22,300 cfs Apr: 10,200 - 24,000 cfs May4,700 - 13,200 cfs
SUMMER			
4	**Restore magnitude and timing (seasonality) of summer baseflows (Jun, Jul, Aug, Sep)**	Approximately 50% of daily flows in Jun, Jul, Aug, and Sep should be within the range defined by the monthly Q_{25} and Q_{75}[3]: **Below Kinzua Dam:** Jun: 1,030 - 3,000 cfs Jul: 600 - 1,900 cfs Aug: 500 - 1,500 cfs Sep: 450 - 1,500 cfs	**At Franklin:** Jun: 2,300[3] - 7,800 cfs Jul: 1,500[3] - 4,600 cfs Aug: 1,200[3] - 3,800 cfs Sep: 1,000[3] - 6,100 cfs
FALL/ WINTER			
5	**Maintain late fall and winter flows that are as high or higher than early fall flows**	Late fall and winter flows should be equal to or exceed the daily flows during October. **Below Kinzua Dam:** Oct: 658 - 2,900 cfs Nov: 600 - 5,300 cfs Dec: 2,700 - 6,450 cfs Jan: 1,758 - 5,100 cfs	**At Franklin:** Oct: 1,600 - 8,000 cfs Nov: 4,300 - 14,900 cfs Dec: 6,900 - 17,800 cfs Jan: 5,700 - 20,000 cfs

[1] When possible, all recommendations for high flow events (bankfull floods and high flow pulses), should be released commensurate with high flow events occurring in the watershed, peaking at the recommended flow and closely following ascending and descending limbs of the hydrograph.

[2] Monthly Q_{10} (also called the 90-percentile flow) is the flow in cubic feet per second which was equaled or exceeded for 10% of the days during the specified months over the period of record (1962-2013).

[3] The Allegheny River reach near Tidioute and West Hickory supports expanding beds of native mussels. The USACE releases water from Kinzua Dam to meet a target of 1,720 cfs at West Hickory (~2,800 cfs at Franklin) for federally listed mussels.

TABLE 7. ECOSYSTEM FLOW RESTORATION OPPORTUNITIES.

Opportunities to restore flow components and ecosystem flow needs (adapted from TNC 2015). 1=Bankfull Flows, 2=Spring Pulse, 3=Spring Baseflows, 4=Summer Baseflows, and 5=Fall and Winter Flows.

Flow Component	Related Ecosystem Flow Need	Impacts & Ecological Benefits of Flow Components in the Allegheny River
1,3,4,5	Improve the heterogeneity and condition of habitats for resident and migratory fishes	• The Study Area includes the region's most diverse fish populations, most notably hosting more than a dozen species of darters (*Nocomis* and *Etheostoma*). Several guilds are present requiring different habitats for rearing including cold-cool water fish (e.g. salmonids and sculpin), riffle obligates (e.g. darters and shiners), and large-bodied migratory species (e.g. white sucker, redhorse species, walleye, and Ohio lamprey).
1,3,4,5	Support habitat conditions for mussel spawning, glochidia transfer and juvenile colonization and growth	• The Study Area host the region's most diverse mussel populations, several of which are federally threatened or endangered, and include the following species: Clubshell, Northern Riffleshell, Rabbitsfoot, Rayed Bean, and Snuffbox.
4, 5	Improve fall salmonid spawning habitat	• Reaches directly below Kinzua Dam support naturalized brown trout populations. Brown trout are not native to the basin but have been introduced for their value as sport fish
5	Improve overwinter habitat for hibernating reptiles and amphibians	• Reptiles (e.g. Eastern Spiny Softshell) and amphibians begin hibernation during late October and early November in the Study Area and require stable aquatic hibernacula from the early spring.
1,2,4	Improve establishment and growth of aquatic, riparian, and floodplain vegetation	• The Study Area supports diverse complexes of submerged and emergent beds (e.g. Water willow, Smartweed, Pondweed), herbaceous riparian communities (e.g. Big bluestem, Twisted sedge), and riparian and floodplain forests (Silver maple and floodplain forests). Seasonal winter and spring high flow pulses and bankfull floods support habitat conditions for vegetation establishment and growth including seed dispersal, moisture regimes, and sediment distribution.
1,2	Improve maintenance of channel morphology and sediment distribution	• Habitat-forming or bankfull flows and small floods have been eliminated or significantly reduced on all regulated reaches of the Allegheny River. These events support channel maintenance and sediment redistribution.

A REVIEW OF THE PROVISIONAL ECOSYSTEM FLOW RECOMMENDATIONS (2020)

Provisional Recommendations provide a starting point for discussions with the District, natural resource agencies, and stakeholders about the desired future condition, ecological benefits, and feasibility, including operational flexibility, structural limitations, and compatibility with other project purposes. A workshop held in September 2020, provided an opportunity to familiarize experts with the Provisional Recommendations and to receive initial feedback regarding the benefits, risks, and uncertainty of implementing each flow component. From the workshop, the following concerns and opportunities for implementing ecosystem flows emerged:

1. DO NO HARM

Practitioners voiced concern about potential unintended impacts occurring to downstream ecosystems by restoring more natural flows. Of priority, were the unintended impacts on the downstream freshwater mussel community, which harbors federally endangered freshwater mussel species. It is hypothesized that mussel beds occurring on the Allegheny River may be a result of or at least benefiting from Kinzua's modified flow regime implemented since 1965 and from the artificially elevated summer baseflows implemented by the District since 2006. Before restoring a more natural flow regime that recommends lower summer base flows, monitoring is necessary to better understand the ecosystem flow needs and the anticipated response of the freshwater mussel community to changes in flow management.

2. THE NATURAL FLOW REGIME

Flow is a major determinant of river form and habitat – river form and habitat are major determinants of riverine ecosystems (Wohl E. , 2012). From an evolutionary or biogeographical perspective, patterns of spatial and temporal habitat dynamics influence the relative success and colonization of species. While workshop participants generally supported the implementation of a more natural flow regime that inherently supports the diversity of native species and communities, there was concern that current, altered flows are supporting the recovering of federally endangered mussels. This conversation raised the issue of evaluating trade-offs between species, between riverine functions, and between ecosystem flow recommendations.

Dam operations often narrow flow variability by eliminating high and/or low flows. While this may result in increases to a few species, it could be at the expense of other native species and of systemwide species diversity. In some riverine ecosystems, the creation or enhancement of ecosystems resulting from flow regulation raises many questions regarding the ability or desire to restore to historic reference conditions. A more thorough understanding of the trade-offs between current conditions and anticipated ecosystem and species responses to flow restoration is necessary.

3. EXPLORE IMPLEMENTATION OF SPRING FLOWS

Many practitioners voiced support for implementing a more natural flow regime but recommended avoiding changes to the high-risk flows, such as bankfull and summer low flows. Instead, practitioners recommended exploring adaptive management and implementation of less-extreme or lower-risk spring pulse and seasonal flows. Determining the current state of spring pulse and seasonal flow implementation should be evaluated as a first step followed as necessary with experimental flows that monitor short-term ecosystem responses. It should be noted that high and low flow events often serve as ecological "bottlenecks" that present critical stresses, resetting the successional clock for disturbance driven floodplain species and communities (Poff & Ward, 1989). So, while the restoration of high and lows flows may pose a greater ecological risk to riverine ecosystems, their removal from the flow regime may be of equal consequence. This affirms the importance of careful experimentation, monitoring, and modeling that evaluates the need and impacts associated with a range of historic and future flows.

4. OPERATIONAL CHALLENGES AND OPPORTUNITIES

The 2020 workshop also provided an opportunity for the District to present an operationalized version of the 2017 Provisional Recommendations (Operational Recommendations) to workshop participants for feedback. Operationalized Recommendations reflect climate limitations, the need to meet downstream water quality and biological targets while ensuring there is no risk from releases to downstream private property. A comparison of Provisional versus Operationalized Recommendations is presented in *An Outline for the Kinzua Dam-Allegheny River Adaptive Management and Monitoring Plan Section*. Areas of overlap provide common ground to advance ecological flow implementation. Areas of conflict highlight the need for further monitoring and validation.

5. ALLEGHENY RESERVOIR

The focus of the workshop was to review the Provisional Recommendations developed to guide releases from Kinzua Dam and that aim to improve downstream ecosystems and riverine health. However, during the workshop, a representative from the Seneca Nation of Indians (SNI), raised concerns regarding the management of the upstream Allegheny Reservoir. The Allegany Indian Territory is located along the Allegheny River from the Pennsylvania border upriver to Vandalia, New York. The Territory originally included

30,469 acres of land surrounding the Allegheny River, of which some 10,000 acres were inundated by the Allegheny Reservoir when the District built the Kinzua Dam in 1964. The Allegheny Reservoir stretches 27 miles long and 120 feet deep. Concerns regarding Allegheny Reservoir water quality, recreational use, the walleye fishery, and environmental stewardship were raised at the workshop. Future efforts need to better understand the intricacies of how Kinzua Dam releases affect both downstream river and upstream reservoir health and goals.

6. CLIMATE CHANGE

Climate change is already resulting in distributional shifts of some species and is projected to result in many more in the coming decades. Non-stationarity in climate, ecosystems, and other environmental conditions presents another layer of complexity when determining environmental flows. Interventions may increasingly be required to manage adaptively for system resiliency and will need to consider shifting hydro-climatic and ecological conditions (Poff, Tharme, & Arthington, 2017). What is the role of water management or dam releases under this emerging paradigm? Can upstream water storage be managed flexibly to meet the downstream ecosystem and human needs? Well-established scientific insights gleaned from studies of historic reference conditions are still necessary, but they can no longer be the only benchmark of comparison. New knowledge gained from controlled dam releases (*see Monitoring Validation Flows*) and climate modeling will be necessary to manage future uncertainty (Poff, 2014; Poff, 2018)

7. CONTINUED COLLABORATION

Continued collaboration to define an Adaptive Management and Monitoring Plan (AMMP) that evaluates trade-offs between ecosystem needs, that considers the scale, scope, and timing of monitoring necessary to fill data gaps, and that develops an effective framework for learning from and implementing ecological flows that "do no harm" to downstream ecosystems was strongly encouraged. This document represents a provisional or initial version of an AMMP for Kinzua Dam and the Allegheny River. Further coordination with federal and state agencies, regional and local conservation partners, the SNI, and river, species, and flow experts is needed to create a final AMMP that is supported by a collective vision and sustained by a collective effort.

In addition to the above feedback, the workshop participants explored and provided insights regarding Provisional and Operational Recommendations, potential experimental or validation flows, as well as monitoring needs and indicators. These insights are summarized in *An Outline for the Kinzua Dam-Allegheny River Adaptive Management and Monitoring Plan Section*.

GUIDING PRINCIPLES FOR THE KINZUA DAM-ALLEGHENY RIVER ADAPTIVE MANAGEMENT AND MONITORING PLAN

MONITORING SCALES

Flow recommendations encompass a range of environmental flow components, from high to low to seasonal flows. Each flow component is intended to support a suite of physical and ecological responses. Monitoring is necessary to determine if dam operations are resulting in their anticipated benefits, producing the intended downstream response, and to refine ecosystem flows recommendations. To capture the range of ecological responses, monitoring will need to occur at multiple spatial and temporal scales. Spatial scales range from reach to sub-reach, to site level assessments. Reach level assessments are often useful to capture baseline geomorphic and community scale information collected infrequently, on the order of every 5-10-years. These long-term monitoring approaches evaluate intermediate to long-term ecosystem trends providing the foundation for long-term comparative analyses that illustrate environmental improvement from ecosystem flow implementation. Sub-reach and site-level assessments capture finer resolution information, collected in response to flow events, annual seasonality, or every 1-3-years. These short-term monitoring approaches evaluate more immediate ecosystem responses occurring directly in response to flow changes and can also help to validate or refine conceptual ecological models that articulate relationships between flow, ecosystem responses, and ultimately ecosystem health. Examples of long and short-term monitoring indicators can be found in (Richter, Mathews, Harrison, & Wigington, 2003; Higgins, Konrad, Warner, & Hickey, 2011; Wallick, et al., 2018).

MONITORING LOCATIONS

The Study Area is focused on the Allegheny River below Kinzua Dam downstream to the confluence of Sandy Creek, including Reaches A1-A5 (Table 1, Figure 1). Monitoring locations should consider longitudinal distance downstream of Kinzua Dam, lateral ecotones between aquatic, palustrine, and terrestrial ecosystems, and the location of tributary contributions. The location of USGS stream gages within the Study Area should also be considered. The Salamanco New York stream gage may also be important for monitoring as it is located on a free-flowing portion of the Allegheny River upstream of the reservoir. Streamflow gages are essential for accurately monitoring discharge and water stage while providing benchmarked stations where additional instrumentation such as water quality probes, cameras, etc. could be added. Ease of access is also important when locating monitoring sites. The Allegheny River floodplain between Warren and Tidoute is part of the Allegheny National Forest and the Allegheny Islands Wilderness, established in 1984, located on seven islands scattered along a 56-mile stretch of the Allegheny River, between the Buckaloons Recreation Area and the town of Tionesta (Reaches A1-A2), both provide ready access through public lands (Table 5).

EXISTING MONITORING SITES AND DATA

Existing data and monitoring efforts pertinent to the AMMP should be identified and summarized, identifying data gaps and opportunities to establish baseline conditions and potential future monitoring locations. A rich source of biological information for the Allegheny River is the Pennsylvania Natural Heritage Program (PNHP). PNHP is a member of NatureServe, an international network of natural heritage programs that gather and provide information on the location and status of important ecological resources (plants, vertebrates, invertebrates, ecological communities, and geologic features). Other agencies engaged in data collection efforts for the Study Area include the Pennsylvania Fish and Boat Commission (PFBC), collecting fisheries data, the Pennsylvania Department of Environmental Protection (PADEP), collecting water quality and macroinvertebrate data, the USFWS collecting species of concern data, the District, collecting temperature and streamflow data, and the SNI, involved in eastern hellbender restoration and freshwater mussel inventory efforts upstream of the reservoir. A thorough evaluation of existing data and existing monitoring efforts is necessary to establish baseline data, identify monitoring gaps, and explore potential opportunities to leverage multi-agency efforts (Table 5).

TABLE 8. STUDY REACH KEY CHARACTERISTICS.

The following notes several key characteristics of Study Reaches. RM=River Miles; ANF=Allegheny National Forest; W&S River=Wild & Scenic River; AIW=Allegheny Wilderness Area.

Reach	River Miles	Designations	Physiographic Province	PNHP Inventory Priorities (*conducted @ county scale*)	Nearest USGS Gage
A1	198 - 189 RM (9 RM)	ANF W&S River AIW	High Plateau	River Islands	at Kinzua Dam Below Conewango Creek at Warren
A2	189-151 RM (38 RM)	ANF W&S River AIW	High Plateau	Mussels Floodplain Forest Floodplain Scour Submerged Vegetation	Below Conewango Creek at Warren West Hickory
A3	151-132 RM (19 RM)	W&S River	High Plateau	Mussels Floodplain Grasslands Submerged Veg	West Hickory Franklin
A4	132-124 RM (8 RM)	None	High Plateau	Mussels Submerged Vegetation Floodplain Forest	Franklin
A5	124-114 RM (10 RM)	W&S River	High Plateau	Mussels Submerged Vegetation	Franklin
A6	114-85 RM (29 RM)	W&S River	Pittsburgh Low Plateau	Mussels Floodplain Grasslands	Parker
A7	85-74 RM (11 RM)	NA	Pittsburgh Low Plateau	Mussels Fish Submerged Vegetation	Parker

MONITOR INDICATORS

The underlying principle behind the restoration of natural flows is to restore the *physical conditions* necessary to support the *native biodiversity* of the riverine ecosystems (Poff & Allan, 1995; Schlosser, 1990; Sparks, Blodgett, & Lerczak, 1992; Stanford, et al., 1996). As a result, leading indicators, such as geomorphic response and in some cases water quality, are strongly recommended for consideration as cost-effective indicators that provide a foundation for the selection of biological indicators that provide an understanding of flow/biotic linkages (Higgins, Konrad, Warner, & Hickey, 2011).

Confounding environmental variables can limit the value of biological or single species monitoring approaches. It is essential to identify biological indicators that respond most clearly to the implementation of ecological flows and are not equally influenced by the "noise" of other environmental drivers. Monitoring single species can also result in developing flow recommendations for one species at a time, as opposed to flow recommendations that address the suite of species integrated into the riverine ecosystem. A suite of flow-sensitive indicator species provided in Appendix B was reviewed when evaluating biological indicators.

The AMMP identifies a few well-considered indicators to monitor as opposed to an exhaustive list that is expensive to implement and not necessarily more informative (Higgins, Konrad, Warner, & Hickey, 2011). Indicators have been identified independently for each flow component but the collective benefit of a suite of inter-related flow indicators was also considered. The indicators selected are hypothesis-driven showing clear linkages between flow management and ecosystem response, flow-sensitive, provide easily measured and interpretable results that capture short-term responses and long-term trends. Indicator selection considered the following criteria (Higgins, Konrad, Warner, & Hickey, 2011):

- *Scientific justification*
- *Relate directly to a flow-ecology relationship and flow recommendations*
- *Represent important structural and/or functional component of riverine ecosystems*
- *Response not strongly influenced by factors other than flow*
- *Can be quantitatively and easily measured, at spatial and temporal scales that are useful for guiding ecosystem flow implementation*
- *Cost-effective*
- *Easily communicated to appropriate audiences*

MONITORING DESIGN

Clear and deliberate decisions regarding the statistical rigor of monitoring approaches and the monitoring frameworks used, for example, the inclusion of control sites, before and after flow event monitoring, reference sites, etc. must be addressed and agreed upon by AMMP practitioners (Higgins, Konrad, Warner, & Hickey, 2011). For example, the Allegheny River upstream of the Allegheny Reservoir may provide a useful reference reach for certain monitoring goals. This river reach is already instrumented with an existing USGS stream gaging station located at Salamanca, New York, and water quality collection efforts have been ongoing by the District since 1969. Coordination with the SNI is necessary to explore the value of this as a potential reference site.

ADAPTING TO A CHANGING CLIMATE

Globally, climate change is already resulting in distributional shifts for some species and is projected to result in many more in the coming decades. The District's recent Ohio River Basin Climate Change Study (Drum, et al., 2017) estimates that low flows on the Allegheny are expected to decrease by more than 25% during the low flow season (late August through October) over the coming decades. New knowledge gained from controlled dam releases and climate modeling is needed to integrate forecasted streamflow changes with anticipated phenological changes in species' life histories. Changes to the timing of flowering and spawning and the functional role of winter flows and ice scour on the Allegheny River will require further exploration. The challenge of balancing flow management to sustain the many significant values and functions of the Allegheny River during critical periods will only become more difficult with a changing climate. Interventions may increasingly be required to manage adaptively for system resiliency while considering shifting conditions (Poff, Tharme, & Arthington, 2017; Poff, 2014).

AN OUTLINE FOR THE KINZUA DAM-ALLEGHENY RIVER ADAPTIVE MANAGEMENT AND MONITORING PLAN

This section outlines components of an AMMP for Kinzua Dam and the Allegheny River. It builds upon foundational work completed by The Nature Conservancy and the District between 2013 and 2020. The section begins with two overarching monitoring principles:

1. Monitoring the Implementation of Ecosystem Flows
2. Monitoring Validation Flows

The remainder of this section is organized by Implementation Goals including:

- Goal 1. Restore Spring Bankfull Flows to Support Dynamic Geomorphic Processes
- Goal 2. Restore Spring Pulses to Support Spawning Cues and Habitat
- Goal 3. Restore Spring Seasonal Baseflows to Support Spawning
- Goal 4. Restore Summer Seasonal Baseflows to Support Species Growth
- Goal 5. Maintain Late Fall and Winter Seasonal Flows to Support Spawning and Overwintering

Evaluating each flow component separately is necessary to understand the extent to which each component is resulting in the ecosystem responses they were designed for (Higgins, Konrad, Warner, & Hickey, 2011). Certain flow components may also provide "less risk", be that to downstream ecosystems or human communities, or more opportunity from an operational perspective to implement; however, the integration and implementation of all flow components are ultimately necessary to ensure the conservation of the downstream riverine ecosystem.

For each Implementation Goal, the following key elements of implementation are addressed:

- Ecological Purpose
- Impacts of Kinzua Dam Operation
- 2020 Ecosystem Flow Recommendation Update
- Monitoring Short-Term Response
- Monitoring Long-Term Trends

The Ecological Purpose Sub-Section details the reasons or hypotheses why the various ecosystem flow components are recommended for implementation. This section pulls largely from an extensive review of existing literature and stakeholder input obtained through prior work and workshops and summarizes the ecological significance of each flow component. For more detail regarding prior work see the *Ecosystem Flow Recommendations for the Upper Ohio River Basin in Western Pennsylvania* (DePhilip & Moberg, 2013).

The Impact of Kinzua Dam Operation Sub-Section discusses the impacts of Kinzua Dam on downstream river flows. The *Ecological Flow Study for the Upper Allegheny River* (The Nature Conservancy, 2015) completed a reach-specific hydrologic analysis for the Allegheny River. This study evaluated streamflow data extending from 1965 to 2013, noting the current level of streamflow alteration occurring as a result of dam operation (Table 1). This study compared baseline (defined as estimated streamflow without the influence of reservoir operations) and current flows (defined as streamflow conditions with operations) to identify the flow components that are altered by current operations.

The 2020 Ecosystem Flow Recommendation Update Sub-Section compares the Provisional Recommendations developed by the Conservancy in 2017 with the Operationalized Recommendations developed by the District in 2020 for Kinzua Dam. The District's Operationalized Recommendations reflect their obligation to meet other downstream flow needs, including a minimum flow guideline of 1,720 cfs for freshwater mussels at the West Hickory gage and a water quality target at the Natrona gage. While the Conservancy's recommendations are based on the natural flow regime of the Allegheny River, the modifications proposed by the District integrate their operational obligations and needs. Final recommendations reflect synergies to advance and differences where more information is needed before advancing flow recommendations.

Monitoring Short-Term Response Sub-Section identifies priority flow-sensitive indicators that are anticipated to respond more rapidly, within a 1-3-year timeframe, to changes in flow regime. Flow-sensitive indicators were identified through extensive literature review (DePhilip & Moberg, 2013) and expert input gained at the 2020 Workshop. Selected indicators reflect some, but not always all, the selection criteria presented in the *Monitor Indicators Sub-Section*, with priority given to those that are anticipated to illustrate the most direct link or clearest response to ecosystem flow management and are representative of the functional and biological diversity of the Allegheny River. As resources for monitoring are always limited, additional consideration was also given to those indicators for which monitoring data is already available and monitoring efforts are underway and anticipated to continue.

Monitoring Long-Term Trends Sub-Section builds from indicators selected for short-term monitoring while emphasizing biological indicator groups. The goal of the Sustainable Rivers Program is to support downstream river ecosystem health. While managing flows to support downstream riverine processes is essential for the creation of a shifting habitat mosaic necessary to support riverine biodiversity, the end goal is to see improvement in downstream ecosystem health in response to changes in dam operations. Therefore, long-term monitoring indicators, while including habitat assessments, largely focused on evaluating the abundance, diversity, and distribution of representative and priority biological guilds/communities. These response times are often on the order of 5-10-years. Establishing baseline data as a foundational comparison to long-term trends is essential. It is also critical that long-term monitoring still be driven by ecological flow hypotheses and not be mistaken with monitoring conducted regularly for reporting purposes and to determine trends in ecosystem condition. While monitoring for each purpose can be leveraged by the other, to improve how dams are operated for ecosystem health monitoring needs to continually focus on responses to flows (Higgins, Konrad, Warner, & Hickey, 2011).

Each flow component section concludes with high-level dashboards organized by flow component that summarize section outcomes.

MONITORING THE IMPLEMENTATION OF ECOSYSTEM FLOW RECOMMENDATIONS

The Provisional Recommendations are composed of five flow components, each of which has specific streamflow targets describing the magnitude frequency, duration, and timing of flow releases to support ecological goals. Comparing actual streamflow with the Provisional and Operationalized Recommendations provides a basis for identifying which flow components are already being implemented, the degree to which the implemented recommendations were achieved each season or year, and an understanding of the operational constraints and potential climatic opportunities necessary to advance and sustain ecological flow implementation. Evaluating the extent to which actual streamflow meets recommendations can be conducted using existing USGS stream gages particularly those located at Kinzua Dam, West Hickory, and Franklin, as flow recommendations are provided for each of these streamflow gages. The influence of major tributary contributions should also be evaluated to better understand the influence of Kinzua Dam releases versus the influence of these tributaries. This evaluation should also include a brief narrative addressing operational constraints, opportunities, and hydrological conditions, such as wet, dry, and average which led to or prohibited implementation. Other operational constraints including dam maintenance, downstream water quality targets, etc., should also be detailed and reflected in the adaptive management decision framework (Higgins, Konrad, Warner, & Hickey, 2011). A method outlining the process for tracking implementation and enabling conditions should be developed.

Maintaining reservoir storage, meeting downstream flow targets, while maintaining or restoring ecosystem flows needs is complicated. Additional hydrologic and water quality modeling of current operations including the reservoir guide curve and downstream flow schedule should be considered to improve ecosystem function while protecting existing project purposes.

Water-stage and depth modeling and monitoring reflecting habitats activated during ecosystem flow implementation should also be a consistent part of the AMMP. Understanding the inundation extent, at what stage, and at which discharge habitats are inundated and for how long, is critical to managing flows for riverine diversity. A bathymetric survey, baseline inundation modeling, and a high-flow water stage survey have been completed for Reach A2. The results of the high-flow water stage survey can be viewed here. This type of monitoring water stage will also aid in calibrating hydraulic models used to estimate flow conditions across reaches of interest.

MONITORING VALIDATION FLOWS

Understanding the relationship between streamflow and downstream ecological health and ecosystem response is the basis for the ecosystem flow recommendations. Yet, often our knowledge of these relationships is bound by limited existing data, qualitative observations, and the best judgment of stakeholders. Existing flow-ecology relations could be improved not only through monitoring short and long-term response to ecosystem flow implementation, but through the implementation of carefully designed experiments evaluating the relationships between flow, immediate geomorphic and short-term biotic responses, and should be used to validate or adaptively manage ecosystem flow recommendations and dam operations (Higgins, Konrad, Warner, & Hickey, 2011). Validation flows advance an applied approach to refining flow recommendations and conceptual ecological models under controlled conditions, that limit risk while increasing understanding.

Conceptual ecological models are qualitative tools used to identify potential drivers, such as riverine flows, and the anticipated ecosystem or species response to those drivers. Varying degrees of complexity can be included in any one model, but they still represent a simplification of natural ecosystems, embedding hypothetical assumptions about ecological flow relationships. Experimentation or validation flows provide an opportunity to begin the process of testing assumptions and resolving uncertainty associated with hypothetical responses to flow regulation. Conceptual models developed for vegetative communities and freshwater mussels guilds are found in Appendix C and Appendix D, respectively.

Validation flows should advance low risk, doing “No Harm”, yet high-value flow tests, exploring assumptions to reveal subtle shifts in species response during a specific flow component at a specific time. They should be structured so that results can be realized in the immediate or short term and can be readily applied to ecological flow releases. For example, in developing flow recommendations for the Savannah River in Georgia, scientists were somewhat uncertain about the level of high flow releases necessary to enable sturgeon to move upstream past the dam. To determine an effective release, USACE advanced an experimental high-flow pulse release from the dam. During the release, they monitored fish movement to verify that fish were able to pass the dam at the targeted flow level and discovered that water temperatures were too cold to attract fish to their spawning grounds at the time of the release. In response, USACE advanced another release after conditions (water temperature) were determined to support fish movement during spawning (Richter, Roos-Collings, & Fahlund, 2005).

During the September 2020 Workshop, expert breakout groups suggested a validation flow that would test the geomorphic effectiveness, habitat activation, and biotic response of mid-range of flows. The suggested validation flow would increase discharge incrementally over a period of 24 – 72 hours, in the spring (March or April) during wet conditions, ideally concordant with an existing rain event. The proposed release would correlate flow hydraulics, potentially sediment transport, and inundation extent, depth, and duration to changes in discharge. Monitoring would occur before, during, and after the event. It was also suggested that monitoring focus in areas of channel complexity, such as around islands, where a convergence of habitat and biodiversity could be monitored synchronously. Validation flows for other ecosystem flow recommendations should be explored during the finalization of the AMMP.

GOAL 1. RESTORE BANKFULL FLOWS TO SUPPORT SYNAMIC GEOMORPHOLOGICAL PROCESSES

ECOLOGICAL PURPOSE

Bankfull flows advance the geomorphic processes necessary to develop dynamic, yet average, channel and floodplain environments (Dunne & Leopold, 1978). Commonly referred to as the channel forming discharge (particularly in lowland rivers in wet climates (Wohl E. , 2012) over time, bankfull flows are responsible for moving the most sediment, maintaining island, valley, and floodplain formation, while shaping channel morphology (Wolman & Miller, 1960; Dunne & Leopold, 1978; Leopold, 1994). As a result of the intimate link between river regimes, channel morphology, and ecosystem response, alteration of river flows can modify channel size and shape, inducing a range of geomorphological changes and cascading biological responses. For example, floodplains often require high flows to scarify the substrate, remove topsoil and fine sediments, deposit plant propagules and seeds that ultimately slow riparian and floodplain succession and terrestrialization (Eco-Hydrologic Conceptual Models for Floodplain Communities are included in Appendix C (Figure 2, Figure 3) (DePhilip & Moberg, 2013).

THE IMPACTS OF KINZUA DAM OPERATION

An analysis of streamflow data extending from 1965 – 2013 shows that bankfull flows in March and April below Kinzua Dam have been reduced (Figure 4). Authorized by the Flood Control Acts of 1936 and 1938, Kinzua Dam and Allegheny Reservoir is one of 16 flood control projects in the Pittsburgh District that serves to retain high flows to protect downstream communities. The reservoir also provides water to meet downstream water quality and biological needs later in the season during anticipated dry periods. As a result, during March and April, Allegheny Reservoir is often 'filling' or storing water, producing monthly medians for March and April that are lower than the baseline conditions.

2020 ECOSYSTEM FLOW RECOMMENDATION UPDATE

Operationalized Bankfull Flow Recommendations vary considerably from Provisional Recommendations found in Table 3. The District anticipates a 27,000 cfs release would flood downstream properties. Depending on seasonal climate conditions, releasing that amount of water for the recommended 7-days may also jeopardize the District's ability to meet downstream flow targets later in the season. Instead, the District suggests the following changes to the bankfull flow:

- Decrease the frequency from once every 2-5 years to once every 5-10 years

- Decrease the duration from a 7-day to a 3-day event
- Decrease the discharge from 27,000 cfs to 18,000 cfs and 22,000 cfs for average and wet hydrologic conditions, respectively (during dry years, a bankfull flow may not be possible)

It is recommended that the Operationalized Bankfull Flow Recommendation be explored for implementation. The first step is to determine the frequency, duration, and magnitude of high flows that have occurred and compare this to the Operationalized Recommendation. This will provide a foundation for evaluating what is possible in terms of an operationalized bankfull flow. Modeling the extent of inundated associated with several bankfull flow options, both with regards to habitat and human infrastructure, is also necessary to ensure downstream ecosystem benefits are realized while harm to private property is not. Further efforts should also advance the validation flow (see the *Monitoring Validation Flows Sub-Section*) and monitoring to determine channel and ecosystem response to the Operationalized Recommendation.

MONITORING SHORT-TERM RESPONSE

Aligning with the purpose of this flow component, monitoring sediment dynamics and associated floodplain vegetative changes are recommended. The USGS plans to kick-off sediment monitoring in 2021, developing sediment rating curves for priority reaches of the Allegheny River. This effort will monitor total suspended sediment concentrations during a range of flows over several months in 2021 in Reaches A2 and A5, both of which are already instrumented with USGS gages. This study will evaluate patterns and trends in suspended sediment concentrations during a range of discharge events providing a better understanding of the impacts of sediment storage by Kinzua Dam, the influx of sediment by tributaries, and the discharge triggers at which sediment entrainment is initiated. Future geomorphic response monitoring should consider monitoring changes to channel substrate and erosion and sedimentation rates in association with different discharges. It is also recommended that a rapid-response biological indicator, such as seedling germination be monitored to determine if the implemented bankfull flow is providing the scour necessary to support seedling re-establishment in complex tributary junctions, shorelines, and floodplain habitats.

MONITORING LONG-TERM TRENDS

Building upon short-term monitoring approaches, monitoring longer-term changes to channel planform, and floodplain community composition and distribution are recommended. This will require that the current (and as possible, historic) baseline channel planform is mapped identifying fundamental geomorphic units that structure general river behavior and associated aquatic habitats for the Allegheny River. Characterization methods include but are not limited to the evaluation of historic and current imagery (aerial and satellite) and desktop analyses using high-resolution imagery and digital elevation models to map channel form, features including tributary fans, islands, bars, and areas of scour and deposition, and floodplain vegetation. Floodplain vegetation inventories completed by the PNHP should be used to help establish a baseline. Coarse-scale mapping of reach-scale geomorphic features provides a baseline for comparison to future imagery which could be repeated every 5-10 years.

<table>
<tr><td colspan="4">Goal 1. Restore Spring Bankfull Flows to Support Dynamic Geomorphological Processes
Ecological Purpose: Bankfull Flows initiate the geomorphic processes necessary to develop dynamic, yet average, channel and floodplain environments
Kinzua Dam Impacts: Bankfull Flows in March and April for the Study Area has been reduced</td></tr>
<tr><td colspan="4">Spring Bankfull Flow Recommendations</td></tr>
<tr><td rowspan="2">2017 Provisional Recommendations</td><td colspan="3">Every 2-5 years, during March or April, support a 7-Day Bankfull Flow[2]</td></tr>
<tr><td>Below Kinzua
> 27,000 cfs</td><td>At West Hickory
>45,000 cfs</td><td>At Franklin
Approaching 100,000 cfs</td></tr>
<tr><td rowspan="2">2020 Operationalized Recommendations</td><td colspan="3">Every 5-10 years, during March or April, support a 3-Day High Flow</td></tr>
<tr><td>Below Kinzua
18,000 cfs (dry conditions)
22,000 cfs (wet conditions)</td><td>At West Hickory
41,000 cfs (dry conditions)
45,000 cfs (wet conditions)</td><td>At Franklin
90,000 cfs (dry conditions)
100,000 cfs (wet conditions)</td></tr>
<tr><td>Challenges & Opportunities</td><td colspan="3">• Provisional Bankfull Flow Recommendations may flood downstream private property
• A 7-day bankfull flow may also jeopardize the District’s ability to have enough water available for releases needed to meet downstream flow targets later in the season</td></tr>
<tr><td>2020 Ecosystem Flow Recommendation Update</td><td colspan="3">• In support of an Operationalized Bankfull Flow Recommendation evaluate existing high flows to provide a baseline comparison to Operationalized Recommendations
• Advance suggested validation flow and monitoring to determine channel and ecosystem response to the Operationalized Recommendation</td></tr>
<tr><td colspan="4">Adaptive Management and Monitoring Planning</td></tr>
<tr><td>Monitoring
Short-Term Response</td><td colspan="3">• Conduct water stage and sediment monitoring to determine inundation extent and sediment variability associated with the Operationalized Recommendation, for 6-12 months, in Reaches A2 & A5
• Conduct a validation flow to monitor the geomorphic value and inundation extent of the proposed Operationalized Bankfull Flows</td></tr>
<tr><td>Monitoring
Long-Term Trends</td><td colspan="3">• Develop baseline hydrogeomorphic maps and monitor geomorphology, substrate, and large wood response every 5-10-years for Reaches A2, A3, & A5
• Develop baseline floodplain maps and monitor floodplain (island, floodplain, wetland, vernal pool communities) community response every 5-10-years in Reaches A2, A3, & A5</td></tr>
</table>

[2] When possible, release commensurate with high flow events closely following ascending and descending limbs of the hydrograph.

Goal 2. RESTORE SPRING PULSES TO SUPPORT SPRING SPAWNING CUES AND HABITAT

ECOLOGICAL PURPOSE

Pulse flows flush fine sediment, redistribute organics and seeds, provide biological cues, while also re-watering back-channel, riverine wetland, and shallow margin habitats. They also help to maintain aquatic and riparian vegetation. The frequency of these events is particularly important in spring when they help to cue spawning fish, maintain access to and quality of slow-moving shallow spawning and nursery habitat, and support vegetation growth. Biological cues are not often linked to instantaneous temperature, but to cumulative degree days (the number of days with temperatures above 0°F). Suitable flow conditions need to coincide with the timing of cumulative degree days for growth, emergence, migration, and other biological events to occur. High flow pulses followed by stable, high flows are key to spawning success for many fish species. For example, nest building fishes may spawn more than once in a season. The length of time between high flow pulses increases the chances of nest success (Figure 2, Figure 3) (DePhilip & Moberg, 2013).

THE IMPACTS OF KINZUA DAM OPERATION

An analysis of streamflow data extending from 1965 – 2013 shows that Allegheny Reservoir operates to retain naturally occurring 1- and 3-day duration Spring Pulse events in March and April (Table 2, Figure 4). Reservoirs are filling during spring to store water for releases later in the year. During filling, pulse events may be captured, creating low flow conditions during a time, such as spring, when higher flows are typical. Part of what makes spring pulses important is their magnitude relative to typical seasonal flows - spring pulses generally have the highest flow magnitude relative to other seasons.

2020 ECOSYSTEM FLOW RECOMMENDATION UPDATE

Operationalized Recommendations are very similar to the Provisional Recommendations found in Table 3 while taking into consideration climatic limitations and opportunities. The District suggests that the annual frequency of Spring Pulses reflect the following seasonal climatic conditions:

- During dry conditions, attempt to advance 1 Spring Pulse
- During average conditions, attempt to advance 2 Spring Pulses
- During wet conditions, attempt to advance 3 Spring Pulses

Spring pulse releases, with a lesser discharge and shorter duration than bankfull flows, may provide an opportunity to re-establish a high-flow component to reservoir releases. While Kinzua Dam typically stores spring runoff for release during summer low flows, in recent years, wetter springs have allowed for releases to occur coincident with spring storm events (N. Lazzarro, personal communication, August 2020). The recommended 3-day spring pulse duration may be problematic due to the volume of water "lost" from storage, so varying durations may need to be considered.

In response to the above challenges, it is recommended that the climatically supported Operationalized Spring Pulse Release be explored for implementation. Documenting the level of implementation that is currently occurring is a necessary first step, followed by advancing the validation flow suggested in the *Monitoring Validation Flows Sub-Section* and monitoring to evaluate ecosystem response.

MONITORING SHORT-TERM RESPONSE

Spring Pulse monitoring approaches should build upon geomorphologic and seedling germination monitoring approaches already established for bankfull flow monitoring. Due to the importance of temperature cues for the movement and spawning of certain aquatic species, it is also recommended that temperature monitoring, evaluating cumulative degree days for water temperature be conducted. The USGS plans to kick off this monitoring in 2021, monitoring temperature variability during a range of flows over the course of several months in Reaches A2 and A5, which are already instrumented with USGS gages. This study will monitor Kinzua releases, discharge, and temperature to better understand seasonal and spatial variation in temperature influences from Kinzua Dam. Existing water temperature data, collected by the District, will be evaluated and as applicable, used to establish a temperature baseline.

MONITORING LONG-TERM TRENDS

Future trend analyses should again build upon Monitoring Long-Term Trends established for bankfull flows. The value of specifically monitoring the Big Blue Stem Riverine Grassland Community should also be considered. This community, composed of warm-season grasses and wild indigo (*Baptisia australis)* is limited to occurring on broad, low-lying fans at the mouths of tributaries on cobbles and boulders of glacial origin. While glacial outwash is found on shores and gravel bars throughout the Allegheny River, this community only occurs in the floodplains downstream of Franklin, where the impacts of Kinzua Dam on stream flows is limited (Zimmerman, 2011) (see Appendix C for more detail regarding floodplain community ecosystem flow needs) (excerpted with permission from (Western Pennsylvania Conservancy, 2020).

Goal 2. Restore Spring Pulses to Provide Spawning Cues and Habitat

Ecological Purpose: Pulse flows flush fine sediment, redistribute organics and seeds, provide biological (temperature) cues, while also re-watering back-channel, riverine wetland, and shallow margin habitats

Kinzua Dam Impacts: The 1- and 3-day Spring Pulse events in March and April for the Study Area has been reduced

Spring Pulse Recommendations

2017 Provisional Recommendations	1-3xs annually, during March or April, support a 3-Day Duration Spring Pulse		
	Below Kinzua >15,000 cfs	At West Hickory >25,000 cfs	At Franklin >38,000 cfs
2020 Operationalized Recommendations	1-3xs annually, during March or April, support 3-Day Spring Pulses *(Advance 1, 2, and 3 Pulses for Dry, Average, and Wet Hydrologic Conditions, respectively)*		
	Below Kinzua >15,000 cfs	At West Hickory >25,000 cfs	At Franklin >38,000 cfs
Challenges & Opportunities	• A 3-day spring pulse may jeopardize the District's ability to have enough water available for releases needed to meet downstream flow targets later in the season • Yet wetter springs may provide an opportunity to advance Spring Pulses		
2020 Ecosystem Flow Recommendation Update	• **In support of an Operational Spring Pulse Recommendation, evaluate the current status of implementation** • **Coordinate spring pulses with agencies to ensure release timing coincides with species readiness** • **Advance validation flow and monitoring to evaluate ecosystem response**		

Adaptive Management and Monitoring Planning

Monitoring Short-Term Response	• Conduct water stage, sediment, and temperature monitoring to determine inundation extent, sediment, and temperature variability associated with the Operationalized Recommendation, for 6-12 months, in Reaches A2 & A5 • Conduct a validation flow to monitor the geomorphic value and inundation extent of the proposed Operationalized Spring Pulse
Monitoring Long-Term Trends	• Develop baseline floodplain maps and monitor floodplain (island, floodplain, wetland, vernal pool communities) community changes every 5-10-years in Reaches A2, A3, & A5. Consider specific monitoring of Big Bluestem Riverine Grassland Community

GOAL 3. RESTORE SPRING BASEFLOWS TO SUPPORT SPAWNING AND REARING

ECOLOGICAL PURPOSE

Spring baseflows provide access to slow-moving margin and backwater habitats for resident fish and amphibian spawning while also supporting vegetation establishment and growth in hydrologically diverse floodplain settings. Spring is typically a high-flow season with elevated monthly flows and high flow variability, both within and among years. Often represented by median daily and monthly flows, spring seasonal flows are correlated with area and persistence of critical fish habitat, juvenile abundance and year-class strength, juvenile and adult growth, and overwinter survival. Decreases in seasonal flows may also shift fish species assemblages. Amphibians, especially stream salamanders, are also highly sensitive to increased frequency of low spring flow conditions. Spring Baseflows are also critical for maintaining channel and floodplain habitats and connections between them (Figure 2, Figure 3) (DePhilip & Moberg, 2013).

THE IMPACTS OF KINZUA DAM OPERATION

An analysis of streamflow data extending from 1965 - 2013, shows that the monthly median flow (Q_{50}) for March has been reduced by 40%, 23%, 16%, and 17% from estimated natural conditions across Reaches A1-A3 and A5, respectively. For April and May, monthly median flows are within the accepted 15% of the hydrologic variation, except for a 17% decline in Reach A1 in April (Table 2, Figure 4). During spring months, particularly during March, streamflow downstream of the Allegheny Reservoir is lower than the baseline conditions resulting in many low flows now occur in spring, which is under natural conditions is usually the highest flow season of the year. Again, particularly during March, Kinzua Dam is filling, storing water to meet summer pool elevations and downstream flow needs later in the season.

2020 ECOSYSTEM FLOW RECOMMENDATION UPDATE

Operationalized Spring Baseflow Recommendations are identical to Provisional Recommendations found in Table 3, except for March flows. During March, the District recommends decreasing Provisional Recommendations from 5,400 cfs to 4,500 cfs at the West Hickory gage. This recommendation reflects the District's need to store water to meet downstream flow guidelines and targets later in the season. Yet, conversations with a District dam operator (N. Lazzaro, personal communication, August 2020), noted that springs seem to be getting wetter, perhaps resulting from the impacts of climate change.

It is recommended that the Provisional-Operational Recommendations, except March, be explored for implementation. The first step is to assess the current level of implementing the Provisional Recommendations, followed by advancing the suggested validation flow (see the *Monitoring Validation Flows Sub-Section*) and monitoring to evaluate ecosystem response to implementation. For March, it is recommended that climate modeling explore the reality of wetter springs and implications for flow recommendations.

MONITORING SHORT-TERM RESPONSE

While several indicators, including fish, mussels, amphibians, and macroinvertebrates could be monitored to evaluate ecosystem response to Spring Baseflows, it is recommended that fish recruitment and diversity be considered. The upper Ohio River Basin sustains the highest fish diversity of any Basin in Pennsylvania, represented by 22 families and more than 120 species (native and introduced) (Cooper, 1983; Hendricks, Stauffer, & Hocutt, 1983; Carlson, Daniels, & Eaton, 1999; Argent, Carline, & Stauffer, 2000). There are quantitative fish studies in every season (except winter) that provide evidence to support seasonal flow hypotheses. One such study documented a longitudinal shift in fish and lotic taxa moving downstream from Kinzua Dam, with diversity generally increasing as downstream distance from Kinzua Dam increased until river mile 116 (near Franklin) (Freedman, Lorson, Taylor, Carline, & Stauffer J.R., 2014). It is also anticipated that fish community data, available from the PFBC for the Study Area, may be used as a baseline, while continued PFBC fish monitoring efforts will support longer-term fish community trend analysis and leverage resources. Monitoring should focus on the characterization of species diversity, the abundance of young of year and cohorts, and habitat use for priority riffle obligate and associate fishes, including darters. As potential host fish for freshwater mussels, monitoring focused on flow-related needs for darters would also support freshwater mussel monitoring.

MONITORING LONG-TERM TRENDS

Following from short term monitoring indicators, future comparative analyses that evaluate changes in abundance, age structure, and distribution of flow-sensitive fishes across lateral (in associated nursery habitats) and longitudinal gradients (downstream from the dam and its impacts) are recommended. Existing data should be summarized to determine if suitable to establish a baseline, if not, gaps and additional monitoring needs should be identified and advanced to establish a clear baseline.

Goal 3. Restore Spring Baseflows to support Spawning and Rearing

Ecological Purpose: Spring Baseflows provide access to slow-moving margin and backwater habitats for spawning while also supporting vegetation establishment and growth in hydrologically diverse floodplain settings

Kinzua Dam Impacts: The monthly median flow (Q_{50}) for March for the Study Area has been significantly reduced

Spring Baseflow Recommendation

<table>
<tr><td rowspan="2">2017 Provisional Recommendations</td><td colspan="3">Approximately 50% of Daily Flows in March, April, and May are
within the range defined by the monthly Q_{25} and Q_{75}</td></tr>
<tr><td>Below Kinzua
March: 3,200 - 9,500 cfs
April: 3,400 - 8,900 cfs
May: 1,800 - 5,000 cfs</td><td>At West Hickory
March: 5,400 – 15,900 cfs
April: 5,700 - 14,900 cfs
May: 3,000 - 8,400 cfs</td><td>At Franklin
March: 9,600 - 22,300 cfs
April: 10,200 - 24,000 cfs
May: 4,700 - 13,200 cfs</td></tr>
<tr><td rowspan="2">2020 Operationalized Recommendations</td><td colspan="3">Approximately 50% of Daily Flows in March, April, and May
are within the following range
(ranges accommodate for Dry, Average, and Wet streamflow conditions)</td></tr>
<tr><td>Below Kinzua
March: 2,600 - 9,500 cfs
Apr: 3,400 - 8,900 cfs
May: 1,800 – 5,000 cfs</td><td>At West Hickory
March: 4,500 - 15,900cfs
Apr: 5,700 - 14,900 cfs
May: 3,000 - 8,400 cfs</td><td>At Franklin
March: 8,300-22,300 cfs
Apr: 10,200-24,000 cfs
May: 4,700-13,200 cfs</td></tr>
<tr><td>Challenges & Opportunities</td><td colspan="3">• The variability of flows particularly flows in March, pose challenges to Kinzua Dam operations as this is a time of reservoir filling
• Many low flows are now occurring more in the spring, during a season noted for streamflow variability and as the highest flow season of the year</td></tr>
<tr><td>2020 Ecosystem Flow Recommendation Update</td><td colspan="3">• In support of the Provisional-Operational Spring Baseflow Recommendation (except March), evaluate the current status of implementation
• Advance climate modeling to explore opportunities for spring baseflows in March
• Advance validation flow and monitoring to evaluate ecosystem response</td></tr>
</table>

Adaptive Management and Monitoring Planning

Monitoring Short-Term Response	• Conduct water stage, sediment, and temperature monitoring to determine inundation extent and sediment and temperature variability associated with the Operationalized Recommendation, for 6-12 months, in Reaches A2 & A5 • Monitor young of the year, cohort, and habitat use for priority fishes, such as darters, during spring for 1-2 seasons, in complex channel areas, potentially including Reaches A2, A3, & A5
Monitoring Long-Term Trends	• Develop baseline and monitor long-term fish community response to ecosystem flows every 5-years, locations to be selected by experts

GOAL 4. RESTORE SUMMER BASEFLOWS TO SUPPORT SPECIES GROWTH

ECOLOGICAL PURPOSE

Summer Baseflows support species growth and development while maintaining water quality and access to a diversity of hydraulic habitats including riffles, runs, pools, and channel margins are maintained by summer seasonal flows – low flows can limit the availability of thermal refugia and slow velocity nursery and rearing habitats. Extreme summer low flows may expose mussels in margin habitats and increase predation or desiccation – high or low flow summer events may also inhibit the transfer of glochidia to host fish, reducing mussel recruitment. Many biological events that begin in spring – including fish spawning, insect emergence, and vegetation establishment – continue during summer. Warm temperatures and high food availability make this the main season for growth for many species. Flows naturally tend to decrease over summer, which can increase water temperature and decrease DO, creating stressful conditions and influencing community assemblages, particularly for fish and freshwater mussels (Figure 2, Figure 3) (DePhilip & Moberg, 2013).

THE IMPACTS OF KINZUA DAM OPERATION

An analysis of streamflow data extending from 1965 – 2013 shows that the monthly median flows (Q_{50}) for June are within the recommended limits of hydrologic alteration, but current flows for July, August, and September are significantly greater than natural flows for the Study Area, with some of the largest increases occurring in September (Table 2, Figure 4). During these months, the District is releasing water to support downstream biological and water quality targets.

2020 ECOSYSTEM FLOW RECOMMENDATION UPDATE

Operationalized Recommendations suggested by the Corp mirror Provisional Recommendations found in Table 3, except all monthly low flows reflect the minimum flow guideline of 1,720 cfs. The Allegheny River reach near Tidioute and West Hickory supports expanding beds of native mussels. Since 2013, the District has been releasing water in June, July, August, September, October, and November from Kinzua Dam to meet a target of 1,720 cfs at the West Hickory gage. This flow target was established to support downstream freshwater mussel communities, including federally endangered and candidate mussel species. Freshwater mussel experts attending the 2020 workshop hypothesize that the minimum flow guideline is supporting the recovery of the freshwater mussel population and cautioned that restoring more natural summer low flows may harm existing mussel populations in the Study Area. However, fishery experts countered by hypothesizing that elevated summer low flows may be negatively impacting native fishes, particularly those occurring in shallow margin habitat while also potentially shifting the distribution of instream riffle and run fish habitat specialists. The District also noted that maintaining the minimum flow guideline decreases the volume of water available in the reservoir during the summer to meet the Natrona water quality flow and pool elevations in the Allegheny Reservoir.

To ensure no harm occurs to downstream freshwater mussel communities, at this time it is recommended that the minimum flow guideline of 1,720 cfs be reflected in ecosystem flow recommendations. The Provisional and Operationalized Recommendations state that "approximately 50% of daily flows in June, July, August, and September should be within the range defined by the monthly Q_{25} (in this case above the 1,720 baseflow) and Q_{75}". The extent to which this recommendation is being met should also be evaluated, followed by monitoring to evaluate ecosystem response to the current status of implementation. Due to potential risks to freshwater mussels, a validation flow is not recommended at this time but should be revisited in the future.

MONITORING SHORT-TERM RESPONSE

Monitoring macroinvertebrate abundance or guild structure associated with in-stream habitat shifts (e.g. pool, riffle, and run habitats) is recommended. Macroinvertebrates are a critical component of all rivers and are frequently used as indicators of ecological integrity. They have also been used cost-effectively to evaluate response to hydrologic alteration and while the direction of response varies, the magnitude of flow alteration has been positively correlated with ecological change (Poff & Zimmerman, 2010). Macroinvertebrate monitoring, already underway by the PADEP, may be used to establish a baseline, guide future monitoring approaches and locations, and leverage multi-agency monitoring capacity. The value and efficacy of using freshwater mussels, suggested for long-term monitoring, as a short-term monitoring indicator should be further vetted by experts.

MONITORING LONG-TERM TRENDS

Long-term monitoring of macroinvertebrate distribution and abundance is recommended; however, monitoring the health and population viability of existing freshwater mussel guilds is recommended as an additional long-term monitoring indicator. The Study Area supports 23 mussel species, two that are federally endangered, three that are federal candidate species, and many that occur in high densities.

Existing conceptual ecological models developed for these freshwater mussels provide eco-hydrologic hypotheses, but additional insights are needed to refine ecosystem flow needs for the Allegheny River's mussel communities. Due to the Allegheny River being a regional and state stronghold for freshwater mussel diversity, coupled with the species' anticipated sensitivity to flow management, monitoring is also needed to ensure that the implemented flow recommendations support mussel health.

Existing mussel data available from PNHP, USFWS, PFBC, and consultants should be summarized and used to guide further inventory characterizing both lentic and lotic mussel species. Future monitoring is recommended to better understand hydro-ecologic relationships, population viability, habitat suitability, and host fish interactions necessary to sustain mussel health. The value of mussel population modeling, building upon spatial (distribution of mussel beds) and population (mussel diversity, abundance, and age class structure and cohorts) monitoring should also be explored and, as appropriate, integrated and leveraged with efforts underway as part of federal freshwater mussel recovery plans.

It is further recommended that submerged aquatic vegetation (SAV) also be considered as a long-term monitoring indicator. Like freshwater mussels, it is hypothesized that SAV populations are expanding and may be linked to changes in the flow regime and the occurrence of freshwater mussels, particularly in fast-flowing runs (M. Walsh, personal observation, August 2020). The seeming affinity of SAV communities to establish in specific in-stream habitats including riffles, runs, and pools, may also enable SAV to be a reach-scale indicator of in-stream habitat shifts in response to flow alteration. The USACE's Engineering Research and Development Center (ERDC) and PNHP are currently testing an approach using hyperspectral imagery calibrated by ground-surveys to characterize SAV for a portion of Reach A2. This study will provide a foundation for SAV characterizations across the Study Area and pilot a cost-effective approach for evaluating priority ecosystem response at the reach or greater scale.

Goal 4. Restore Summer Baseflows to Support Species Growth

Ecological Purpose: Summer Baseflows support species growth while supporting water quality and maintaining access to key habitats

Kinzua Dam Impacts: The monthly median flow (Q_{50}) for July, August, and September for the Study Area has increased significantly

Summer Baseflow Recommendations

2017 Provisional Recommendations	Approximately 50% of daily flows in June, July, August, and September are defined by the monthly Q_{25} and Q_{75}		
	Below Kinzua June: 1,030 - 3,000 cfs July: 600 - 1,900 cfs Aug: 500 - 1,500 cfs Sept: 450 - 1,500 cfs	At West Hickory June: 1,720 - 5,040 cfs July: 1,000 - 3,200 cfs Aug: 840 - 2,500 cfs Sept: 750 - 2,500 cfs	At Franklin June: 2,300 - 7,800 cfs July: 1,500 - 4,600 cfs Aug: 1,200 - 3,800 cfs Sept: 1,000 - 6,100 cfs
2020 Operationalized Recommendations	Approximately 50% of daily flows in June, July, August, and September are defined by the monthly Q_{25} and Q_{75}		
	Below Kinzua June: 1,300 - 3,000 cfs July: 1,300 - 2,000 cfs Aug: 1,300 - 2,000 cfs Sept: 1,300 - 2,000 cfs	At West Hickory June: 1,720 - 5,040 cfs July: 1,720 - 3,200 cfs Aug: 1,720 – 3,200 cfs Sept: 1,720 – 3,200 cfs	At Franklin June; 2,800-7,840 cfs July: 2,800-4,600 cfs Aug: 2,800- 4,600 cfs Sept: 2,800-6,100 cfs
Challenges & Opportunities	• The minimum flow guideline of 1,720 cfs at West Hickory is hypothesized to support mussels but is also hypothesized to negatively impact native shallow margin fishes, and shift instream riffle and run habitats • The minimum flow guideline may impact the water volume available to meet the Natrona water quality flow target • Releases supporting downstream river health should balance Allegheny Reservoir health		
2020 Ecosystem Flow Recommendation Update	• **Reflect the minimum flow of 1,720 cfs in ecosystem flow recommendations** • **In support of the Provisional-Operational Summer Baseflow Recommendation, evaluate the current status of implementation (above 1,720 cfs)** • **Advance monitoring to evaluate ecosystem response to implementation**		

Adaptive Management and Monitoring Planning

Monitoring Short-Term Response	• Conduct water stage, sediment, and temperature monitoring to determine inundation extent, sediment, and temperature variability associated with the Summer Baseflow Recommendations, for 6-12 months, in Reaches A2 & A5 • Monitor macroinvertebrate communities, during summer for 1-2 seasons, in complex channel areas, potentially where fish cohort monitoring occurs, potentially including Reaches A2, A3, & A5
Monitoring Long-Term Trends	• Building upon baseline, monitor mussel population response to ecosystem flows, in Reaches A2, A3, & A5, on a 3-5-year frequency • Building upon baseline, monitor submerged aquatic vegetative community response to ecosystem flows every 10-years, in Reach A2

GOAL 5. MAINTAIN LATE FALL AND WINTER FLOWS TO SUPPORT FALL SPAWNING AND OVERWINTERING

ECOLOGICAL PURPOSE

Fall and winter are resource-limited periods when streamflow changes can increase bioenergetic demands, impact breeding and hibernation habitats, and influence the pattern and scale of erosional and deposition processes initiated by ice scour. Some of the lowest flows typically occur in September but flows tend to increase during fall months. Fall marks the beginning of the spawning period for brown trout and fall breeding amphibians. Several studies describe the interrelationship of low and seasonal flows to salmonid spawning success and egg and larval development. Fall is also an energetically demanding time for long-term brooding mussel species, which typically spawn during fall (Figure 2, Figure 3) (DePhilip & Moberg, 2013).

Winter is recognized as a critical time for many species of fishes, mussels, and aquatic insects and winter flows are necessary to maintain overwinter habitats for resident fish, thermal regimes for mussels, and stable habitats for breeding and hibernating amphibians. Fall spawning salmonids require winter flows to be maintained at or near fall spawning levels to ensure egg and larval development. Deeper water refugia are critical for more mobile species, while consistency in environmental conditions is important for those more vulnerable, less mobile species, including freshwater mussels and amphibians. Species like freshwater mussels may bury themselves within the stream channel to avoid freezing and desiccation, while hibernating herptiles rely on sites capable of buffering winter air and water temperatures, often with flowing water. Shoreline ice scour along channel margins provides a disturbance necessary to support early successional riparian and scour vegetation communities (Figure 2, Figure 3) (DePhilip & Moberg, 2013; Storey & Storey, 1992; Graham & Forsberg, 1991).

THE IMPACTS OF KINZUA DAM OPERATION

An analysis of streamflow data extending from 1965 – 2013 shows that the fall and winter monthly median flow (Q_{50}) in October, December, and January remain considerably above natural flows. Flows also vary between months, as November and February flows are within 15% of the Q_{50}, while October, December, and January are often greater than 30% above the Q_{50} (Table 2, Figure 4). Elevated monthly medians in October and November result from Kinzua Dam making releases to meet the minimum flow guideline of 1,720 cfs for freshwater mussels and to ensure Allegheny Reservoir has the space needed to store anticipated late winter and spring runoff events.

2020 ECOSYSTEM FLOW RECOMMENDATION UPDATE

Operationally, the District's recommendations mirror the Provisional Recommendations found in Table 3, except for maintaining the 1,720 cfs minimum flow guideline for mussels. To ensure no harm occurs to downstream freshwater mussel communities, at this time it is recommended that the minimum flow guideline of 1,720 cfs be reflected in ecosystem flow recommendations for October and November. The Provisional and Operationalized Recommendations state that "late fall and winter flows should be equal to or exceed the daily flows during October". The extent to which this recommendation is being met or implemented should also be evaluated, followed by monitoring to evaluate ecosystem response to implementation. A validation flow is not recommended at this time but should be revisited in the future.

MONITORING SHORT-TERM RESPONSE

Fall spawning and overwintering habitat conditions are priorities for this season and the flow component. An indicator considered for short-term monitoring was the number, abundance, and distribution of fall fish redds; however, as this would focus on brown trout which only occur in Reach A1, monitoring this indicator is limited in scale and scope. As ecological flows in the fall and winter are necessary to provide stable temperatures and hibernation habitats for reptiles and amphibians throughout the reaches of the Allegheny River, monitoring amphibian recruitment and associated habitat use, and habitat suitability is recommended[3]. The waters and floodplains of the Allegheny River support habitat for salamanders, frogs, turtles, and semi-aquatic snakes. Twelve families and 35 species of reptiles and amphibians use the basin's riverine and riverine dependent habitats during some or all of their life cycle. To capture both amphibian breeding and hibernacula needs and response, it is recommended that monitoring be conducted in early spring and fall.

MONITORING LONG-TERM TRENDS

Building upon short-term monitoring approaches, long-term monitoring that compares the abundance, species composition, and spatial extent of indicator groups, such as amphibians, and their associated floodplain habitats, including wetlands, vernal pools, and back-channel hibernacula, is recommended.

[3] It is recommended that the potential of also monitoring reptiles be tested with experts.

Goal 5. Restore Fall and Winter Flows to support Spawning and Overwintering

Ecological Purpose: Fall and winter are resource-limited periods when streamflow changes can increase stress and destabilize fall breeding and overwintering habitats for fall breeding fish, herptiles, and mussels

Kinzua Dam Impacts: Fall and winter monthly median flow (Q_{50}) in October, December, and January have been increased above natural flows and flow variability occurs between months

Fall & Winter Flow Recommendations

2017 Provisional Recommendations	Late fall and winter flows should be equal to or exceed the daily flows during October		
	Below Kinzua Oct: 658 - 2,900 cfs Nov: 600 - 5,300 cfs Dec: 2,700 - 6,450 cfs Jan: 1,758 - 5,100 cfs	At West Hickory Oct: 1,100 - 4,900 cfs Nov: 1,000 - 8,900 cfs Dec: 4,500 - 10,800 cfs Jan: 2,950 - 8,600 cfs	At Franklin Oct: 1,600 – 8,000 cfs Nov: 4,300 - 14,900 cfs Dec: 6,900 - 17,800 cfs Jan: 5,700 - 20,000 cfs
2020 Operationalized Recommendations	Late fall and winter flows should be equal to or exceed the daily flows during October		
	Below Kinzua Oct: 1,300 - 2,900 cfs Nov: 1,300 - 5,300 cfs Dec: 2,700 - 6,450 cfs Jan: 1,758 - 5,100 cfs	At West Hickory Oct: 1,720 - 4,900 cfs Nov: 1,720 - 8,900 cfs Dec: 4,500 - 10,800 cfs Jan: 2,950 - 8,600 cfs	At Franklin Oct: 2,800 - 8,000 cfs Nov: 2,800 - 14,900 cfs Dec: 6,900 - 17,800 cfs Jan: 5,700 - 20,000 cfs
Challenges & Opportunities	• Fall and winter baseflows are elevated due to fall & winter releases from Kinzua Dam • October and November baseflows are maintained at the minimum flow guideline of 1,720 cfs at West Hickory to prohibit mussel stranding • The minimum flow guideline may impact water available to meet the Natrona water quality flow schedule • There is concern regarding the stability and conditions (inundation and temperature) for amphibians hibernating in back-channel, wetland, vernal pool, and shallow-water habitats due to fluctuating fall and winter flows		
2020 Ecosystem Flow Recommendation Update	• **Reflect the minimum flow guideline of 1,720 cfs in October & November ecosystem flow recommendations** • **In support of Provisional-Operational Recommendations, evaluate if fall & winter flows are exceeding the daily flows in October** • **Advance monitoring to evaluate ecosystem response to implementation**		

Adaptive Management and Monitoring Planning

Monitoring Short-Term Response	• Conduct water stage, sediment, and temperature monitoring to evaluate inundation extent, sediment, and temperature variability associated with recommendations for 6-12 months, in Reaches A2 & A5 • Conduct rapid assessments of shoreline breeding and overwintering amphibian habitat activation and use during early spring and fall
Monitoring Long-Term Trends	• Develop baseline and monitor amphibian response to ecosystem flows, during spring and fall for 1-2 seasons, in complex back-channel areas, potentially including Reaches A2, A3, & A5, on a 5-year frequency

CONCLUSIONS

The success of any Adaptive Management and Monitoring Plan hinges on the willingness of a collective body of practitioners to support a long-term commitment to the restoration and preservation of the resource. The AMMP seeks to bring together a community of interdisciplinary practitioners who can leverage the resources and expertise necessary to support the long-term goals of the AMMP and the needs of the Allegheny River.

Existing monitoring is already occurring in the Allegheny River. The question is, does it, or can it, align with the goals of the AMMP to leverage resources without comprising AMMP monitoring goals. As long-term and even short-term funding for monitoring are often limited, finding ways to leverage existing monitoring efforts will be critical to ensure resources are available to implement AMMP monitoring.

Future monitoring efforts are also being initiated by the District. The District, in partnership with the USGS, is initiating efforts to begin monitoring temperature and sediment variability in priority reaches of the Allegheny River in 2021. In partnership with ERDC and WPC, the District is advancing efforts to monitor SAV, again in priority reaches, using hyperspectral imagery. Additional conversations with academic partners are also exploring collaborative monitoring opportunities.

The Adaptative Management and Monitoring Framework provides a flexible structure for evaluating ecosystem responses to the implementation of ecosystem flows. Its value relies on developing a process for managing adaptation and change. A yearly or perhaps bi-annual meeting is recommended to stay connected, to learn from monitoring efforts, and to adapt to change. Emerging conservation issues, such as the impacts of climate change, must be integrated into the AMMP and again into decision making.

Identifying actionable low-risk, high-benefit actions will be necessary to catalyze implementation of the AMMP and rapidly build collective understanding and thereby support. Recognizing short-term gains will be key, and when realized, provide much-needed momentum and energy to the collective effort, but should not replace long-term trend analyses that often align more closely with the responses of biological populations.

This framework is currently provisional – it should be reviewed, further detail added addressing monitoring approaches and identifying triggers for action, and an annual AMMP finalized in partnership with agency, academic, and conservation partners.

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APPENDIX A. ALLEGHENY RIVER TRIBUTARIES

Tributaries of the upper Allegheny River (Pennsylvania Fish and Boat Commission, 2011). Small < 100 ft; Medium = 100-200 ft; Large = 200-400 ft; Very Large > 400ft. RDB = Right Descending Bank; LDB = Left Descending Bank

River	Tributary Stream	Confluence River Mile	Stream Width at Mouth	Confluence Side	Exposed Alluvial Fan
Allegheny River	Bear Creek	82.2	Medium	RDB	Yes
	Clarion River	84.6	Very Large	LDB	No
	Scrubgrass Creek	106.9	Medium	RDB	Yes
	Sandy Creek	114.1	Medium	RDB	Yes
	East Sandy Creek	118.4	Medium	LDB	No
	French Creek	123.9	Large	RDB	No
	Oil Creek	131.9	Large	RDB	Yes
	Pithole Creek	140.9	Medium	RDB	No
	Hemlock Creek	114.6	Medium	LDB	Yes
	Tionesta Creek	151.4	Large	LDB	No
	West Hickory Creek	157.2	Small	RDB	Yes
	East Hickory Creek	158.9	Medium	LDB	Yes
	Tidioute Creek	166.7	Small	RDB	Yes
	Brokenstraw Creek	181.2	Very Large (braided channel)	RDB	Yes
	Conewango Creek	188.9	Large	RDB	No

APPENDIX B. ALLEGHENY RIVER FLOW-SENSITIVE SPECIES GROUPS

(The Nature Conservancy, 2015)

Summary of flow-sensitive groups within the Allegheny River reach A1

Fish

- Cold cool (Brown trout, Mottled sculpin)
- Riffle obligates (Channel darter, Gilt darter, Bluebreast darter, Longhead darter, Mountain madtom)
- Riffle associates (Northern hogsucker, White sucker)
- Nest builders (River chub)
- Migratory residents (Walleye, Ohio lamprey)

Mussels

- Swift current (Round Pigtoe)* not likely reproducing

Reptiles and Amphibians

- Aquatic-Lotic (Eastern Hellbender, Mudpuppy)

Birds and Mammals

- Fish-eating raptors (Bald eagle)
- Insectivores (Silver-haired Bat)

Vegetation

- Submerged and Emergent bed (Water willow)
- Herbaceous community (Tufted Hairgrass, Twisted sedge hervaceous riverine)
- Floodplain forest (Sycamore (box elder) river floodplain forest)

Summary of flow-sensitive groups within the Allegheny River reach A2

Fish

- Cold cool (Burbot)
- Riffle obligates (Spotted darter, Longhead darter, Channel darter, Tippecanoe darter, Bluebreast darter, Gilt darter, Mountain madtom)
- Riffle associates (Northern hogsucker, White sucker, *Moxostoma* (River, Shorthead and Golden redhorse)
- Nest builders (River chub, Green sunfish)
- Migratory residents (Walleye, Ohio lamprey)

Mussels

- Moderate gradient (Elktoe, Rabbitsfoot)
- Swift current (Northern Riffleshell, Clubshell, Rayed Bean Mussel, Pocketbook)
- Low gradient (Wabash Pigtoe, White Heelsplitter, Paper Pondshell)
- Great rivers (Creek Heelsplitter, Pink Heelsplitter, Fragile Papershell)

Reptiles and Amphibians

- Aquatic-Lotic (Eastern Hellbender, Mudpuppy, Eastern Spiny Softshell)

Birds and Mammals

- Fish-eating raptors (Bald eagle, Osprey)
- Insectivores (Silver-haired Bat, Northern long-eared myotis)

Vegetation

- Submerged and Emergent bed (Podostemum- Smartweed)
- Herbaceous community (Tufted Hairgrass, Meadow Willow)
- Scrub/Shrub and Floodplain forest (Sycamore and Silver maple floodplain forest)

Summary of flow-sensitive groups within the Allegheny River reach A3

Fish

- Riffle obligates (Channel darter, Gilt darter, Bluebreast darter, Longhead darter, Mountain madtom)
- Riffle associates (White sucker, Moxostoma (River, Shorthead and Golden redhorse)
- Nest builders (Smallmouth bass, River chub, Green sunfish)
- Migratory residents (Walleye, Ohio lamprey)

Mussels

- Moderate gradient (Elktoe, Rainbow Mussel)
- Swift current (Clubshell, Round Pigtoe, Wavy-rayed Lampmussel, Sheepnose Mussel
- Low gradient (Three-ridge)
- Great rivers (Purple wartyback, Long-solid)

Reptiles and Amphibians

- Riparian and floodplain (Mountain Earth Snake)

Birds and Mammals

- Fish-eating raptors and mammals (Bald eagle, River otter)
- Insectivores (Northern Myotis)

Vegetation

- Submerged and Emergent Bed (Podostemum (Smartweed), Potomogeton (Red-head and Illinois Pondweed))
- Herbaceous community (Big bluestem – indian grass community, Stalked bulrush, Blue False-indigo)
- Floodplain forest (Sycamore and Silver maple floodplain forest)

Summary of flow-sensitive groups within the Allegheny River reach A4

Fish

- Riffle obligates (Longhead Darter, Tippecanoe Darter, Northern Madtom, Channel Darter, Gilt Darter, Bluebreast Darter)
- Riffle associates (White sucker, *Moxostoma* (River, Shorthead and Golden redhorse)
- Nest builders (Hornyhead chub, Smallmouth bass, River chub)
- Migratory residents (Walleye, Ohio lamprey)

Mussels

- Moderate gradient (Elktoe)

Reptiles and Amphibians

- Aquatic-Lotic (Eastern Spiny Softshell)

Birds and Mammals

- Fish-eating raptors and mammals (Bald eagle, River otter)

Vegetation

- Submerged and Emergent bed (Potamogen (Red-head Pondweed))
- Herbaceous community (StalkedBulrush)
- Floodplain forest (Sycamore and Silver maple floodplain forest)

Summary of flow-sensitive groups and species within the Allegheny River reach A5

Group	Flow-sensitive groups and species
Fish	
	• Riffle obligates (Gravel chub, Spotted darter, Tippecanoe darter, Bluebreast darter)
	• Riffle associates (White sucker, Moxostoma (River, Shorthead and Golden redhorse)
	• Nest builders (Smallmouth bass)
	• Migratory residents (Walleye, Ohio lamprey)
Mussels	
	• Swift current (Wavy-rayed Lampmussel, Rayed Bean Mussel)
Reptiles and Amphibians	
	• Aquatic-lotic (Eastern Hellbender, Mudpuppy)
Birds and Mammals	
	• Fish-eating raptors and mammals (Bald eagle, River otter)
	• Insectivores (Northern Myotis)
Vegetation	
	• Submerged and Emergent Bed (Potomogeton (Red-head and Illinois Pondweed))
	• Herbaceous community (Engelmann's Flatsedge, White trout-lily, Wild Kidney Bean)
	• Floodplain forest (Sycamore and Silver maple floodplain forest)

Summary of flow-sensitive groups within the Allegheny River reach A6

Group	Flow-sensitive groups
Fish	
	• Riffle obligates (Bluebreast darter, Gravel Chub)
	• Riffle associates (*Moxostoma* (River, Shorthead and Golden redhorse)
	• Nest builders (Smallmouth bass, Spotted bass)
	• Migratory residents (Walleye, Ohio lamprey)
Mussels	
	• Moderate gradient (Rabbitsfoot)
	• Swift current (Clubshell, Northern Riffleshell, Rayed Bean, Round Pigtoe, Brush-tipped Emerald, Pocketbook)
Reptiles and Amphibians	
	• Aquatic-Lotic (Eastern Spiny Softshell)
Birds and Mammals	
	• Fish-eating raptors (Bald eagle)
	• Insectivores (Northern Myotis)
Vegetation	
	• Submerged and Emergent bed (Potamogen (Red-head Pondweed), Polygonum (Water smartweed))
	• Herbaceous community (Big bluestem-indian grass, Tufted Hairgrass, Blue False-indigo, Flat-stemmed spike rush)
	• Scrub/Shrub and Floodplain forest (Silver maple floodplain forest)

Summary of flow-sensitive groups within Allegheny River reach A7

Fish

- Riffle obligates (Longhead darter)
- Riffle associates (Moxostoma (River, Shorthead and Golden redhorse)
- Nest builders (Streamlined chub, Spotted bass, Smallmouth bass)
- Migratory residents (Walleye)

Mussels

- Moderate gradient (Elktoe, Snuffbox, Rainbow Mussel)
- Swift current (Clubshell, Northern Riffleshell, Rayed Bean Mussel)
- Low gradient (Wabash Pigtoe, Pocketbook)

Birds and Mammals

- Fish-eating raptors (Bald eagle)
- Colonial nesters (Great blue heron)
- Insectivores (Northern Myotis)

Vegetation

- Submerged and Emergent Bed (Potomogeton (Red-head and Illinois Pondweed))
- Herbaceous community (Big bluestem – indian grassland community)
- Floodplain forest (Silver maple floodplain forest)

APPENDIX C. FLOODPLAIN AND AQUATIC VEGETATION CONCEPTUAL ECOLOGICAL MODELS

Floodplain & Aquatic Community Ecosystem Flow Needs. The following illustrates ecosystem flow needs for floodplain, riparian, and aquatic vegetative communities of the upper Ohio Basin. Schematics illustrate the influence of inundation and disturbance on community shifts.

Key Flow-Related Needs for Ohio Basin Floodplain, Riparian and Aquatic Vegetation

Maintain ice scour events and floodplain connectivity

- During winter, seasonal and high flow events maintain ice scour disturbance necessary for preparing riparian, island, and floodplain seed beds and sustaining the riverine scour community
- High flows provide lateral connectivity to backwaters, providing inundation and soil moisture conditions that support seed dispersal and recruitment

Support establishment and growth of floodplain, riparian and aquatic vegetation

- During winter and spring, seasonal and high flow events provide disturbance to sustain communities with a high scour disturbance fidelity such as sycamore and silver maple floodplain forests
- High flows transport water-dispersed seeds and prepare seedbeds for propagules
- During the low flow season, flows must be adequate to support growth and maintain the extent of submerged aquatic vegetation

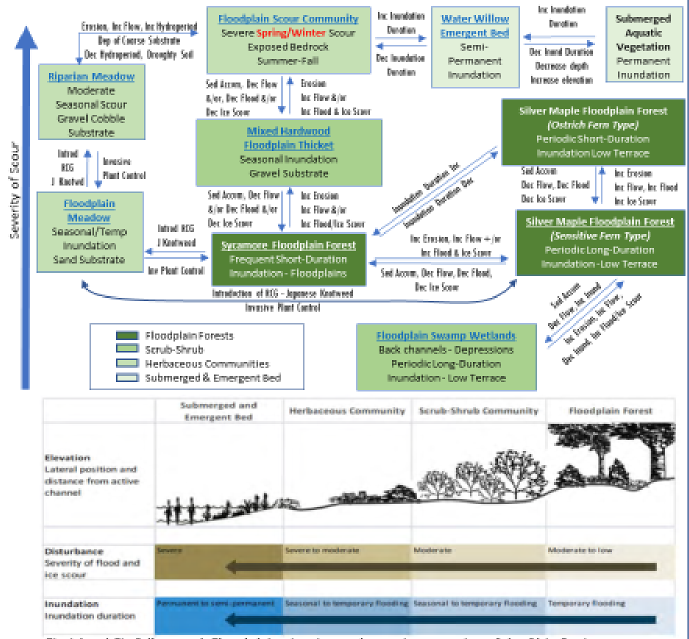
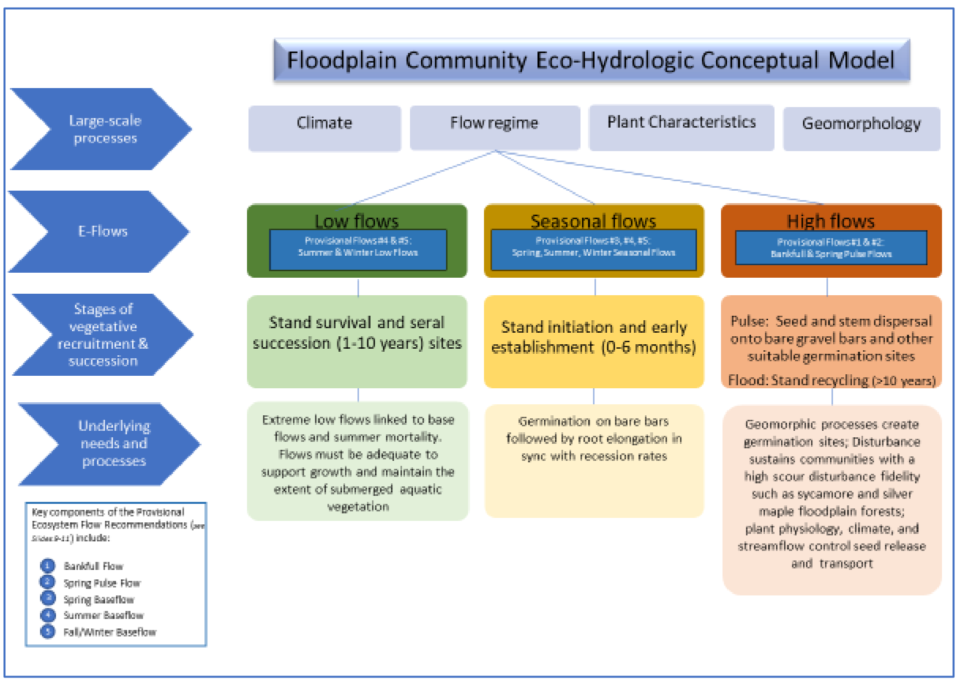
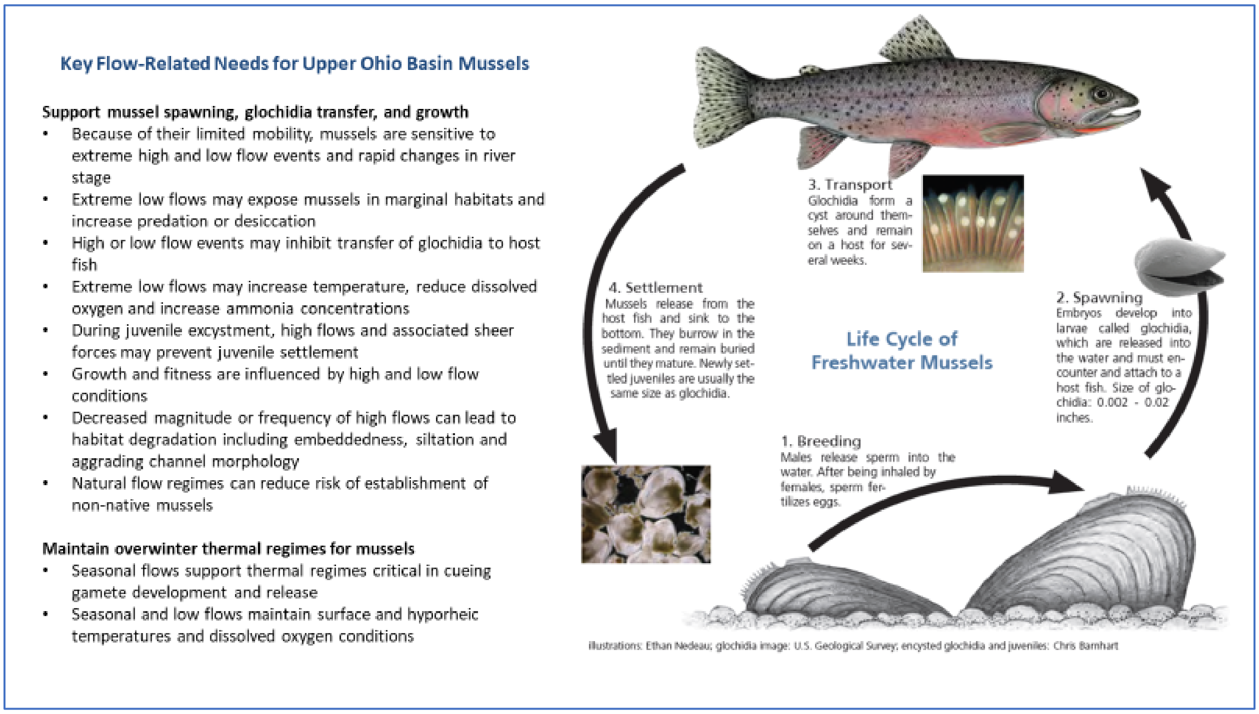


Fig 1 (top) Fig 2 (bottom). Floodplain, riparian and aquatic vegetation of the Ohio Basin – Floodplain Community disturbance fidelity and shared life history requirements illustrated.

Floodplain Community Eco-Hydrologic Conceptual Ecological Model



Freshwater Mussel Ecosystem Flow Needs. The following illustrates ecosystem flow needs for mussels and critical life stages (reprinted with permission from the USGS).



Freshwater Mussel Eco-Hydrologic Conceptual Models