Rapid Flow Change Mitigation Evaluation

Report from the Subcommittee on Ecological Flows
to the Regulated Flow Advisory Committee
of the Delaware River Basin Commission

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2020 Membership of the Subcommittee on Ecological Flows:
Jake Bransky, Delaware River Basin Commission, SEF Staff
Bob Bachman
Scott Collenburg – New Jersey Division of Fish and Wildlife
Lori Emery – New York City Department of Environmental Protection
Sheila Eyler – U.S. Fish and Wildlife Service
Molly Hesson – Philadelphia Water Department
Peter Kolesar
Ian Park – Delaware Department of Natural Resources and Environmental Control
Garth Pettinger
Daryl Pierce – Pennsylvania Fish and Boat Commission
Tim Pokorny - New York State Department of Environmental Conservation
Jim Serio
Peter Sharpe – National Park Service
Ross Shramko – New Jersey Division of Fish and Wildlife
Erik Silldorff – Delaware Riverkeeper Network
Jeff Skelding – Friends of the Upper Delaware River
Chris VanMaaren – New York State Department of Environmental Conservation, SEF Chair

This report was prepared by the Rapid Flow Change Workgroup of the Subcommittee on Ecological Flows.
Rapid Flow Change Workgroup:
Sheila Eyler
Daryl Pierce
Jim Serio
Garth Pettinger
Erik Silldorff
Jake Bransky

EXECUTIVE SUMMARY

The Subcommittee on Ecological Flows (SEF) was charged by the Regulated Flow Advisory Committee of the Delaware River Basin Commission to evaluate the Rapid Flow Change Mitigation (Current Protocol) within the 2017 Flexible Flow Management Plan (2017 FFMP). The intent of the Current Protocol is to mitigate potentially harmful ecological conditions caused by rapid reductions in New York City (NYC) directed releases to meet the Montague Flow Objective. The available bank consists of 1,000 cubic-feet-per-second-days (cfs-days) from the Interim Excess Release Quantity which resets each year on June 1st.

The rate at which down-ramping can occur in the West Branch, as a result of cessation of directed releases from the Office of the Delaware River Master, is not typical of natural riverine conditions. SEF has identified the most significant ecological impacts from this water management practice are the potential stranding of aquatic species, and the short-term dewatering of aquatic habitats in both the West Branch and the upper Delaware River. SEF was not able to quantify habitat loss at different flow rates for the upper Delaware River, but assumed fully wetted conditions West Branch at Hale Eddy at flows of 325 cfs. For the main stem Delaware River, Callicoon flows at 929 cfs are known to provide optimal support for dwarf wedgemussel habitat, with minimum protection at 558 cfs. Rapid changes in flow, leading to dewatered conditions downriver of Cannonsville Reservoir, should be mitigated to promote a more gradual rate of flow change, especially at lower Cannonsville release levels.

SEF was not provided a list of rapid flow change events to evaluate in the historical time series, but established a set of criteria to identify events in 10-year time series from 2008-2017. SEF used the following criteria to identify rapid flow change (RFC) events requiring mitigation:

1) The event occurred during a change in an Office of the Delaware River Master (ODRM) directed release, or within 2 days of the end of an ODRM directed release;
2) The flows at the USGS Stilesville gage dropped or would drop below 500 cfs in association with a change in ODRM directed release;
3) The rate of flow reduction was or is expected to be $\geq$250 cfs over an 8-hour period during a time associated with a change in ODRM directed release;
4) The minimum flow for the 24-hours post-RFC event (i.e. lower rate) was less than 90% of the median 5-day flow prior to the event; and
5) The RFC event occurred during normal (non-drought) operating conditions.

Initially, evaluation of RFC events was completed using actual flow data from the time of the event. A total of 38 RFC events were identified in the 10-year time series. SEF assumed that the changes to the conservation releases in the 2017 FFMP would reduce the magnitude of mitigation required for historic events, so the evaluation of historic data may not be an accurate reflection of bank usage under the 2017 FFMP. The pre- and post- event flow data from the historic RFC events were updated to flow levels that would have occurred during the event if the 2017 FFMP were in place. Using the historic data updated with 2017 FFMP flows improved post-event flow conditions on more than half of the events and eliminated the need for mitigation on three previously identified RFC events during the 10-year time series, resulting in 2.7 RFC events on-average occurring annually. The 2017 FFMP updated flow data for the remaining 27 RFC events were used to evaluate the Current Protocol as well as several alternative protocols.

SEF established the following evaluation criteria for measuring the success of a given mitigation protocol for the first 48 and 72 hours after the peak flow of the RFC event:

1) Achievement of flow criteria for downriver gages,
    a. Stilesville achieving 300 cfs,
    b. Hale Eddy achieving 325 cfs,
    c. Callicoon achieving 930 cfs,
    d. Callicoon achieving 560 cfs;
2) Stilesville maximum flow reduction <200 cfs at the conclusion of mitigation; and
3) Annual mitigation bank demand was 1,000 cfs-days or less.

Implementing the Current Protocol demonstrated improvement in meeting the evaluation criteria over non-mitigated events, but did not achieve 100% satisfaction of all criteria, for all events, in the time series. The Current Protocol did remain within total the RFC Mitigation Bank allotment of 1,000 cfs-days annually during the entire time series (2008-2017). The Wait-for-the-Rain Protocol (48-hour hold at 500 cfs or 300 cfs) did show some improvements in achieving downriver criteria over the Current Protocol, but allowed for significant drops in flow at Stilesville post-mitigation. The Wait-for-the-Rain Protocol also exceeded RFC Mitigation Bank allotment in 4 years, using about 50% more water than the Current Protocol. An alternative protocol was evaluated that was similar to the Current Protocol, but implemented 100 cfs drop after day 1 and day 2 and held flows on day 3 for 12 hours before dropping to the low flow condition. This alternative protocol improved achievement of downriver criteria over the Current Protocol and stayed within, or nearly so, the annual allotment of the RFC Mitigation Bank in all years. A second alternative protocol was evaluated that had high achievement for all evaluation criteria. To meet high achievement of all criteria, a protocol would require about 3,000 cfs annually in a RFC Mitigation Bank.

Based on the analysis of RFC events from 2008-2017 and an available mitigation bank of 1,000 cfs-days, SEF recommends the following Alternative Protocol for mitigation to be implemented in future RFC events.

1. If the Cannonsville release is above or equal to 700 cfs
    a. The release shall be lowered to 500 cfs for the first day (0-24 hours)
    b. The release shall be lowered to 400 cfs for the second day (25-48 hours)
    c. The release shall be lowered to 300 cfs for the first half of the third day (49-60 hours)
    d. Normal operations would apply starting on the second half of the third day (hour 61 post-event) when the Lower Rate would be released.
    e. If at any time during this procedure, the Lower Rate is higher than the specified mitigation rate, the Lower Rate should be applied.
2. If the Cannonsville release is above 450 cfs but less than 700 cfs
    a. The release shall be lowered to 300 cfs for the first day (0-24 hours)
    b. The release shall be lowered to 200 cfs for the second day (25-48 hours)
    c. The release shall be lowered to 100 cfs for the first half of the third day (49-60 hours)
    d. Normal operations would apply starting on the second half of the third day (hour 61 post-event) when the Lower Rate would be released.
    e. If at any time during this procedure, the Lower Rate is higher than the specified mitigation rate, the Lower Rate should be applied.

Per the request of NYC and ORDM, SEF completed an evaluation of the implementation of the Current Protocol in 2019. Two events were mitigated in October 2019. Based on SEF's review, mitigation did not appear to be fully implemented in the two events, and a third unmitigated event also

occurred in October. A total of 739 cfs-days were used in 2019. Using the same methods as review of historic events, a full implementation of the Current Protocol for the three identified events would have slightly exceeded the available mitigation bank (1,119 cfs-days) in 2019. Implementation of the recommended Alternative Protocol for all three events would have exceeded the bank by ~500 cfs-days. Despite this potential exceedance, SEF continues to recommend the alternative protocol, as it could be fully implemented in most years based on available data.

SEF also recommends that the protocol be fully implementing beginning on the first RFC event of the year and continue to be fully implemented through the remaining RFC events, with priority on fully exhausting the available bank, versus preservation of the bank for potential future events.

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INTRODUCTION

The Delaware River Basin Commission (DRBC), Regulated Flow Advisory Committee (RFAC), re-initiated the Subcommittee on Ecological Flows (SEF) workgroup in 2018[1]. SEF was charged by RFAC (Attachment 1), in part, with the evaluation of the Rapid Flow Change Mitigation (Current Protocol) within the 2017 Flexible Flow Management Plan (2017 FFMP)[2]. The Current Protocol (Attachment 2) was designed to support Habitat Protection Program management within the 2017 FFMP Appendix A, as described in Section 3.c.iii. A prescribed bank of dedicated water storage (i.e., 0.65 billion gallons, 1,000 cubic-feet-per-second-days (cfs-days) from the Interim Excess Release Quantity (IREQ)) was assigned to the Current Protocol; and resets each year on June 1st. The intent of the Current Protocol is to mitigate potentially harmful ecological conditions caused by rapid reductions in New York City (NYC) directed releases to meet the Montague Objective. This bank is available at the direction of the Office of the Delaware River Master (ODRM)[3] and New York City, Department of Environmental Protection (NYCDEP)[4] during basin-wide normal conditions.

The RFAC seeks to provide information to inform the Decree Parties about the use of the Protocol in relation to ecological resources and whether potential adjustments to the proposed guidelines may be necessary. The SEF review of the Current Protocol evaluated information related to the habitat and physical river conditions needs relative to species of concern in the tailwaters of Cannonsville and the Delaware River upstream of Lordville, NY[5]. This evaluation focused on characterizing an event that may warrant Rapid Flow Change (RFC) mitigation, establish protocol evaluation criteria, and update historic RFC events to better evaluate the success of the Current Protocol. Based on study findings, SEF has developed recommendations for guidelines to best support aquatic communities.

Flow Management for the Montague Target and Occurrence of Rapid Flow Change Events

The 2017 FFMP, consistent with the 1954 Supreme Court Decree, seeks to maintain a minimum basic rate of flow at the gaging station of the United States Geological Survey (USGS) at Montague, N.J. of 1,750 cfs, as directed by the ODRM. The Montague gage station (ID 01438500, Montague) is located at river mile 246 in the Delaware River main stem (Figure 1). Located on the West Branch, Cannonsville Reservoir is located 17 miles upriver of the confluence with the main stem, and approximately 102 miles upriver from Montague; whereas, the Pepacton Reservoir, located on the East Branch, is approximately 117 miles upriver from Montague; and the Neversink Reservoir, located on the Neversink River, is approximately 51 miles upriver from Montague. A total of 3,480 mi^2 drainage area contributes to the discharge rates as measured at the Montague gaging station. Water travel times from the NYC Delaware Reservoirs to Montague are 60 hours from Pepacton Reservoir, 48 hours from Cannonsville Reservoir and 33 hours from Neversink Reservoir. Thus, ODRM directed releases, which are designed to meet the anticipated needs at Montague from all reservoirs, need to be calculated at least three days in advance of meeting the Montague target.

[1] DRBC Resolution2018-2
[2] https://webapps.usgs.gov/odrm/ffmp/
[3] https://webapps.usgs.gov/odrm/
[4] https://www1.nyc.gov/html/dep/html/home/home.shtml
[5] RFAC Memorandum Charge to SEF

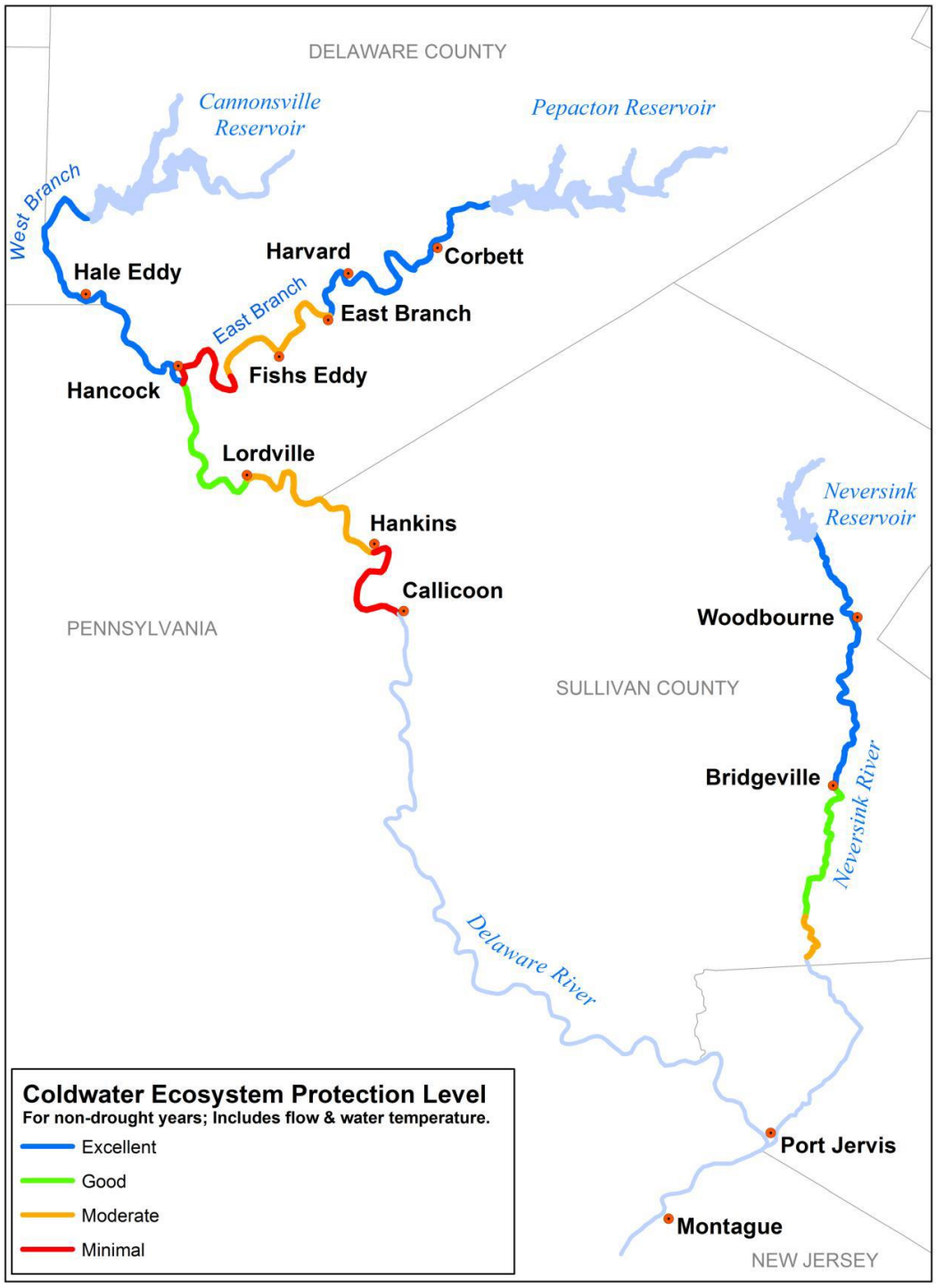


Figure 1. The Upper Delaware River watershed. Figure source – joint fisheries white paper.[6]

[6] Recommended improvements to the Flexible Flow Management Program for coldwater ecosystem protection in the Delaware River tailwaters. January 12, 2010. Report prepared by the New York Department of Environmental Conservation and the Pennsylvania Fish and Boat Commission.

Computation of the ODRM Montague directed releases requires the ODRM to consider various components of flow at Montague. Sources of flow at Montague include releases from NYC Delaware Reservoirs, hydropower generation, and runoff from the basin upriver from Montague. Hydropower facilities operate both within the Lackawaxen River Basin and Mongaup River Basin, with one facility per basin. Discharges from both facilities enter the Delaware River upriver of Montague at river miles 278 and 261, respectively. These facilities are principally peaking facilities, which irregularly augment Delaware River main stem flow rates. However, the facility within the Lackawaxen River Basin also supports a proof-of-concept trout tailwater program as part of their FERC re-license agreement. Final evaluation of the Lackawaxen River Basin tailwater program is anticipated to occur by year-end, 2024. Forecasted hydropower generation schedules are provided to ODRM that can be used in the planned achievement of the Montague target, but the hydropower facility owners are not legally bound to their forecasted generation and actual generation can be different than forecasted. Precipitation (i.e., rainfall, snow melt, etc.) into the upper Delaware River Basin can be a significant contributor to main stem flow rates, both in terms of uncontrolled reservoir spill but also from various fluvial pathways. In cooperation with USGS, the National Weather Service (NWS) maintains river forecasts[7] to aid in quantifying forecasted precipitation and snow melt to aid in the planned achievement of the Montague flow target.

Minimum flow releases are required out of the NYC Delaware Reservoirs as part of the 2017 FFMP, Habitat Protection Program (HPP). The HPP is designed to support the cold-water fishery while maintaining aquatic community diversity, structure, and function through improved ecological flow releases, under normal operations. A series of table releases (i.e., Table 4a-g) support this program (Section 5, Appendix A, 2017 FFMP). These releases encapsulate a seasonal component, the magnitude of which is determined by NYCs Operations support Tool (OST). The HPP Conservation Releases are altered pending NYC's OST risk assessment, by adjusting Delaware Reservoir table Conservation Releases accordingly. When release conditions change, (i.e. conservation release table changes), NYCDEP uses a ramp down rate of 65 mgd per hour (100 cfs/hr). Flow changes during NYCDEP operational changes are not as dramatic as can be seen during changes in ORDM directed releases as described below.

Managing the Montague flow target is dependent solely on manipulating controlled NYC Delaware Reservoir releases in excess of the required Conservation Releases, as the other sources of input (hydropower and precipitation) are considered and incorporated into planning but they cannot be managed. Operationally, most NYC Delaware Reservoir releases occur from the Cannonsville Reservoir, either in support of the Conservation Releases or various mitigation protocols. Natural flow combined with conservation releases are typically sufficient to meet the Montague flow target. However, in the event that conservation releases are not sufficient to meet the Montague flow target, the ORDM may direct supplemental releases from the reservoirs to achieve downriver flow targets. At times, ORDM supplemental releases can be at a much higher level than is prescribed by the Conservation Release table in order to meet the Montague flow target. These supplemental releases typically occur when precipitation and hydropower inputs are low. If rainfall is predicted or hydropower releases increase, ORDM will reduce or cease the supplemental (directed) releases because less NYC Delaware Reservoir water would be needed to achieve the Montague flow target. During these events where the supplemental directed releases are reduced or ended, it is not uncommon for releases from the Cannonsville Reservoir to decline 50-90% over a period of several hours. These "knife-edge" rapid flow

[7] https://www.weather.gov/marfc/

change events are evidenced in the historical gage information from the USGS station at Stilesville (ID 01425000).

Ecological Significance of Rapid Flow Change Events

Rapid "knife-edge" decreases in flow, as associated with reduction or cessation of ORDM directed releases, can impact available habitat downriver from the reservoirs. The downriver extent of rapidly reduced flows influence is dependent on the severity of the reduction of releases and downriver tributary inputs. Typically, the West Branch reaches are consistently impacted by rapid reductions in flow from the Cannonsville Reservoir as the releases from the reservoir are the primary water source for this portion of the river. Changes in Cannonsville releases may not be as impactful to main stem portions of the Delaware River, especially if tributary flows to the main stem are higher. The Current Protocol for ramp-down mitigation was developed to lessen the immediate severity of rapid flow reductions by spreading the reduction out over a longer period of time (days vs. hours). The Current Protocol is intended to directly support the West Branch reaches for each rapid flow change event and may also benefit Delaware River main stem flows in some cases.

Ecologically, SEF has two basic concerns related to RFC events associated with reduced ODRM directed releases:

1) The potential stranding of aquatic species, and
2) The short-term dewatering of aquatic habitats.

Quantification of ramping rates relative to survival of aquatic communities from peer-reviewed literature have not been identified by SEF, but it is generally accepted rapidity and extent of flow reductions occurring in the West Branch downriver of Cannonsville Reservoir, as a result of cessation of ORDM directed releases, do not occur naturally in river systems. In an attempt to determine a natural down-ramping rate in the upper Delaware River, daily historic flow data from the USGS Gage at Hale Eddy (ID 01426500) were evaluated from 1912-1955, which was prior to the installation of the Cannonsville Reservoir. The evaluation focused on declining flows that occurred between the months of July and November (typically when RFC events occur). The maximum flow change per day from the peak events was converted to an hourly rate of flow decline for the 24-hour period. The peak rate of flow decline was 3.0% per hour in the time series, and the top 25% of declining flow values averaged 1.1% flow decline per hour. It is assumed that a natural ramping rate, such as described here, would be adequately protective of aquatic habitats and could be considered in mitigation protocol alternatives.

SEF has not been able to quantify habitat loss at different flow rates for the upper Delaware River, but have information to evaluate habitat availability of the West Branch and main stem at Callicoon. Fully wetted width occurs in the West Branch at Hale Eddy at 325 cfs flow at that site's USGS gage station[8]. Callicoon has optimal support for dwarf wedgemussel habitat at flows of 928 cfs at the site's USGS gage (ID 01427510), and minimal protection at 558 cfs at the same location[9]. When flows

[8] McBride, N., J. Daley, B. Anygal, and D. Zielinski. 2012. Final Report: Delaware River Tailwaters Monitoring, Flexible Flow Management Program, Oct. 1, 2007 – May 31, 2011. New York State Dept. Envir. Cons. Albany, NY 1223

[9] Cole, J. C., P. A. Townsend, and K. N. Eshleman. 2008. Predicting Flow and Temperature Regimes at Three *Alasmidonta heterodon* Locations in the Delaware River. Technical Report NPS/NER/NRTR—2008/109. National Park Service. Philadelphia, PA.

decrease quickly from fully wetted habitat to less than fully wetted, primary concerns are for stranding of fish and exposure of river beds that support aquatic macroinvertebrates. In the case of fish, they are presumed to be able to quickly utilize habitats supported by higher flows that may later become detached from the main stem by sudden reductions. However, adult fishes (trout) are also presumed to be highly responsive to flow rate changes and are generally thought to be able to find suitable habitats and avoid stranding during a natural rate of flow reduction[10]. Typically, young-of-year (YOY) fishes inhabit the shallow shoreline littoral zones. As water rapidly recedes, YOY fishes will either follow to stay within the littoral zone or burrow down into crevices within the bottom substrate. Mortality may occur to YOY fishes if the littoral zone or interstitial water availability with bottom habitat become unsuitable for YOY fishes, where rapid change in water temperature may occur or dissolved oxygen levels are reduced.

Dewatering of habitat can have significant impacts aquatic benthic macroinvertebrates. Benthic macroinvertebrates are slower to colonize new habitats compared to adult trout. They are also unable to quickly respond to exposure of riverbed habitat occurring in habitats that were previously under water that become dewatered due to changes in ORDM directed releases. Colonization rates into newly available habitat varies among invertebrate taxa, with highly mobile taxa (e.g., swimming mayflies) able to colonize newly inundated habitats within hours or days, while less mobile invertebrates can take days to weeks to colonize areas newly wetted by higher water levels. Typically, full colonization of either new habitats or artificial substrates introduced into rivers and streams is considered near-complete after 4 weeks, although competitive and priority effects can lead to transitory species composition and relative abundance far longer than 4 weeks. As a result, the short-term inundation and subsequent immediate de-watering of a habitat from either naturally or artificially elevated water levels is are not considered problematic for benthic communities, particularly if those areas have been wetted for a period of only a few days or less. The sudden loss of inundated habitats that has been colonized for long-term durations (weeks to months) is much more problematic and likely to be catastrophic for individuals and established communities within the dewatered habitat.

Characterization of Flow Patterns during and after Rapid Flow Change Events

There are two types of RFC event flow patterns to be considered when applying mitigation. Understanding the flow patterns is important for evaluating various mitigation protocols, but flow patterns post-RFC event may not be fully known at the time of protocol implementation, so having differing protocols for differing post-RFC event flow patterns is not feasible. The two flow patterns types are characterized by a transition to long-term lower flows (transition events) or short-term decreases in flow followed quickly by higher flows (gap events). The mitigation protocol is designed to address ramping rates associated with reductions in ODRM directed releases and effective ramping can provide a more gradual flow reduction during transition events. In addition to gradual flow reductions during transition events, a mitigation protocol can also mitigate short-term dewatering events that occur in gap events. Gap events, in many cases, occur when forecasted rainfall is supporting a large reduction in directed releases. During these events, the Cannonsville releases may be transitioning down to a long-term lower flow condition, but the downriver sites may be switching from Cannonsville supported flows to tributary supported flows. In events where the forecasted rainfall is realized, prevention of temporary dewatering main stem habitats is also possible with implementation of the ramping protocol, ensuring sufficient flows are released from the NYC Reservoirs until rainfall from the watershed reaches downriver locations (i.e. Hale Eddy, Callicoon). In instances where predicted rainfall

[10] Daryl Pierce, Pennsylvania Fish and Boat Commission, personal communication, November 13, 2019.

does not occur, or occurs at a reduced amount, implementation of a ramping protocol can also prevent short-term dewatering during gap events until ODRM directed releases resume. It is important to note that prevention of long-term dewatering (> 3 days) is not the intent of the mitigation protocol and will not be considered by SEF within this initial RFAC charge. Yet, long-term dewatering may have influence at the population level of both fish and benthic macroinvertebrates by effectively reducing the river's overall carrying capacity.

SEF also recognizes that inherent in the FFMP structure is an attempt to simulate natural flow regimes to the greatest extent practicable, maintaining the magnitude, duration, and seasonality of water levels and flows. Such efforts to mimic natural flow regimes help to maintain and restore natural communities and native species, including such species as the American Shad and the Dwarf Wedgemussel. SEF therefore recognizes that low seasonal flows and exposed margins of the river are a natural process, and that gradual exposure of river margins during low-flow periods can be expected to naturally occur. The mitigation protocol does not seek to eliminate all periods of low flows for the Delaware River, particularly those low flows that are both seasonally appropriate and mimic naturally gradual lowering of river levels.

Operational Assumptions of the Current Protocol Procedures

Operationally the Current Protocol has taken a simplified approach to mitigate knife-edge ramping (Attachment 2). The intent was to limit operational complexity while supporting critical flow components for the aquatic communities. Enactment of these protocol steps are contingent on flow rates prior to the reduction of ODRM directed releases and target flow as specified by the conservation release tables. All criteria are relative to Cannonsville Reservoir releases. Steps 3 and 4 of the Protocol contain the heart of the ameliorating ramping rates. Within these two steps, threshold flow criteria have been identified ($\geq$ 700 cfs, $\geq$ 450 cfs). The mitigation entails implementation of "holding" flow rates (i.e., 500 cfs and 300 cfs) for a 24-hour duration per step to mimic a more "natural" ramp down. After the 24-hour hold at 500 cfs, the rate is then reduced to 300 cfs for an additional 24-hour period. After 24 hours at 300 cfs (either day 1 or day 2), the mitigation ends and flows are allowed to drop to Conservation Release levels as identified in the tables of the HPP (2017 FFMP Appendix A, Section 5b, Tables 4a-4g).

The Current Protocol identifies two holding rates (500 cfs and 300 cfs) that have ecological significance. Within the HPP release tables, 500 cfs has been identified as the maximum conservation release for Cannonsville Reservoir under Table 4g. Holding flows at this rate for the first 24 hours of enacting the Current Protocol (when starting flows exceed 700 cfs) implies the aquatic community will not be adversely impacted and is assumed to prevent stranding or dewatering of downriver habitats. The second identified holding level of 300 cfs is similar to an assumed value of 325 cfs (at Hale Eddy) which is supportive of bank-to-bank inundation within the West Branch. Implementation of a 300 cfs release will maintain some level of protection in the West Branch and main stem, but will not necessarily support fully wetted width in the Delaware River main stem, which is also influenced by East Branch and other tributary flows.

These holding rates are assumed to have ecological benefits to downriver habitats, but the selection of these values (500 cfs and 300 cfs) are somewhat arbitrary. A better assessment of these holding rates criteria requires knowledge of USGS gage ratings (flow to stage) relative to bank-to-bank inundation and tributary connectivity. Bathymetry data exists within the original Decision Support System (DSS), which

may offer insight into suitable holding rate criteria and quantify percent loss of aquatic habitat relative to identified species or species guilds in the upper Delaware River. Presently, the DSS and its successor REFDSS, are not operational. Additionally, the DSS/REFDSS temporal scale (i.e., daily) may be too coarse for evaluating the Protocol, which should be addressed on an hourly temporal scale. Furthermore, the USGS has a more extensive bathymetry dataset for the entire Delaware River main stem, but this is currently unavailable pending rectification of various elevation stratum standardizations. The bathymetry coupled with USGS gage ratings could quantify percent dewatering to be expected under various flow regimes. Finally, enactment of the Protocol tends to be during the fall season when cold-water species in the West Branch may be seeking entry into tributary spawning habitats. The relationship between tributary connectivity based on flow and bathymetry will need quantifying to potentially evaluate/adjust protocol criteria. Until these data become available, SEF's evaluation of holding rates protective of aquatic communities will be severely hampered.

The assumption of 24-hour holding durations and number of holding steps also requires additional consideration. Likely these were developed as logistical compromises for bank management. Ramping tends to consume considerable water storage. Keeping relatively short durations with few holding steps aids conservation of the allocated Protocol bank but provide some level of support for the aquatic community. Traditionally, the Pennsylvania Fish and Boat Commission advocated 25% reduction rates in 12-hour increments to mimic natural flow declines; however, this is water resource costly and likely beyond practical support by the Protocol. There are also logistical considerations for the implementation of the protocol, that the steps of flow decrease can be implemented by the Cannonsville water control structure, and the time increments between changes can also be managed by available staff.

INITIAL IDENTIFICATION OF RAPID FLOW CHANGE EVENTS IN HISTORIC FLOW DATA

Flow data from 2008-2017 were used in the identification of RFC events and subsequent evaluation of mitigation protocols for those events. This time-series was initially limited to those years under the various iterations of the FFMP philosophy, to preserve annual comparability of flow regimes. A complete list of RFC events was not provided to SEF, so SEF evaluated flow data over the 10-year time series with the following criteria to identify RFC events:

1) An RFC event occurred during a change in an ODRM directed release, or within 2 days of the end of an ODRM directed release;
2) Flows at the USGS Stilesville gage dropped below 500 cfs in association with a change in ODRM directed release; and
3) The rate of flow reduction had to be $\geq$250 cfs over an 8-hour period during a time associated with a change in ODRM directed release.

Justification for selection criteria:

1) Directed release data were provided to SEF on a daily (not hourly) timestep. To ensure that all RFC events were captured, including those that may have occurred in transition between two calendar days, any significant flow reductions that occurred within 2 days of an RFC flow reduction event were considered.
2) A trigger of 500 cfs was used to identify critical events requiring mitigation. The 500 cfs value was assumed to be ecologically significant as it is identified as a maximum conservation release in the FFMP. Also, in most cases, sustaining releases of 500 cfs or more at Stilesville is presumed to support fully wetted habitats both in the West Branch and have a higher probability for

supporting fully wetted habitat downriver at Callicoon. Releases under 500 cfs could result in sections of the Delaware River main stem to become dewatered.

3) Several values were considered for both magnitude of change in flow as well as the duration over which that flow change occurred for identifying events. Using a lower threshold for flow changes (i.e. <250 cfs) and/or longer time step (>8 hrs) resulted in more dates being identified. SEF was initially provided a partial list of RFC events from NYSDEC, and using the current protocol was effective at identifying all known dates as listed by NYSDEC, as well as, including several more dates that had similar hydrographs to the known RFC events, but not adding significantly more dates for consideration that had less drastic flow reductions.

A total of 38 events were identified as RFC events during the 10-year time series. During the 10-year time series, an average of 3.8 events occurred per year and a range of 0 to 8 events per year. RFC events occurred in each year except 2011. Most RFC events occur during the fall months, with 67% occurring in September and October. Some RFC events occur closely to each other (i.e. October 2017) so evaluation of any mitigation protocol that may have overlapping benefits between events would not be captured in these analyses (each event is evaluated separately). A comprehensive list of identified RFC events can be found in Appendix A. An example of a hydrograph depicting an RFC event can be found in Figure 2.

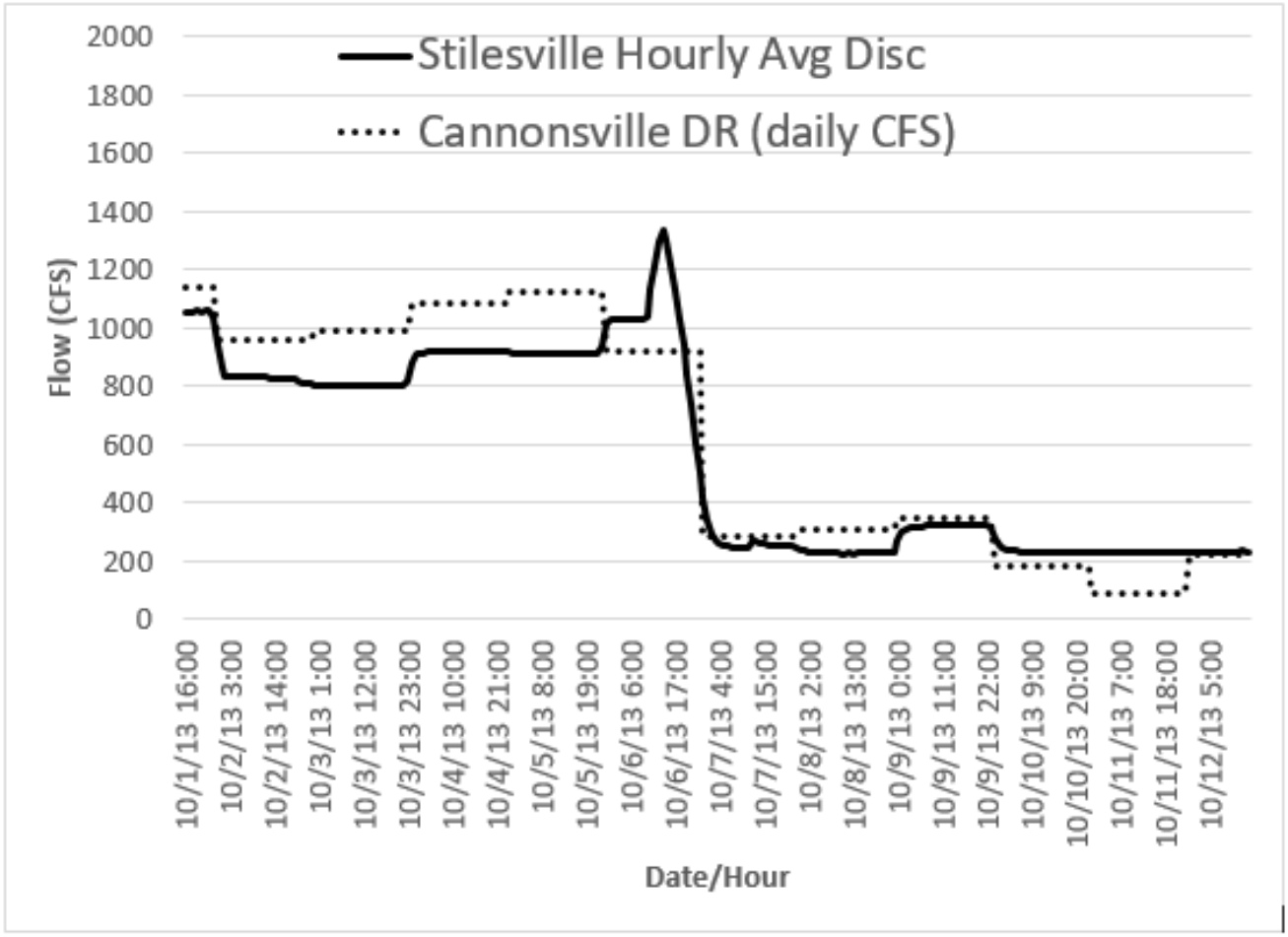


Figure 2. Example hydrograph of a Rapid Flow Change event occurring as a result of reduced ORDM directed releases (discharge) from Cannonsville Reservoir as depicted by the Stilesville USGS gage (RFC Event 16). The peak flow starting the RFC event occurred on 10/6/2013 at 15:00 hours. Note the 600 cfs reduction in Cannonsville (ORDM directed releases) between 10/6/2013 and 10/7/2013.

CRITERIA FOR EVALUATING CURRENT PROTOCOL APPLICATION ON IDENTIFIED RFC EVENTS

Cannonsville release data for the time series were not provided to SEF, so flow data were acquired from the Stilesville USGS Gage. The Stilesville flows were assumed to mirror releases from the Cannonsville Reservoir as there is no tributary input between the Cannonsville output and the Stilesville gage. Cannonsville release data for October 2019 were provided to SEF as part of the analysis of the implementation of the Current Protocol for RFC mitigation in 2019. Based on those data, the Stilesville gage generally follows the release data from Cannonsville, but Stilesville data may not be completely accurate due to debris accumulation at the Stilesville gage.[11] The USGS Gage website[12] has the following disclaimer, supporting this assertion:

[11] B. Dramozos, NYCDEP personal communication, November 21, 2019.
[12] https://waterdata.usgs.gov/nwis/uv?01425000 last accessed 11/25/2019.

"USGS provisional real-time discharge data can differ from NYCDEP discharge data at flows less than 2,100 ft^3/s as a result of debris or other obstructions affecting the USGS stage-discharge relationship. USGS and NYCDEP data may also differ as a result of accuracy limitations of the stage-discharge rating and the release valve ratings. Release valve changes are recorded at the stream-gaging station after a brief period due to travel time between the two locations."

Flow data from Stilesville were downloaded in 15 minute time intervals and averaged to derive hourly flow data. From the hydrograph for the two days surrounding the beginning of the RFC event, the peak flow hour was identified and used as a starting point for evaluation of mitigation. Flow data were considered for 5 days before through 5 days after each RFC event, although mitigation implementation occurred on flows post-RFC event only.

No set criteria were described in the current RFC mitigation protocol or in Appendix A of the 2017 FFMP for evaluating success of the RFC mitigation. Loosely, the protocol refers to habitat protection in the West Branch and Delaware River main stems, but does not set forth specific criteria (i.e. maintain fully-wetted widths, achieve less than X% reduction in available habitat, specify a rate of flow reduction, etc.) for which to compare different protocol alternatives for the best use of the available mitigation bank or to determine if additional mitigation bank is required to meet the purpose of the mitigation. To that end, SEF has identified a somewhat arbitrary set of criteria to facilitate in moving forward in evaluating the effectiveness of the current RFC mitigation protocol and evaluating potential alternative protocols.

The following criteria were established to evaluate mitigation protocols for RFC events:

1) Number of years where mitigation required was less than available bank (1,000 cfs-days); and
2) Average proportion of hours within 48 hours post-RFC event where flow criteria were achieved in downriver reaches.

Flow criteria were described as achieving either the fully-wetted width or, in the event that fully-wetted conditions did not occur prior to the RFC event, then the achievement of the median of flow for the 5 days prior to the RFC event. Flow criteria were time lagged to allow for water to travel from Cannonsville to reach the appropriate gage station downriver. Locations for three flow criteria were identified:

1) Stilesville – Fully wetted width assumed to occur at 300 cfs as measured at the USGS gage, no time delay applied to releases from Cannonsville;
2) Hale Eddy – Fully wetted width assumed to occur at 325 cfs as measured at the Hale Eddy USGS gage, with a 3-hour time delay applied to releases from Cannonsville; and
3) Callicoon – Fully wetted width assumed to occur at 930 cfs as measured at the Callicoon USGS gage, with a 24-hour time delay applied to releases from Cannonsville.
    a. A secondary flow criteria was applied to Callicoon of 560 cfs as measured at the Callicoon USGS gage, with a 24-hour time delay applied to releases from Cannonsville.

There were nine RFC events where flow criteria post-RFC event were less than fully wetted width. Flow criteria used for each event are listed in Table 1.

Table 1. Flow criteria for all RFC events. Note reduced flow criteria in italics where fully wetted conditions did not occur prior to the RFC event.

Event ID	Stilesville Criteria (cfs)	Hale Eddy Criteria (cfs)	Callicoon Criteria (cfs)
1	300	325	930
2	*256*	*306*	*847*
3	*284*	325	*716*
4	*259*	*320*	930
5	300	325	930
6	*102*	*187*	*912*
7	300	325	930
8	300	325	930
9	300	325	930
10	300	325	930
11	300	325	930
12	300	325	930
13	300	325	930
14	300	320	*887*
15	300	325	*887*
16	300	325	930
17	300	325	930
18	300	325	930
19	*209*	325	930
20	*231*	325	930
21	300	325	930
22	300	325	930
23	300	325	930
24	300	325	930
25	300	325	930
26	300	325	930
27	300	325	930
28	300	325	930
29	300	325	930
30	300	325	930
31	300	325	930
32	300	325	930
33	300	325	930
34	300	325	930
35	*299*	325	*881*
36	300	325	930
37	300	325	930
38	300	325	930

An excel model was developed to evaluate the mitigation bank usage by implementing the 2017 FFMP Current Protocol as described in Attachment 2 as well as all alternative protocols. For the Current Protocol, the model compiled the sum of flow differences on an hourly time step for 24 hours (starting flows $\geq$ 450 cfs and $\leq$ 700 cfs) or 48 hours (starting flows $\geq$ 700 cfs) from the initiation of the RFC event. Mitigation was completed the earlier of when either the 24- or 48-hour mitigation period had ended or

when Cannonsville releases equaled or exceeded required mitigation flows. Water usage for ramping between different mitigation steps was not included in the analysis, but assumed to be a small percentage of overall water usage for a mitigation event.

Initial Evaluation of the Current Protocol Performance for Identified RFC Events

The Current Protocol was applied to the 38 identified RFC events. Of the ten years of available data, the amount of water required to implement the current protocol exceeded what was available in the RFC mitigation bank (1,000 cfs-days) in two years (2008 & 2016, Table 2). This analysis indicates that the allotment to the mitigation bank would not have allowed the Current Protocol to be fully implemented in all years. For this protocol, the downriver flow criteria were met, on average, between 78% and 99% of the time (Table 3). Figure 3 depicts an example RFC event hydrograph and subsequent mitigation using the Current Protocol. Data for water usage and achievement of criteria for all 38 events can be found in Appendix B.

Table 2. Required RFC mitigation bank storage by year to implement the Current Protocol for 38 RFC events.

Year	Mitigation Required (cfs-days)	Exceeded Mitigation Bank	Events Per Year
2008	1957	Yes	8
2009	296	No	2
2010	759	No	3
2011	0	No	0
2012	305	No	2
2013	697	No	5
2014	798	No	4
2015	678	No	3
2016	1253	Yes	7
2017	781	No	4

Table 3. Evaluation of the Current Protocol against defined criteria.

Evaluation Criteria	Average Value per event	Min Recorded Value per event	Max Recorded Value per event
Water Usage	198 cfs	0 cfs	572 cfs
Stilesville Flow Criteria	92%	54%	100%
Hale Eddy Flow Criteria	96%	54%	100%
Callicoon Flow Criteria (930 cfs)	78%	0%	100%
Callicoon Flow Criteria (560 cfs)	99%	60%	100%

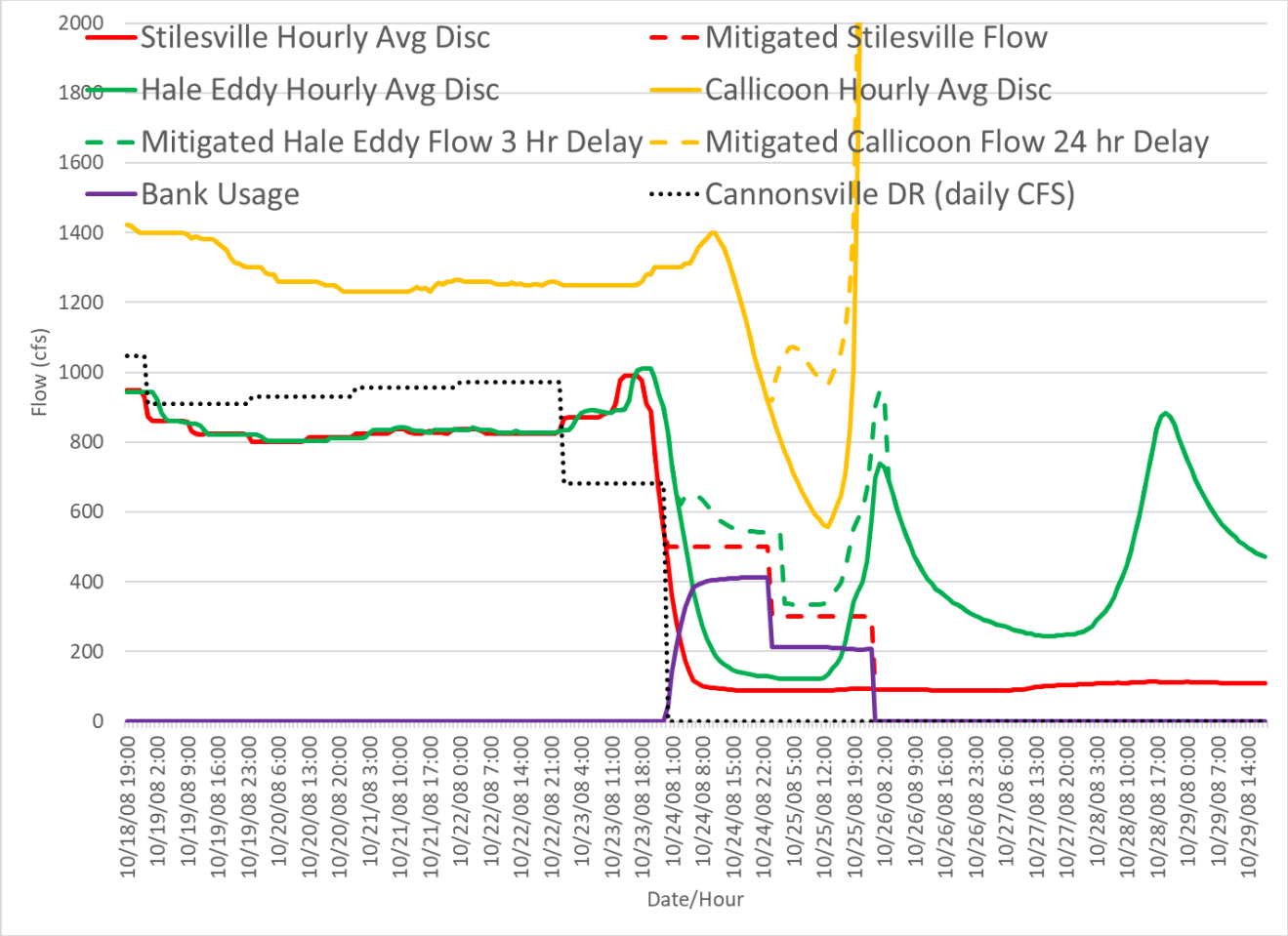


Figure 3. Example hydrograph of a Rapid Flow Change event occurring as a result of reduced discharge from the Cannonsville Reservoir (RFC Event 8). The peak flow starting the RFC event occurred on 10/23/2008 at 18:00 hours. The hydrograph shows actual conditions in the solid lines and proposed mitigated conditions using the Current Protocol in the dashed lines for each of the three assessment locations (Stilesville, Hale Eddy, and Cannonsville). The purple solid line indicates mitigation bank usage for this event (572 cfs-days total).

REFINEMENT OF RFC EVENT CHARACTERIZATION

Because of the limited amount of water available in the RFC mitigation bank, and the likelihood that the need for the bank could be exceeded using the Current Protocol in some years, further refinement of identification of RFC events was considered. The focus was to remove events that may be less impactful to aquatic communities, therein reducing the number of events requiring mitigation, leaving a larger quantity of water available to address more significant RFC events.

Several RFC events that were identified using the previously described criteria may have limited impact on fish and benthic macroinvertebrate populations and may not warrant RFC mitigation because of the temporary nature of the flow changes. In particular, some RFC events had sustained flows from Cannonsville (Stilesville) followed by temporary (i.e. typically less than 2.5 days) increase in flows, driven by a short-term increase in ORDM releases, then followed by a return to previous lower-flow conditions

(Figure 4). These temporary increases and subsequent decreases in flow likely do not support a meaningful increase in habitat available for aquatic species and therefore should not be considered for RFC mitigation.

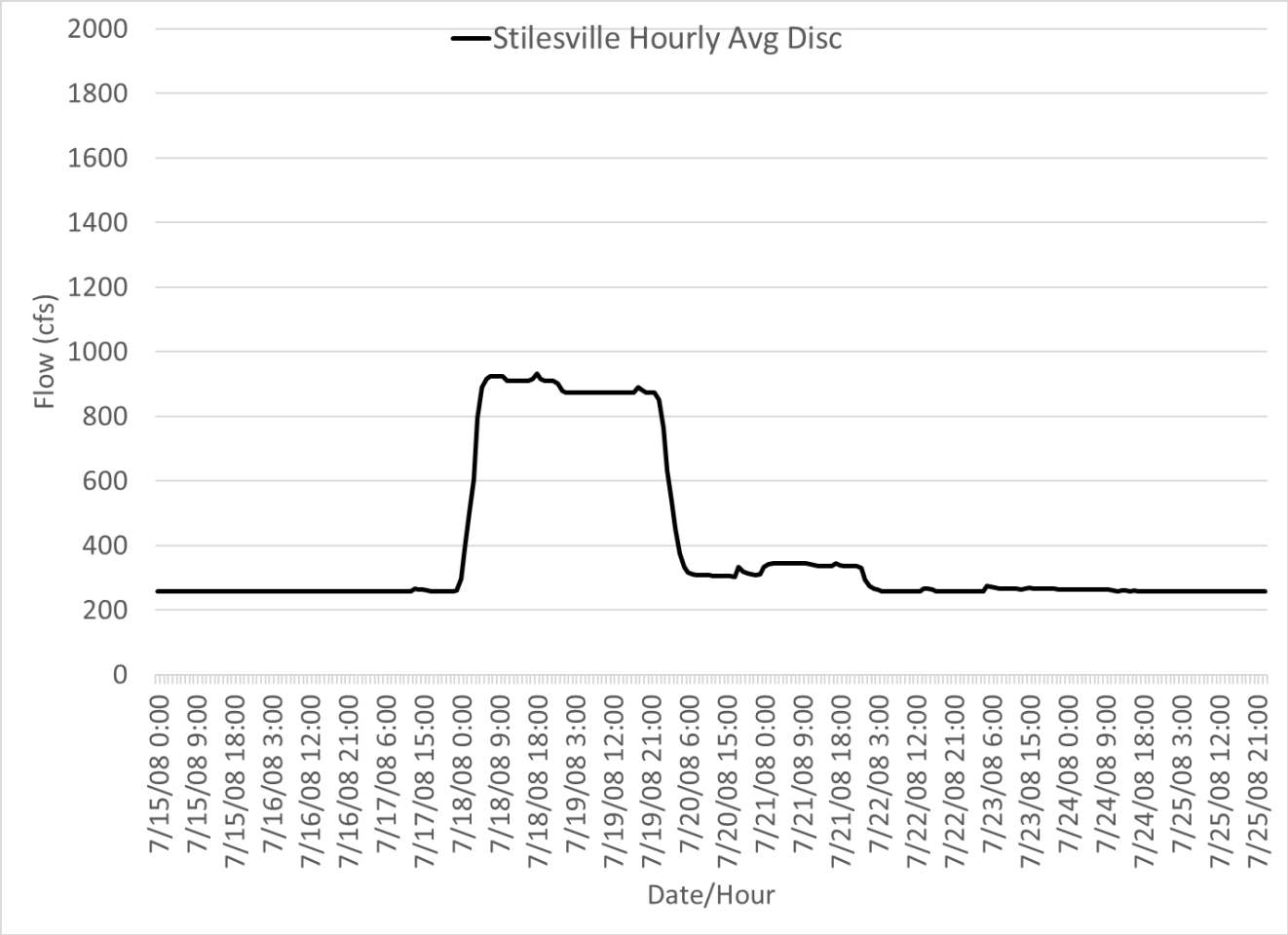


Figure 4. Stilesville hourly discharge from July 15 – July 25, 2008 (RFC Event 4). A temporary increase in flow occurred over a 53-hour time period. Median flow for 5 days prior to the RFC event was 259 cfs. Median flow for 5 days after the start of the RFC event was 266 cfs.

The justification for exclusion of these events is that temporary flow increases do not allow time for newly inundated habitats to be colonized by benthic macroinvertebrates, which require days to weeks to become established in new habitats. Fish are able to respond more quickly to changes in habitat accessibility, but it is assumed that high mobility of fish species will allow them to exit temporary increased access to habitats as quickly as they were able to enter those habitats. However, in cases where habitats have been accessible (i.e. watered) for longer periods of time (i.e. several days to weeks), that allows for establishment of macroinvertebrate populations and established habitats for fish, where loss of water in those areas may have a more significant impact on populations.

To identify temporary flow increases, the median flow for 5 days prior to, and including the peak, of the RFC event was compared to the minimum flow that occurred in the first 24 hours post event. If the minimum flow in the first 24 hours (lower rate) post-event RFC event was 10% reduction or less than median pre-event flows, then RFC mitigation is recommended. A total of seven events (Event # 2, 3, 4,

6, 9, 11, and 35) from the previously described 38 RFC events were eliminated from the mitigation evaluation because they were associated with temporary increases in flow (See Event Flow Change column in Appendix A).

Further refinement of identified historical RFC events removed of one event (Event #34) because the event occurred during drought conditions in 2016. As part of the 2017 FFMP, mitigation banks, including the RFC mitigation bank, are not available for use during declared drought conditions.

SEF recommends the following updated criteria be used to identify Rapid Flow Change events requiring mitigation:

1) The event must occur during a change in an ODRM directed release, or within 2 days of the end of an ODRM directed release;
2) The flows at the USGS Stilesville gage dropped or will drop below 500 cfs in association with a change in ODRM directed release;
3) The rate of flow reduction is expected to be $\geq$250 cfs over an 8-hour period during a time associated with a change in ODRM directed release;
4) The minimum flow for the 24-hours post-RFC event (i.e. lower rate) will be less than a 10% reduction of the median 5-day flow prior to the event; and
5) The RFC event occurs during normal (non-drought) operating conditions.

Using these updated criteria, the list of RFC events was refined to 30. These 30 events were used to re-evaluate the Current Protocol as well as potential alternative protocols.

Evaluation of Current Protocol for Refined List of RFC Events

During the 10-year time series, RFC events occurred on average 3 times per year with a range of 0 to 6 events per year. RFC events occurred in each year except 2011. Most RFC events occur during the fall months, with 73% occurring in September and October. Of the ten years of available data, the amount of water required to implement the Current Protocol still exceeded what was available in the RFC mitigation bank (1,000 cfs-days) in two years (2008 and 2016, Table 4). The downriver flow criteria were met, on average, between 79% and 99% of the time (Table 5).

Table 4. Required mitigation by year to implement Current Protocol with refined list of 30 RFC events.

Year	Mitigation Required (cfs-days)	Exceeded Mitigation Bank	Events Per Year
2008	1319	Yes	4
2009	146	No	1
2010	628	No	2
2011	0	No	0
2012	305	No	2
2013	697	No	5
2014	798	No	4
2015	678	No	3
2016	1100	Yes	6
2017	775	No	3

Table 5. Evaluation of Current Protocol against defined criteria of success.

Evaluation Criteria	Average Value per event	Min Recorded Value per event	Max Recorded Value per event
Water Usage	215 cfs	0 cfs	571 cfs
Stilesville Flow Criteria	92%	54%	100%
Hale Eddy Flow Criteria	95%	54%	100%
Callicoon Flow Criteria (930 cfs)	79%	0%	100%
Callicoon Flow Criteria (560 cfs)	99%	60%	100%

Eliminating eight of the originally identified 38 RFC events reduced the total amount of mitigation required to address RFC events in 5 of the 10 years, but the reduction of events did not result in sufficient water savings to overcome estimated flow needs in 2008 and 2016 when bank usage would have exceeded the allotted 1,000 cfs-day (Table 6). There also was not a substantial change in average achievement of evaluation criteria by the elimination of the 8 RFC events. The percentage of time where the Hale Eddy criteria were met on average dropped by 1%, and the percentage of time where the Callicoon criteria was met on average increased by 1%. The minimum and maximum recorded values for criteria remain unchanged from the original evaluation of 38 events compared to the evaluation of the 30 more significant RFC events.

Table 6. Comparison of required mitigation by year to implement current RFC mitigation bank protocol using original 38 RFC events compared to the 30 more significant RFC events.

Year	38 Events Mitigation Required (cfs/days)	38 Events Exceeded Mitigation Bank	30 Events Mitigation Required (cfs/days)	30 Events Exceeded Mitigation Bank
2008	1957	**Yes**	1319	**Yes**
2009	296	No	146	No
2010	759	No	628	No
2011	0	No	0	No
2012	305	No	305	No
2013	697	No	697	No
2014	798	No	798	No
2015	678	No	678	No
2016	1253	**Yes**	1100	**Yes**
2017	781	No	775	No

IDENTIFICATION OF POTENTIAL ALTERNATIVE MITIGATION PROTOCOLS

Alternate options for mitigation protocols were considered in an attempt to improve achievement of downriver flow criteria utilizing the 1,000 cfs-days available in the current RFC mitigation bank and still provide down-ramping conditions. The Current Protocol focuses on a holding rate and holding duration depending on flow conditions entering an RFC event. Alternative protocols evaluated alternative holding rates, holding durations and frequency of holding steps in an effort to potentially simulate a more natural flow declination condition.

A diverse suite of alternative mitigation protocols were evaluated for 30 RFC events (Table 7). Three different generalized types of protocols were identified:

1) a set flow maintained for 24-hour intervals (categorized as "S"),
2) a percentage decline by hour for a set number of hours (categorized as "R"), and
3) a combination approach of holding for a 24-hour period and then implementing a stepped protocol where flow was reduced at smaller time intervals (categorized as "C").

Table 7. Alternative mitigation protocols evaluated for RFC events for 2008-2017. "S" = 24-hour step protocols, "R" = hourly percentage ramping protocols, "C" = combined protocols with a 24-hour hold followed by hourly ramping.

Protocol	Short Name	Description
0	No Mitigation	No mitigation waters applied for any RFC event
S1*	500-300 or 300-0/700-450 cfs/24 hr*	If starting flows are >700 cfs, hold at 500 cfs first 24-hours and 300 cfs second 24-hours, if starting flows are >450 cfs and <700 cfs, hold at 300 cfs for first 24-hours
S2	500-500 or 300-300/700-450 cfs/24 hr	If starting flows are >700 cfs, hold at 500 cfs first 48-hours, if starting flows are >450 cfs and <700 cfs, hold at 300 cfs for first 48-hours
S3	500-400 or 400-300/700-450 cfs/24 hr	If starting flows are >700 cfs, hold at 500 cfs first 24-hours and 400 cfs second 24-hours, if starting flows are >450 cfs and <700 cfs, hold at 400 cfs for first 24-hours and 300 cfs for second 24-hours
R1	1% per hour/max/144 hr	Reduce flows at 1% per hour starting at peak flow of RFC event for a maximum of 144 hours
R2	1% per hour/700 cfs/144 hr	Reduce flows at 1% per hour starting at when flows reach 700 cfs after the peak flow of RFC event for a maximum of 144 hours
R3	1% per hour/700 cfs/48 hr	Reduce flows at 1% per hour starting at when flows reach 700 cfs after the peak flow of RFC event for a maximum of 48 hours
R4	1% per hour/500 cfs/48 hr	Reduce flows at 1% per hour starting at when flows reach 500 cfs after the peak flow of RFC event for a maximum of 48 hours
R5	2% per hour/max/144 hr	Reduce flows at 2% per hour starting at peak flow of RFC event for a maximum of 144 hours
R6	2% per hour/700 cfs/144 hr	Reduce flows at 2% per hour starting at when flows reach 700 cfs after the peak flow of RFC event for a maximum of 144 hours
R7	2% per hour/700 cfs/48 hr	Reduce flows at 2% per hour starting at when flows reach 700 cfs after the peak flow of RFC event for a maximum of 48 hours
R8	2% per hour/500 cfs/48 hr	Reduce flows at 2% per hour starting at when flows reach 500 cfs after the peak flow of RFC event for a maximum of 48 hours
R9	3% per hour/max/144 hr	Reduce flows at 3% per hour starting at peak flow of RFC event for a maximum of 144 hours

Table 7. Continued.

Protocol	Short Name	Description
R10	3% per hour/700 cfs/48 hr	Reduce flows at 3% per hour starting at when flows reach 700 cfs after the peak flow of RFC event for a maximum of 48 hours
C1	500 or 300/24 hrs and 10 cfs/hr/24 hrs	If starting flows are >700 cfs, hold at 500 cfs first 24-hours and then drop at rate of 10 cfs/hr for 24-hours, if starting flows are >450 cfs and <700 cfs, hold at 300 cfs for first 24-hours and then drop at rate of 10 cfs/hr for 24-hours
C2	500 or 300/24 hrs and 10 cfs/hr/48 hrs	If starting flows are >700 cfs, hold at 500 cfs first 24-hours and then drop at rate of 10 cfs/hr for 48-hours, if starting flows are >450 cfs and <700 cfs, hold at 300 cfs for first 24-hours and then drop at rate of 10 cfs/hr for 48-hours
C3	500 or 300/24 hrs and 15 cfs/hr/24 hrs	If starting flows are >700 cfs, hold at 500 cfs first 24-hours and then drop at rate of 10 cfs/hr for 24-hours, if starting flows are >450 cfs and <700 cfs, hold at 300 cfs for first 24-hours and then drop at rate of 15 cfs/hr for 24-hours
C4	500 or 300/24 hrs and 15 cfs/hr/48 hrs	If starting flows are >700 cfs, hold at 500 cfs first 24-hours and then drop at rate of 10 cfs/hr for 48-hours, if starting flows are >450 cfs and <700 cfs, hold at 300 cfs for first 24-hours and then drop at rate of 15 cfs/hr for 48-hours
C5	300/24 hrs and 10 cfs/hr/24 hrs	Hold flow at 300 cfs for first 24-hours and then drop at rate of 10 cfs/hr for 24-hours
C6	300/24 hrs and 10 cfs/hr/48 hrs	Hold flow at 300 cfs for first 24-hours and then drop at rate of 10 cfs/hr for 48-hours

*Protocol S1 is the Current Protocol as described in the 2017 FFMP.

Evaluation of Alternative Protocols for Refined List of RFC Events

Alternative protocols were evaluated using the same flow criteria as previously identified in the report. All protocols achieved improved downriver flow criteria compared to non-mitigated RFC events (Protocol 0, Table 8). No protocols achieved 100% of downriver criteria for all years. Protocol R1 (1% hourly down-ramping rate for 5 days) had the overall best achievement of downriver criteria, but exceeded the mitigation bank allotment of 1,000 cfs-days in 8 of 10 years. Only five of the evaluated protocols (including the current protocol) used less than the allotted mitigation bank of 1,000 cfs-days in 8 or 10 of the 10-year time series. Average annual mitigation bank required for the 10-year time series for the alternative protocols evaluated ranged from 355 to 2,985 cfs-days (Table 9).

Table 8. Evaluation of different mitigation protocols compared to non-mitigated RFC events (Protocol 0) and the current mitigation protocol (Protocol S1).

Protocol	Average cfs-days per Event	% Stilesville Criteria Achieved	% Hale Eddy Criteria Achieved	% Callicoon Criteria Achieved	% Callicoon 560 cfs Achieved	# Years Exceeding >1,000 cfs-days
0	N/A	55%	74%	63%	95%	N/A
S1	215	92%	95%	79%	99%	2
S2	339	100%	100%	83%	100%	7
S3	304	100%	100%	81%	100%	3
R1	995	100%	100%	95%	100%	8
R2	632	100%	100%	90%	100%	7
R3	450	100%	100%	90%	100%	7
R4	259	100%	100%	76%	100%	3
R5	475	94%	98%	87%	99%	7
R6	315	92%	98%	83%	99%	3
R7	292	92%	98%	83%	99%	3
R8	166	82%	94%	72%	99%	2
R9	279	82%	92%	80%	98%	3
R10	192	78%	90%	77%	98%	2
C1	310	93%	97%	82%	99%	4
C2	319	93%	97%	82%	99%	4
C3	284	90%	96%	81%	99%	4
C4	285	90%	96%	81%	99%	4
C5	118	88%	93%	67%	99%	0
C6	118	88%	93%	67%	99%	0

Table 9. Mitigation bank water usage by year (cfs-days) for different mitigation protocols compared to non-mitigated RFC events (Protocol 0) and the Current Protocol (Protocol S1).

Protocol	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Avg
0	0	0	0	0	0	0	0	0	0	0	0
S1	1319	146	628	0	305	697	798	678	1100	775	645
S2	1947	295	1026	0	619	1383	1113	1146	1622	1020	1017
S3	1921	195	826	0	419	1565	948	853	1513	895	913
R1	5312	416	2658	0	2077	5068	2734	4667	4513	2407	2985
R2	4083	424	1845	0	905	3432	1863	2276	2347	1793	1897
R3	2375	385	1200	0	814	2413	1421	1329	2265	1293	1350
R4	1822	108	621	0	230	1721	747	594	1223	693	776
R5	2606	190	1239	0	927	2328	1320	1770	2637	1229	1425
R6	1998	201	868	0	435	1675	969	843	1505	948	944
R7	1675	201	783	0	435	1568	924	765	1505	890	875
R8	1248	50	374	0	111	1078	512	342	825	443	498
R9	1594	110	726	0	552	1370	722	951	1610	748	838
R10	1200	123	518	0	276	962	603	463	1019	581	575
C1	1541	194	781	0	420	980	1198	829	1896	1465	930
C2	1646	194	812	0	420	980	1264	863	1914	1488	958
C3	1391	178	692	0	387	879	1105	739	1773	1363	851
C4	1395	178	692	0	387	879	1128	743	1779	1363	854
C5	812	0	205	0	0	726	422	383	634	368	355
C6	812	0	205	0	0	726	422	383	634	368	355

Summary of Selected Alternative Protocols

An alternative flow protocol (Protocol S2) for 24-hour step intervals was investigated that held a higher flow rate than the current protocol. This protocol mimicked the proposed "Wait for the Rain" (WFTR) protocol, advocated by stakeholders at previous RFAC public meetings. The total time for mitigation remained at 48 hours, however flows were held at the highest starting value (i.e. 500 or 300 cfs) for 48 hours and there was no subsequent reduced flow step. This WFTR protocol used 63% more water on average per year than the Current Protocol (Protocol S1) and exceeded the available water in the mitigation bank for 7 of 10 years. The highest level of bank needed in a given year for the WFTR protocol was 1,947 cfs, nearly double the current bank allotment. However, there was improvement for meeting downriver criteria compared to the Current Protocol. When comparing the WFTR Protocol to other protocols with comparable average bank usage per event (i.e. within 25% of 339 cfs, Protocols S3, R4, R6, R7, R9, C1, C2, C3, and C4), none of the other protocols considered preformed as well for downriver criteria as the WFTR.

A second alternative 24-hour flow step interval was also considered (S3). That protocol was intermediate to the Current Protocol (S1) and the WFTR protocol (S2). This intermediate protocol held flows at 500 or 400 cfs the first day and dropped flows by 100 cfs for the second day. The S3 protocol used less water than the WFTR protocol, and only exceeded the mitigation bank allowance in 3 of 10 years. Achievement of downriver criteria was similar between the WFTR and the intermediate protocol, with only a 2% reduction in achieving the Callicoon criteria. One additional issue of concern with the "Wait for the Rain" proposal, is that there is no down-ramping applied to the RFC events, but rather a holding of a single rate for 48 hours and a subsequent knife-edge drop to the lower rate if ORDM

directed releases at Stilesville are not resumed. The drop to the lower rate could be substantial and not necessarily protective after the 48-hour mitigation period for downriver habitat (Figure 5).

Conceptually, the WFTR protocol appears desirable for maintaining existing habitat through an RFC event. Yet, compared to the Current Protocol performance, the WFTR protocol performance demonstrated minor improvement at greater water resource cost. Furthermore, a knife-edge decline still occurred at Stilesville in some cases with implementation of the WFTR protocol, potentially exacerbating impacts to the aquatic community in the immediate reaches downriver of Cannonsville. These deficiencies are suggestive WFTR protocols do not represent a justifiable improvement over the Current Protocol relative to water usage.

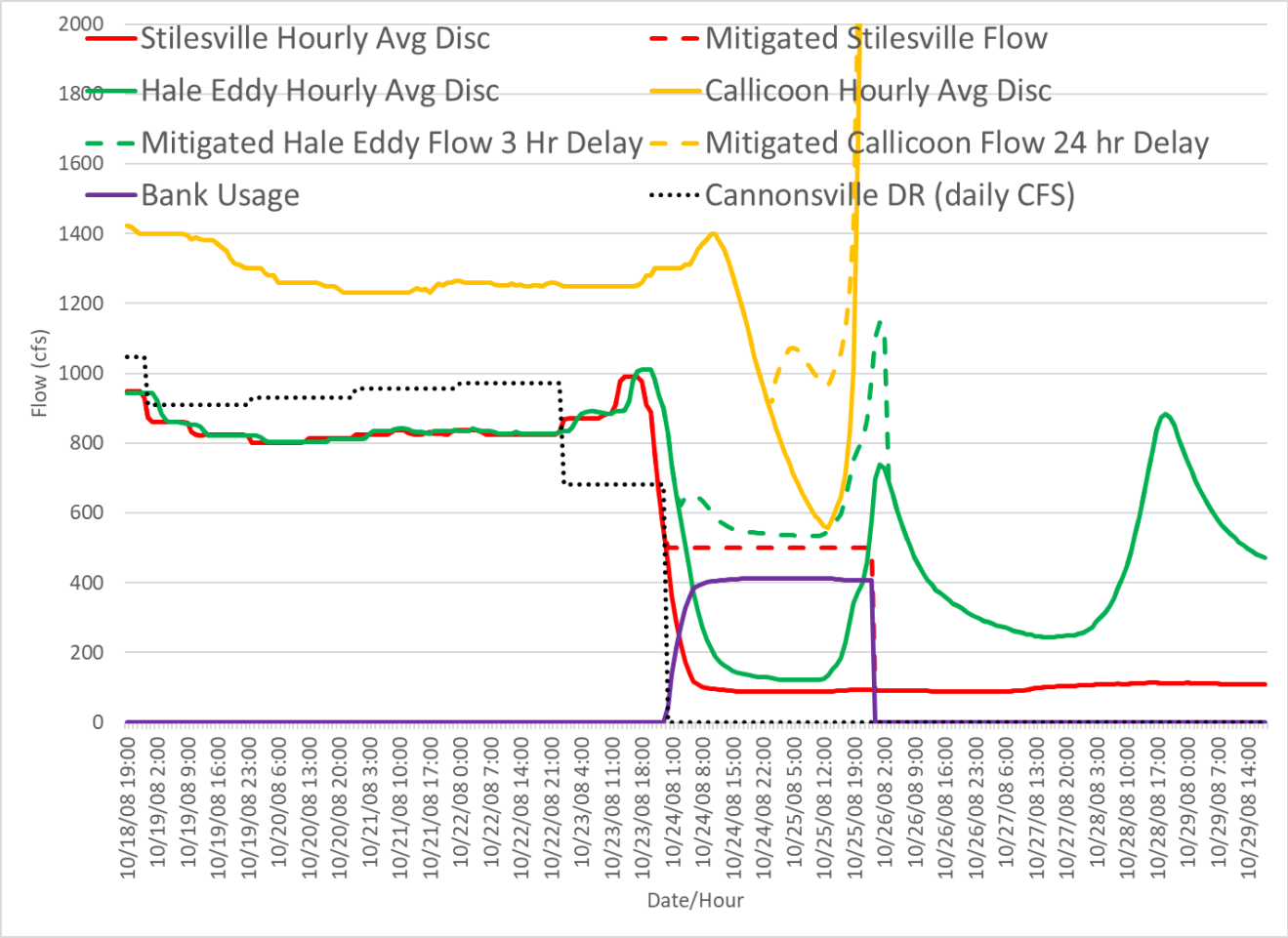


Figure 5. RFC Event 8 depicting implementation of Protocol S2 (Wait for the Rain). Note the drop in mitigated flows at Stilesville from 500cfs to 100 cfs at the end of the day on 25 October.

Protocols (R1 – R10) involving simulated natural flow declination rates (i.e. 1-3% per hour flow declination) were evaluated (See Figure 6 for an example). These protocols generally required water in amounts that exceed the current bank availability most years and had varying rates of success for meeting downriver criteria. Using a 1% declination rate for up to 5 days starting at the peak flow of an RFC event was the best alternative considered in meeting downriver criteria (Protocol R1); however, it exceeded the available bank in 8 of 10 years. Simulating a faster rate of natural declination (i.e. 2%, Protocol R5), reduced mitigation needed by half, but still exceeded the available bank in 7 of 10 years.

Starting a declination rate at a value lower (i.e. 700 or 500 cfs) than the maximum flow at the beginning of an RFC event, further reduced bank storage required to mitigate the event (i.e. Protocols R2, R3, R4, R6, R7, R8). Protocols R6 and R7 had similar or slightly better achievement of downriver criteria than the Current Protocol, but both alternate protocols exceeded the available bank in 7 of 10 years. A more aggressive declination rate of 3% per hour was also evaluated in an attempt to stay within the annual mitigation bank allotment. Under the most conservative option, declining at 3% per hour starting at the peak flow of the RFC event for up to 5 days (Protocol R9), the alternative was less protective of downriver criteria compared to the current protocol and still only met available bank in 7 of 10 years. The slight improvement of achievement in downriver criteria using a natural flow declination rate does not justifiably support a request for additional bank storage to implement this type of protocol. Logistically, a natural declination rate would also be difficult to implement. After discussion between the SEF and New York City DEP, it was determined that using a percentage rate reduction was not practical for implementation at the Cannonsville Reservoir as the amount of change for ramping would change each hour in the event. Further, the minimum amount of ramping that can occur at the Cannonsville water control structure at one time is about 40 cfs, which would not necessarily be small enough intervals to meet the ramping rates proposed.

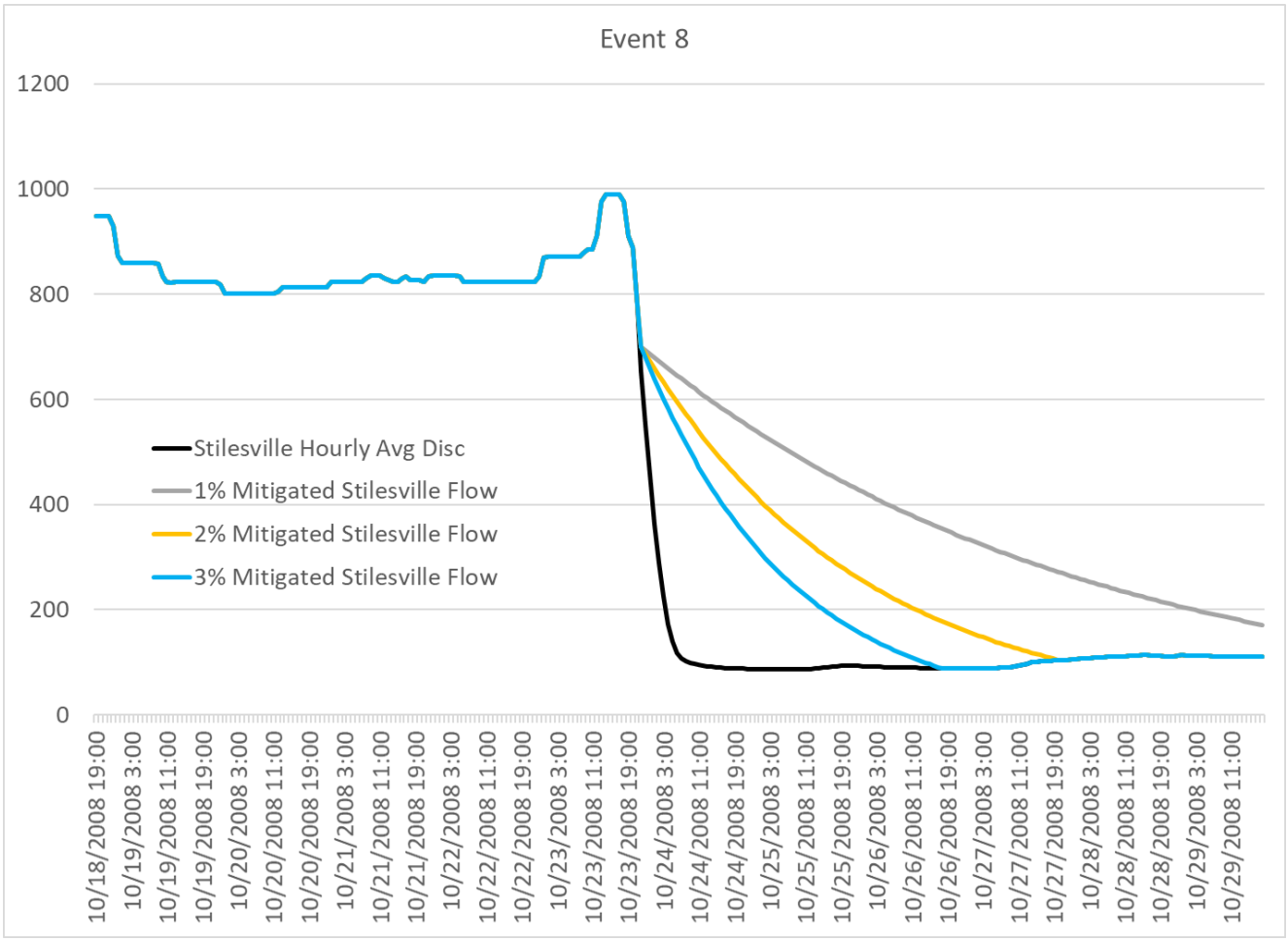


Figure 6. Examples of different percentage reductions of flow for an RFC event (#8) at the Stilesville gage.

Additional alternative protocols were considered that used a combination of a 24-hour holding period followed by an hourly reduction to simulate more natural ramp down after the first 24 hours. Two different declination rates were used in the analysis. A 10 cfs per hour rate was selected to mimic a 2% flow reduction and a 15 cfs per hour rate was selected to mimic a 3% flow reduction (starting at 500 cfs). Protocols that had a 500 or 300 cfs initial holding rate for 24 hours and then a 10 or 15 cfs reduction per hour for 24 hours, these protocols stayed within the available mitigation bank for 6 of the 10 years (Protocols C1, C2, C3, and C4). When reducing flows to 300 cfs for the first 24 hours and then applying an hourly declination for the second 24 hours, then the mitigation bank was not exceeded in the 10-year time series (Protocols C5 and C6). Although the bank was not exceeded for these alternative protocols (C5 and C6), achievement of downriver flow criteria was lower and achievement of the Callicoon criteria was lowest of all alternatives considered. For any of the combination protocols, there was no advantage of having 48 hours over 24 hours of ramping after the first 24-hour hold period, so hourly ramping should only be considered for the first 24 hours after the 24-hour hold. Generally, the combination protocols (C1, C2, C3 & C4) that had similar water usage as the stepped protocols (i.e. S3), the combination protocols did achieve downriver flow criteria as well as the stepped protocols.

Of the alternative protocols evaluated, only three (R8, R10, C5, and C6) had equal or better achievement of using less than the annual water availability in the mitigation bank compared to the Current Protocol (S1). Of the five protocols, the Current Protocol performed better in meeting downriver criteria compared to the rate protocols (R8 and R10) and the combination protocols (C5 and C6).

Overall, the Current Protocol appears to maintain a good compromise between supporting downriver flow criteria, and by extension protecting the aquatic community, vs. use of available water storage for enabling that level of RFC mitigation. Potential alternative protocols can improve achievement of downriver criteria but, in some cases, require considerably more water storage.

STANDARDIZATION OF HISTORIC FLOW DATA (2008-2017) TO THE 2017 FFMP

Observational gage data was utilized in SEF's evaluation of the current and alternative protocols. These observational data inherently introduced bias towards over-estimation of protocol water needs, given the successive iterations of the FFMP conservation table improvements over the 10-year evaluation period. Flow data prior to the 2017 FFMP, in some cases, may have had different minimum flow conditions post-event than what would be allowed for under the 2017 FFMP. By standardizing observational flow data to the 2017 FFMP conservation tables, potentially mitigation needed per event could be reduced and higher conservation release flows may also eliminate some RFC events from consideration. Standardization by the Delaware River Basin Planning Support Tool (DRB-PST) while available, is not applicable, given output cannot be resolved to hourly units. In an attempt to update historic flow data, SEF used an ad hoc method to standardize historic data to the 2017 FFMP. The update was completed by determining which flow table was in place on the date of the historic RFC event, which was then verified with NYCDEP. Post-RFC event minimum flows were then modified in the model to match the flows that would occur in corresponding Conservation Release table under the 2017 FFMP.

Improved base flow rates were achieved in some cases by standardizing historic post-RFC event flow conditions to the conservation releases of the 2017 FFMP. Minimum flow conditions in the 2017 FFMP post-RFC event were higher in 16 of 30 events (Table 10), and high enough in three events that those events no longer met the criteria to be considered RFC events. Two events (Event 1 and 21) would have

not fallen below the 500 cfs during the event because the 2017 FFMP tables would have required a minimum of at least 500 cfs flow post-event. Event 7 did not meet the flow change requirement (>250 cfs drop over 8 hour period) because the post-flow conditions were high enough to mitigate the most severe of the rapid flow reduction. The removal of 3 events from RFC consideration would allow for more bank to be available for the remaining events, however, the events that were eliminated were generally smaller events to mitigate (Events 1, 7, and 21 used 39, 170, and 26 cfs-days, respectively, under the Current Protocol with unadjusted flows). The improvement of some post-event flow conditions was not significant enough to remove any events from consideration based on flow change from the pre-event 5-day median flows. A total of 27 RFC events remained for evaluation of mitigation protocol alternatives.

Table 10. Changes in minimum flow post-RFC event when historic (2008-2017) RFC event conditions were standardized to 2017 FFMP conservation releases. Bold-Italicized RFC events (1, 7, and 21) no longer met RFC event criteria and were removed from further analysis.

RFC Event	RFC Event Peak Flow Hour	Peak RFC-Event Flow at Stilesville (cfs)	Actual Minimum Flow at Stilesville Post-RFC Event (cfs)	Standardized 2017 FFMP Minimum Flow at Stilesville Post-RFC Event (cfs)	FFMP Table
1	***6/14/2008 23:00***	***507***	***259***	***500***	***4g***
5	9/4/2008 17:00	863	100	450	4g
7	***9/26/2008 18:00***	***462***	***112***	***400***	***4g***
8	10/23/2008 18:00	976	89	150	4g
10	10/22/2009 17:00	703	336	175	4g
12	8/22/2010 23:00	734	354	415	4e
13	9/26/2010 15:00	969	134	190	4c
14	9/1/2012 18:00	716	350	360	4e
15	9/16/2012 16:00	1190	326	400	4g
16	10/6/2013 15:00	1300	247	175	4g
17	10/17/2013 23:00	601	307	175	4g
18	11/3/2013 19:00	671	177	175	4g
19	11/10/2013 16:00	609	145	175	4g
20	11/25/2013 19:00	504	139	150	4g
21	***8/31/2014 14:00***	***897***	***450***	***550***	***4g***
22	10/15/2014 22:00	885	172	150	4g
23	11/4/2014 15:00	780	138	150	4g
24	11/20/2014 0:00	923	482	150	4g
25	9/8/2015 23:00	956	394	450	4g
26	9/28/2015 10:00	1245	313	400	4g
27	10/26/2015 10:00	876	157	150	4g
28	9/16/2016 23:00	1388	479	400	4g
29	9/28/2016 16:00	715	273	400	4g
30	10/4/2016 11:00	512	123	150	4g
31	10/19/2016 23:00	810	164	105	4d
32	10/25/2016 23:00	834	150	105	4d
33	10/27/2016 22:00	1120	278	105	4d
36	10/7/2017 23:00	1010	150	150	4g
37	10/22/2017 23:00	776	303	150	4g
38	10/26/2017 23:00	768	299	150	4g

Of the remaining 27 RFC events, there were both transition (changing to long-term lower flows) and gap (short-term reductions in flow) events. There are seven events that transition to lower flows (Events 5, 14, 17, 19, 22, 25, and 30). Three of the events have flows that, post-RFC event, stay above 300 at Stilesville, ensuring that downriver flow criteria are met regardless of protocol implemented. For the remaining four events, there is no set scientifically-based standard rate by which to decrease flows at Stilesville, so any protocol to decrease flows at a more gradual level than knife-edge will likely benefit aquatic populations. Achievement of the step reduction at Stilesville at no more than 200 cfs per step (including after end of mitigation) is the only criteria evaluating the down-ramping for these events, and other downriver flow criteria for these events should not be evaluated equally with gap bridging events when selecting the best protocol.

Twenty 20 events are relatively short-term decreases in flow, where bridging gaps in flow with mitigation have the most potential to protect downriver habitats from temporary, and sometimes drastic, flow reductions. These gap events are most notable at the Hale Eddy and Callicoon gages where input of precipitation may help in achieving downriver flow criteria after cessation of large releases from Cannonsville (related to achievement of the Montague flow target). In many of these gap events, expected precipitation is driving the reduction in Cannonsville releases, and the Stilesville gage is transitioning to a long-term lower flow condition. Of the 20 gap events, eleven of those events meet all downriver flow criteria, regardless of what mitigation protocol is selected. The remaining nine events (Events 8, 18, 23, 27, 31, 32, 36, 37, and 38) warrant most consideration comparing effectiveness of different protocols. Most of the gap events span 48 hours or less, but three events (Events 18, 23, and 38) would require longer mitigation to maintain high flows downriver. The gap between high flow peaks for Event 18 is greater than 3 days, so this event should be considered as a transition event as there is likely not enough water in the mitigation bank to apply more than three days of flows to an individual event. Two other events (Events 23 and 38) would benefit from a 72-hour mitigation protocol over a 48-hour protocol to improve meeting flow criteria at Callicoon. It is important to note that during many of the gap events, Stilesville is transitioning to a long-term lower flow condition, so the step-down rate during and after mitigation is applied is still important for habitat protection, regardless of the length of time that mitigation is applied.

Evaluation of Current and Alternative Protocols to address RFC Events under the 2017 FFMP Standardized Flows

The Current Protocol along with 17 alternative protocols were evaluated using the observational data standardized to 2017 FFMP conservation tables for each event (Table 11). Alternative protocols were restricted to set reductions using hourly time-steps with various holding periods applied. With the physical and practical limitations of water releases at the reservoir, ramping rates were evaluated for alternatives starting at a minimum step of 50 cfs. Ramping rates that would mimic natural conditions (i.e. 2% decline per hour) would require initial flow changes of about 10 cfs/hour. Since that resolution of flow change that best mimics natural declinations (i.e., 1-2 % change), is not practical to implement, attempts to simulate natural declination were evaluated using 50 cfs increments every 5 hours.

Table 11. Mitigation protocols evaluated to address 27 RFC events using updated post-RFC flow conditions to match the 2017 FFMP Flow Tables.

Protocol	Cutoff Flow to Determine High and Low Starting Flow (cfs)	High Starting Flow (cfs)	Low Starting Flow (cfs)	Ramp Steps (hrs)	Ramp Rate (cfs)	Total Mitigation Hours (hrs)	Comments
0	0	0	0	0	0	0	No Mitigation (Worst Case)
SS1	700	500	300	24	200	48	Current Protocol
SS2	700	500	300	48	0	48	Wait-for-the-Rain
SS3	700	500	300	24	100	48	Intermediate Current/Wait-for-Rain
SS4	700	500	300	24	100	72	S3 extended to 72 hours
SS5	700	500	400	24	100	72	S4 with increased low starting flow
SS6	700	500	300	24	100	60	S3 reduced to 60 hours
SS7	700	500	350	24	100	60	S6 with increased starting low flow
SS8	700	400	400	24	100	72	S5 with reduced high starting flow
SS9	700	700	500	24	200	48	Higher starting flows, larger ramp
SS10	700	700	500	24	200	72	S9 extended to 72 hours
SS11	700	500	300	24	150	72	S4 with larger ramp
SS12	700	500	300	12	50	48	S2 with more frequent steps
SS13	700	500	400	12	50	48	S12 with increased starting low flow
SS14	700	500	300	5	50	48	More natural flow declination
SS15	700	600	400	5	50	48	S14 with higher starting flows
SS16	700	650	450	24	75	72	Keeping all criteria >=90% in 3 days
SS17	700	650	450	24	75	144	All criteria >=90%, better ramp
SS18	700	700	700	144	0	144	Sustained High Flow (Best Case)

All protocols were evaluated using the same evaluation criteria as previously identified in the report as well as an added criteria to measure frequency of Stilesville flows dropping more than 200 cfs immediately after mitigation ends (Table 12). Criteria evaluation was also extended to the first 72 hours post-RFC event to evaluate mitigation of events with short-term gaps in flow and those events transitioning toward sustained lower flows.

Protocol SS18 showed the best case for achievement of downriver flow criteria, by implementing sustained high flows for 5-days post-RFC event (Appendix C). There were six events where complete (100%) achievement of downriver flow criteria was not achievable in either 48 or 72 hours. For five of the events (Events 13, 29, 30, 36, and 37), this is likely due to slight changes in flow lags at downriver sites, causing the Callicoon flow criteria to be missed in the first hours of the mitigation event. The remaining event (Event 32) does not fully achieve the Stilesville criteria during the 72-hour period because of flows exceeding 325 cfs occurred during the 48-hour period mitigation period, which resulted in the model ceasing application of mitigation. A subsequent temporary drop in flows occurred before 72-hours post-RFC event resulting in lack of achievement of the Stilesville criteria for the third day. Values depicted in Protocol SS18 should be considered the highest possible achievement of downriver flow criteria, however this protocol used excessive amounts of water annually and should not be considered a viable protocol for implementation (Table 13). Average annual mitigation bank required for the 10-year time series for all alternative protocols evaluated ranged from 247 to 1,943 cfs days (Table 13).

Table 12. Average achievement of downriver criteria by applying various mitigation protocols as described in Table 11 to RFC events post-event flows standardized to the 2017 FFMP.

Protocol	Avg cfs-days per Event	% Stilesville Criteria Achieved 48-hr	% Hale Eddy Criteria Achieved 48-hr	% Callicoon Criteria Achieved 48-hr	% Callicoon 560 cfs Achieved 48-hr	% Stilesville Criteria Achieved 72-hr	% Hale Eddy Criteria Achieved 72-hr	% Callicoon Flow Achieved 72-hr	% Callicoon 560 cfs Achieved 72-hr	% of Events when Stilesville dropped <200 cfs after mitigation	# Years >1,000 cfs-days
0	N/A	63%	80%	66%	97%	63%	83%	72%	98%	N/A	N/A
SS1	187	94%	97%	80%	99%	86%	95%	81%	99%	100%	0
SS2	288	100%	100%	83%	100%	91%	97%	83%	100%	78%	4
SS3	222	94%	98%	81%	99%	86%	96%	82%	99%	81%	1
SS4	248	94%	98%	81%	99%	91%	98%	82%	99%	100%	3
SS5	281	100%	100%	81%	100%	95%	100%	82%	100%	100%	4
SS6	235	94%	98%	81%	99%	89%	98%	82%	99%	100%	1
SS7	250	97%	100%	81%	99%	92%	98%	82%	99%	100%	2
SS8	170	100%	100%	74%	100%	91%	98%	77%	100%	100%	1
SS9	461	100%	100%	90%	100%	89%	97%	88%	100%	78%	7
SS10	487	100%	100%	90%	100%	95%	99%	88%	100%	100%	7
SS11	207	94%	97%	81%	99%	86%	95%	82%	99%	100%	0
SS12	190	93%	98%	79%	98%	85%	95%	81%	99%	100%	0
SS13	218	99%	100%	79%	99%	90%	97%	81%	99%	100%	2
SS14	91	80%	90%	74%	97%	75%	89%	77%	98%	100%	0
SS15	175	88%	95%	80%	98%	80%	92%	81%	98%	100%	0
SS16	594	100%	100%	93%	100%	98%	100%	91%	100%	81%	8
SS17	720	100%	100%	93%	100%	98%	100%	91%	100%	100%	8
SS18	1893	100%	100%	99%	100%	99%	100%	99%	100%	70%	9

Table 13. Total cfs-days used annually by applying various mitigation protocols as described in Table 11 to RFC events using post-event flows standardized to the updated 2017 FFMP.

Protocol	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Average
0	0	0	0	0	0	0	0	0	0	0	0
SS1	517	146	481	0	231	666	764	527	934	775	504
SS2	767	295	766	0	471	1266	1079	877	1229	1020	777
SS3	617	195	581	0	271	866	913	627	1027	895	599
SS4	767	201	691	0	271	867	1046	776	1027	1038	668
SS5	767	201	691	0	271	1589	1046	776	1220	1038	760
SS6	692	198	636	0	271	867	979	701	1027	970	634
SS7	692	198	636	0	271	1175	979	701	1124	970	675
SS8	431	59	317	0	40	1394	625	353	796	563	458
SS9	1114	469	1122	0	840	2075	1517	1339	2437	1538	1245
SS10	1264	469	1232	0	840	2083	1649	1488	2437	1683	1314
SS11	617	150	541	0	231	716	866	626	964	877	559
SS12	542	150	506	0	201	691	834	527	883	800	513
SS13	542	150	506	0	201	1263	834	527	1073	800	590
SS14	269	58	234	0	78	262	450	210	502	405	247
SS15	476	139	427	0	229	617	728	454	975	685	473
SS16	1595	647	1567	0	1130	2771	1908	1963	2559	1888	1603
SS17	2174	731	2046	0	1220	3247	2419	2572	2559	2463	1943
SS18	4635	2015	4638	0	3481	13056	5201	6163	7818	4108	5111
# Events	2	1	2	0	2	5	3	3	6	3	2.7

Using the standardized 2017 FFMP data, the Current Protocol (Protocol SS1) used less than the full mitigation bank allotment of 1,000 cfs annually in all 10 years of the time series. The Current Protocol used, on average, 187 cfs-days per event with a range of 0 to 469 cfs per event (Table 14). All events achieved a drop at Stilesville no larger than 200 cfs during or after application of mitigation. A total of seven events had full achievement of downriver flow criteria. Of the remaining 23 events, they had varying levels of achievement of downriver criteria ranging from 0% to 100%. The Stilesville and Hale Eddy flow criteria for both 24 and 48 hours were achieved on average >90% of the time. The Callicoon criteria were achieved >80% of the time. The 560 cfs criteria was achieved 100% of the time for all events except for Event 30, where the flow criteria were missed for 60% of the time in the first 48 hours and 68% of the time in the first 72 hours. Event 30 was a transition event and had poor achievement of downriver flow criteria under nearly all alternative protocols evaluated. Graphic representation of the Current Mitigation Protocol applied to all 27 events can be found in Appendix D.

Table 14. Performance of Current RFC Mitigation Protocol (SS1) using the 2017 FFMP standardized flow data from 2008-2017.

Event	% Stilesville Criteria Achieved 48-hr	% Hale Eddy Criteria Achieved 48-hr	% Callicoon Criteria Achieved 48-hr	% Callicoon 560 cfs Achieved 48-hr	% Stilesville Criteria Achieved 72-hr	% Hale Eddy Criteria Achieved 72-hr	% Callicoon Criteria Achieved 72-hr	% Callicoon 560 cfs Achieved 72-hr	Stilesville dropped <200 cfs after mitigation	Mitigation by Event (cfs-days)
5	100%	100%	100%	100%	100%	100%	100%	100%	Y	48
8	100%	100%	100%	100%	74%	100%	100%	100%	Y	469
10	100%	100%	100%	100%	100%	100%	100%	100%	Y	146
12	100%	100%	100%	100%	100%	100%	100%	100%	Y	84
13	100%	100%	35%	100%	74%	74%	33%	100%	Y	397
14	100%	100%	0%	100%	100%	100%	18%	100%	Y	132
15	100%	100%	75%	100%	100%	100%	83%	100%	Y	99
16	100%	100%	100%	100%	97%	100%	100%	100%	Y	305
17	100%	100%	100%	100%	75%	100%	71%	100%	Y	0
18	75%	75%	100%	100%	50%	50%	100%	100%	Y	106
19	63%	100%	100%	100%	42%	100%	100%	100%	Y	118
20	58%	100%	100%	100%	39%	100%	100%	100%	Y	137
22	100%	100%	100%	100%	82%	100%	100%	100%	Y	406
23	100%	98%	83%	100%	100%	99%	89%	100%	Y	350
24	100%	100%	100%	100%	100%	100%	100%	100%	Y	7
25	100%	100%	17%	100%	100%	100%	11%	100%	Y	50
26	100%	100%	100%	100%	100%	100%	100%	100%	Y	98
27	100%	100%	100%	100%	74%	96%	100%	100%	Y	379
28	100%	100%	100%	100%	100%	100%	100%	100%	Y	2
29	100%	100%	46%	100%	100%	100%	47%	100%	Y	95
30	54%	54%	0%	60%	67%	65%	0%	68%	Y	123
31	100%	94%	85%	100%	100%	96%	90%	100%	Y	268
32	100%	98%	100%	100%	82%	99%	100%	100%	Y	276
33	100%	100%	100%	100%	100%	100%	100%	100%	Y	169
36	100%	100%	92%	100%	100%	100%	94%	100%	Y	269
37	100%	100%	67%	100%	100%	100%	78%	100%	Y	204
38	100%	100%	67%	100%	75%	81%	78%	100%	Y	302
Avg	94%	97%	80%	99%	86%	95%	81%	99%	100%	187
Min	54%	54%	0%	60%	39%	50%	0%	68%		0
Max	100%	100%	100%	100%	100%	100%	100%	100%		469

With the different combinations of time steps, rate of flow change, and starting flows, there were some general observations that held for the various protocols tested. There was higher achievement of downriver flow criteria for gap events when mitigation time-steps were 24-hour periods. Changing the time-step to 12-hour periods, especially when starting at lower flows (i.e. 500 and 300 cfs), reduces likelihood of achieving downriver flow criteria (ex. Protocol SS12 vs. SS2). Starting mitigation at higher flows (i.e. 600 & 450) combined with 12-hour time-steps exceeds water available in the mitigation banks (ex. Protocol SS13 vs. SS12). Reducing starting flows (i.e. 400 cfs) makes a protocol more likely to achieve the annual bank allotment, but provides limited improvement in meeting downriver flow criteria (ex. Protocol SS8 vs. SS5). Changing the minimum starting flow to 350 instead of 300 did increase bank usage, but offer improvements in achieving the Hale Eddy flow criteria in the first 48 hours (ex. Protocol SS7 vs. SS6).

To determine if there was an alternative protocol that performed better than the Current Protocol for achieving evaluation criteria, all protocols were compared that stayed within, or nearly so, to the current mitigation allotment of 1,000 cfs-days annually during the 10-year time series. There were a total of seven protocols evaluated that required less than the allotted mitigation bank each year (SS1, SS11, SS12, SS14, and SS15) or only exceeded the 1,000 cfs bank one year by less than a 10% overage (SS3 and SS6, in 2016). These protocols were compared to determine which protocol had the highest level of achievement of the criteria established to evaluate the protocols. Protocol SS6 preformed best of all protocols compared, having equal to or better average achievement of all criteria.

Protocol SS6 is an intermediate protocol between the Current Protocol (SS1) and the "Wait-for-the-Rain" protocol (SS2). This protocol had starting flows at 500 cfs and 300 cfs (depending if the peak RFC flow was < or >700 cfs). The mitigation held at starting flows for the first day, dropped by 100 cfs on day 2 and dropped another 100 cfs for the first half of day 3 of mitigation, followed by a return to base flow conditions. This intermediate protocol allowed for extended application up to 60 total hours, which provided improvements for meeting downriver criteria on day-3 post event, and also allowed for Stilesville to drop less than 200 cfs post-mitigation event (Table 15). This protocol used less than the mitigation bank allotment in 9 of 10 years, and exceeded the mitigation bank allotment in 2016 by 27 cfs. Protocol SS6, on average, provided slight improvements over the Current Protocol (SS1) for the Hale Eddy and Callicoon criteria in the first 48 hours, and showed improvement in all but the Callicoon 560 cfs criteria (protocols equivalent) in the first 72 hours. This alternative protocol also had 100% achievement of all criteria for 9 events and improvements for criteria over the Current Protocol in 11 of the 27 RFC events. Similar to the Current Protocol, Protocol SS6 was unsuccessful in achievement of the 560 cfs criteria at Cannonsville (minimum flow of 416 cfs) only for Event 30. Graphic representation of Protocol SS6 applied to all 27 events can be found in Appendix E.

Table 15. Performance of alternative Protocol SS6 using the 2017 FFMP standardized flow data from 2008-2017.

Event	% Stilesville Criteria Achieved 48-hr	% Hale Eddy Criteria Achieved 48-hr	% Callicoon Criteria Achieved 48-hr	% Callicoon 560 cfs Achieved 48-hr	% Stilesville Criteria Achieved 72-hr	% Hale Eddy Criteria Achieved 72-hr	% Callicoon Criteria Achieved 72-hr	% Callicoon 560 cfs Achieved 72-hr	Stilesville dropped <200 cfs after mitigation	Mitigation by Event (cfs-days)
5	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	Y	**48**
8	100%	100%	100%	100%	90%	100%	100%	100%	Y	644
10	100%	100%	100%	100%	100%	100%	100%	100%	Y	198
12	100%	100%	100%	100%	100%	100%	100%	100%	Y	84
13	100%	100%	35%	100%	90%	90%	38%	100%	Y	552
14	**100%**	**100%**	**0%**	**100%**	**100%**	**100%**	**18%**	**100%**	**Y**	**172**
15	100%	100%	75%	100%	100%	100%	83%	100%	Y	99
16	100%	100%	100%	100%	100%	100%	100%	100%	Y	407
17	**100%**	**100%**	**100%**	**100%**	**75%**	**100%**	**71%**	**100%**	**Y**	**0**
18	**75%**	**100%**	**100%**	**100%**	**50%**	**83%**	**100%**	**100%**	**Y**	**131**
19	**63%**	**100%**	**100%**	**100%**	**42%**	**100%**	**100%**	**100%**	**Y**	**143**
20	58%	100%	100%	100%	39%	100%	100%	100%	Y	187
22	**100%**	**100%**	**100%**	**100%**	**99%**	**100%**	**100%**	**100%**	**Y**	**572**
23	100%	100%	100%	100%	100%	100%	100%	100%	Y	400
24	100%	100%	100%	100%	100%	100%	100%	100%	Y	7
25	**100%**	**100%**	**17%**	**100%**	**100%**	**100%**	**11%**	**100%**	**Y**	**50**
26	100%	100%	100%	100%	100%	100%	100%	100%	Y	98
27	100%	100%	100%	100%	90%	100%	100%	100%	Y	553
28	100%	100%	100%	100%	100%	100%	100%	100%	Y	2
29	100%	100%	46%	100%	100%	100%	47%	100%	Y	95
30	**54%**	**60%**	**0%**	**63%**	**67%**	**69%**	**0%**	**69%**	**Y**	**153**
31	100%	96%	85%	100%	100%	97%	90%	100%	Y	296
32	100%	100%	100%	100%	82%	100%	100%	100%	Y	311
33	100%	100%	100%	100%	100%	100%	100%	100%	Y	169
36	100%	100%	92%	100%	100%	100%	94%	100%	Y	269
37	100%	100%	69%	100%	100%	100%	79%	100%	Y	224
38	100%	100%	73%	100%	92%	97%	82%	100%	Y	477
Avg	94%	98%	81%	99%	89%	98%	82%	99%	100%	235
Min	54%	60%	0%	63%	39%	69%	0%	69%		0
Max	100%	100%	100%	100%	100%	100%	100%	100%		644

The "Wait-for-the-Rain" Protocol (SS2, WFTR) achieved 100% of all downriver criteria for 8 of 27 events. The WFTR protocol showed some (in some cases slight) improvement over Current Protocol (SS1) in downriver flow criteria in 11 events. The WFTR protocol also had improvements in achieving downriver flow criteria in 8 events compared to Protocol S6, however the SS6 protocol had improvements in 5 different events compared to the WFTR protocol. The WFTR protocol used 50% more water than the Current Protocol and exceeded the 1,000 cfs-day bank in 4 of 10 years. The maximum annual exceedance of the WFTR was 1,266 cfs-days. Although the WFTR protocol demonstrates increased protection of downriver flow criteria for several events over the Current Protocol, it does not offer ramping (just a 48-hour hold). This protocol allowed for a significant (~350 cfs) knife-edge drop in flows at Stilesville post-mitigation in six events. The intent of the mitigation protocol is to provide ramping to allow for a more gradual drop to a lower rate. The WFTR protocol provides temporary sustained high flows, does not offer an adequate ramping condition in West Branch post-mitigation. Graphic representation of the WFTR Protocol applied to all 27 events can be found in Appendix F.

Protocol SS17 (starting flows at 650 and 450 cfs with 75 cfs drop every 24-hours for 5 days) had the overall best achievement of all downriver criteria of all protocols evaluated, but exceeded the mitigation bank allotment of 1,000 cfs-days in 8 of 10 years. Maximum bank usage in a given year (2013) was 3,247 cfs-days, more than three times the current bank size. This protocol had improvements in all downriver criteria to some degree in nearly all events compared to the Current Protocol and Protocol SS6. Graphic representation of Protocol 17 applied to all 27 events can be found in Appendix G.

Several events whose achievement of evaluation criteria varied based on the protocol selected are depicted in Appendix H for the Current Protocol (SS1), the WFTR Protocol (SS2), the best protocol for the available mitigation bank (SS6) and the best protocol for achieving criteria (SS17).

EVALUATION OF 2019 RFC EVENTS USING THE CURRENT PROTOCOL AND PREFERRED ALTERNATIVE PROTOCOL

In 2019, based on the Stilesville flow data and events with known mitigation applied, there were three events that met the following criteria for being classified as an RFC event (Figure 7).

1) The event must occur during a change in an ODRM directed release, or within 2 days of the end of an ODRM directed release
2) The flows at the USGS Stilesville gage dropped or will drop below 500 cfs in association with a change in ODRM directed release;
3) The rate of flow reduction is expected to be $\geq$250 cfs over an 8-hour period during a time associated with a change in ODRM directed release;
4) The minimum flow for the 24-hours post-RFC event (i.e. lower rate) will be less than 90% of the median 5-day flow prior to the event; and
5) The RFC event occurs during normal (non-drought) operating conditions.

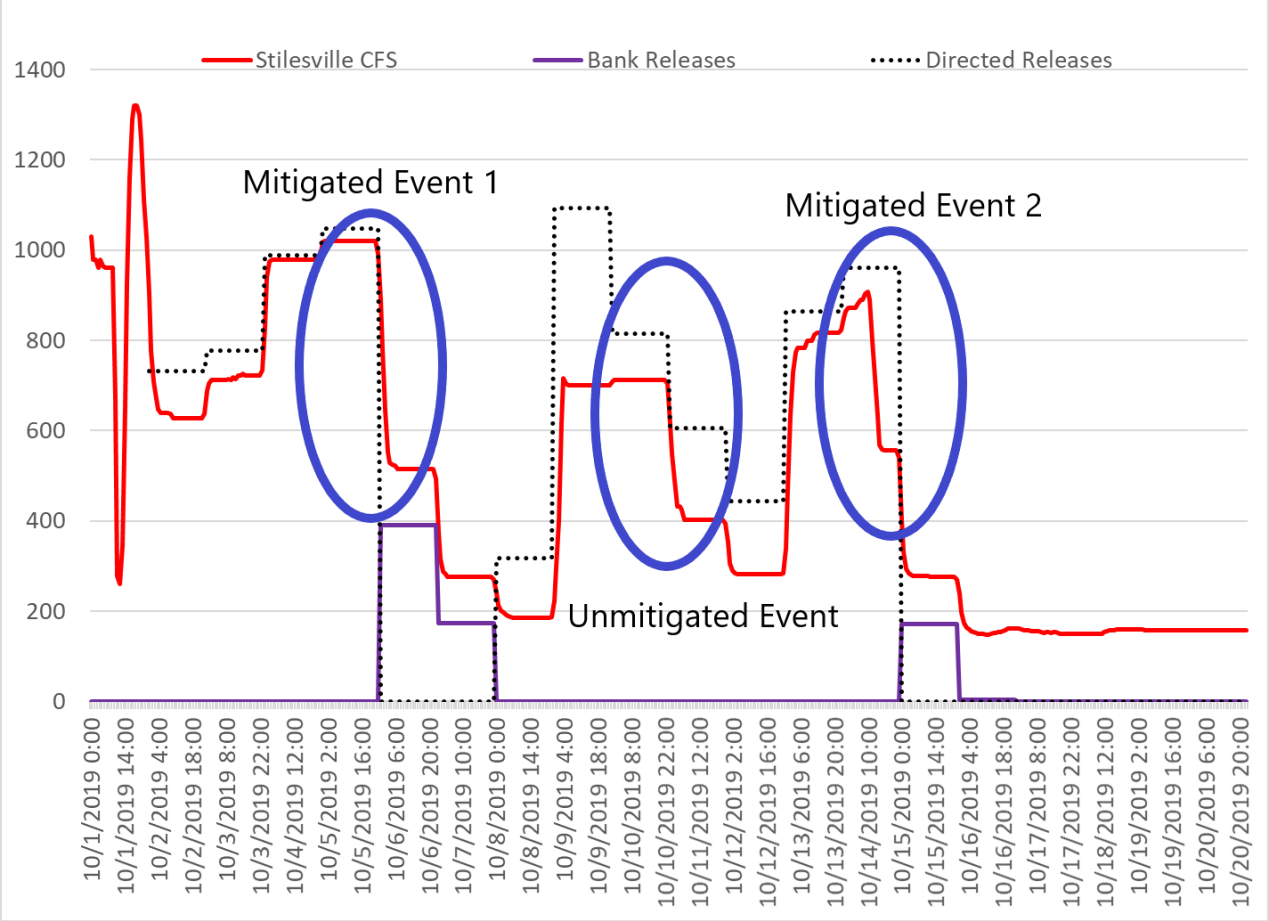


Figure 7. Identified RFC events in fall 2019. Note: the rapid flow change event that occurred on 10/1/2019 did not qualify as an RFC event because flows were dropped temporarily at Cannonsville for an emergency situation.

Mitigation was applied to two of the events. The first event was on October 5 (Event 1) and second event was on October 14 (Event 2). Both events occurred during implementation of 2017 FFMP Table 4f, where a minimum flow was 135 cfs. Based on actual implementation of the Current Protocol for the two mitigated events, most evaluation criteria were not fully achieved (Table 16).

Table 16. Evaluation of performance of Current Protocol in practice on 2019 RFC events.

Criteria		**Event 10/5/2019**	**Event 10/14/2019**
% Stilesville Criteria Achieved	48-hr	56%	29%
% Hale Eddy Criteria Achieved	48-hr	100%	83%
% Callicoon Criteria Achieved	48-hr	38%	31%
% Callicoon >560 cfs Achieved	48-hr	100%	100%
% Stilesville Criteria Achieved	72-hr	38%	19%
% Hale Eddy Criteria Achieved	72-hr	100%	85%
% Callicoon Criteria Achieved	72-hr	58%	54%
% Callicoon >560 cfs Achieved	72-hr	100%	100%
Stilesville dropped <200 cfs after mitigation		Y	Y
Mitigation by Event (cfs-days)		564	175

Description of the observed Current Protocol implementation and resulting flows

1) Event October 5, 2019 (Figure 8) – This event had poor achievement of Stilesville flow criteria during both the 48 and 72 hour post event periods. Achievement of Hale Eddy criteria was fully successful for three days after the RFC event. Callicoon had poor achievement of criteria during both the 48 and 72 hour period post event. Based on flow data from Stilesville, it appears that Cannonsville releases were held at ~500 cfs for 21 hours and then reduced to ~275 cfs for 24 hours. The reduction of Cannonsville releases below 300 cfs during the second 24-hour period resulted in poor achievement of the Stilesville criteria. As to the Callicoon criteria, it appears that the 500 cfs release from Cannonsville was not sufficient to support a fully-wetted flow at Callicoon during the mitigation event, allowing Cannonsville to drop to a minimum of 792 cfs within the first 24 hours of mitigation water reaching that location.

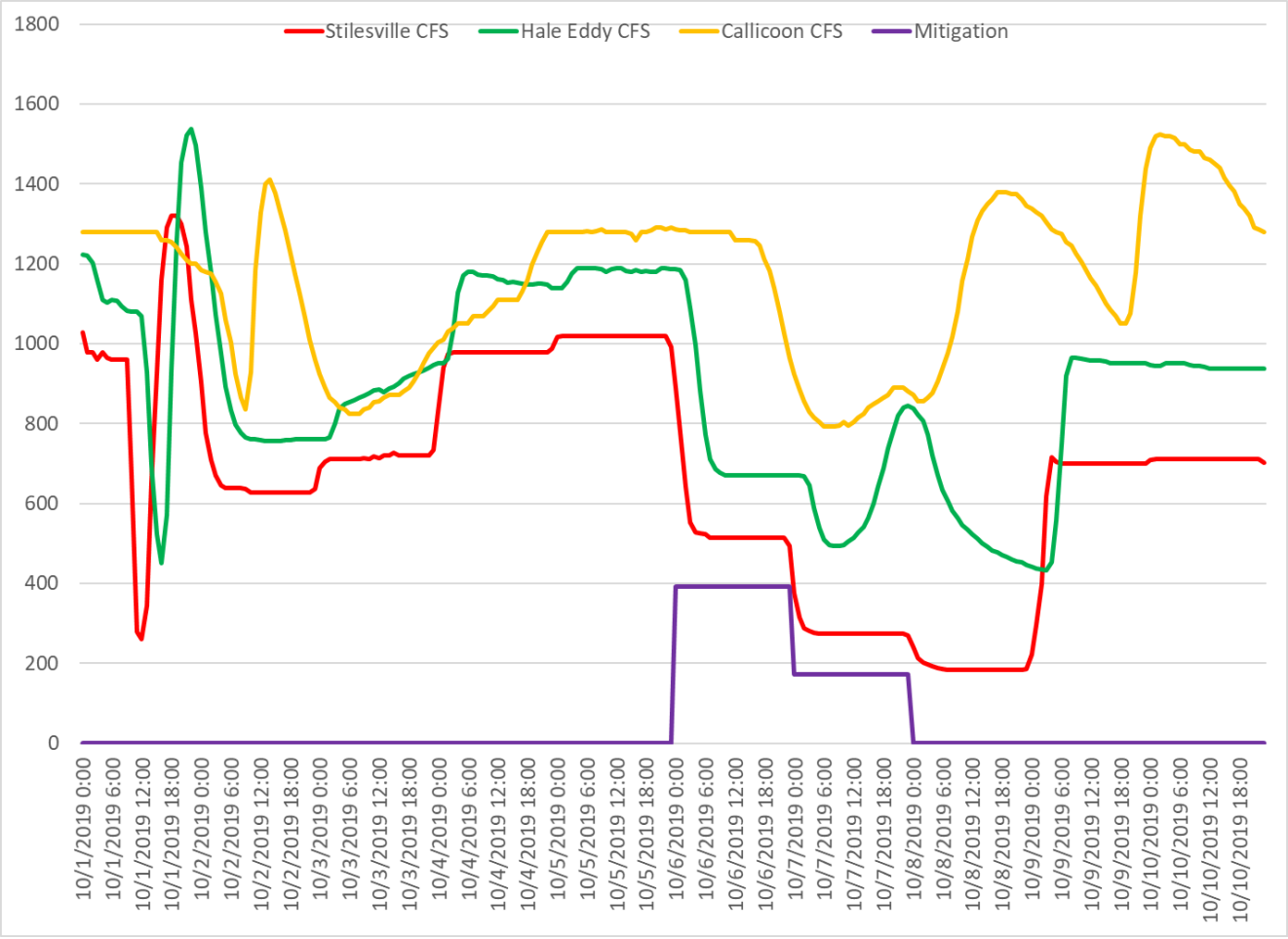


Figure 8. Actual implementation of the Current Protocol on 2019 RFC Event 1, 10/5/2019.

2) Event October 14, 2019 (Figure 9) – This event had poor achievement of the Stilesville, Hale Eddy, and Callicoon criteria during both the 48 and 72 hour period post event. Based on flow data from Stilesville, it appears that Cannonsville releases were held at ~500 cfs for 9 hours and then reduced to ~275 cfs for 24 hours. The short duration of the 500 cfs holding of Cannonsville releases and subsequent second holding below 300 cfs during the second 24-hour period

resulted in poor achievement of criteria. Stilesville flows dropped under 300 cfs just 14 hours into the mitigation event. This relatively rapid flow decline was also observed at Hale Eddy and Callicoon. Hale Eddy flows dropped below 350 cfs for a 12-hour period, with a minimum flow of 262 cfs. Callicoon flows fell below criteria (930 cfs), prior to the mitigation waters reaching that site, suggesting that mitigation holding of 500 cfs was not sufficient to maintain 930 cfs at Callicoon. Callicoon was below the flow criteria for 33 hours, with a minimum flow of 562 cfs.

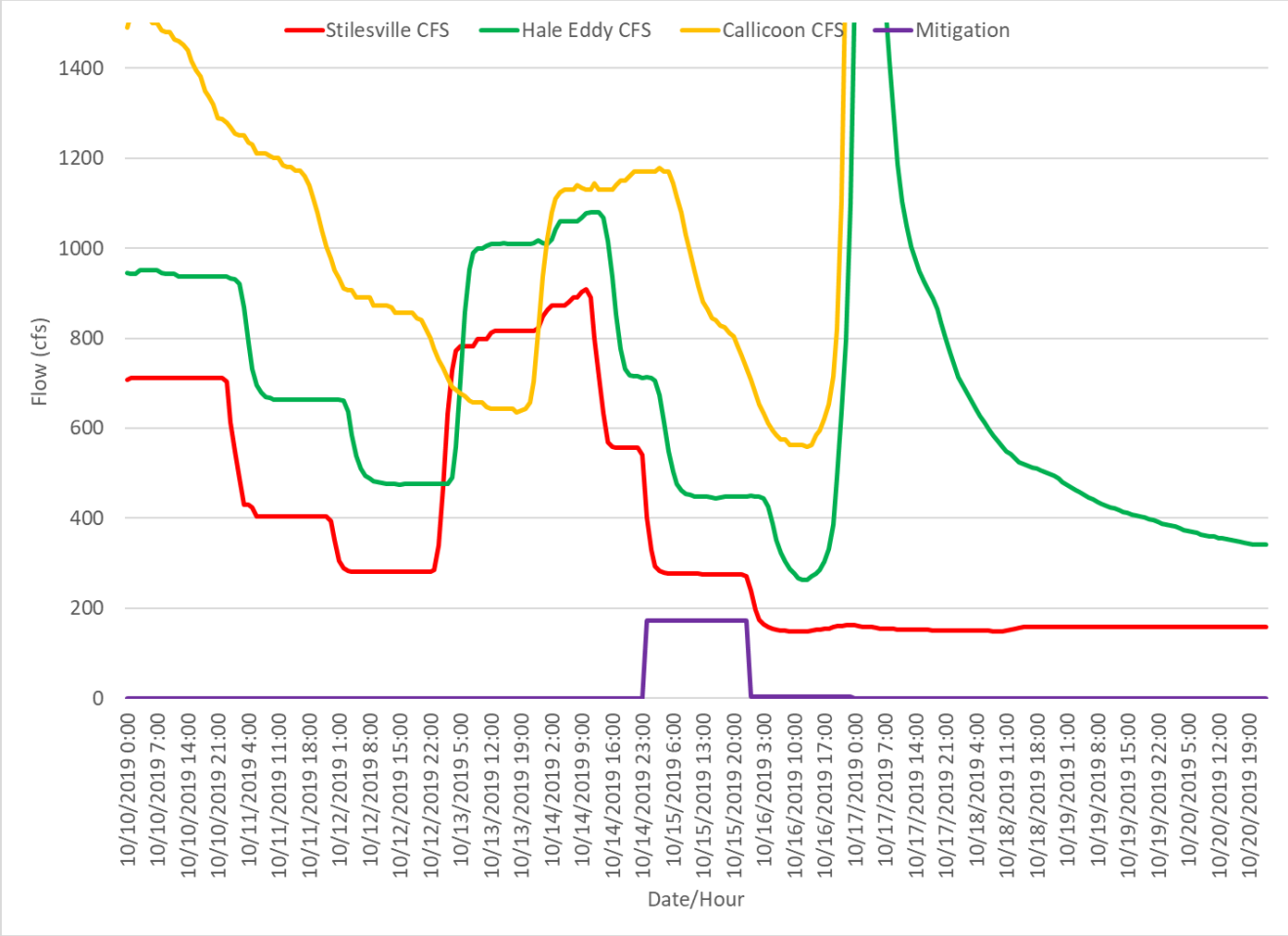


Figure 9. Actual implementation of the Current Protocol on 2019 RFC Event 2, 10/14/2019.

Based on flow data from the gages at Stilesville, Hale Eddy, and Callicoon, it does not appear that the Current Protocol was fully implemented for the two RFC events in October 2019. For both events, the full 24-hour hold at 500 cfs did not occur and the second 24-hour hold, which should have been 300 cfs, was reduced to 275 cfs. However, Cannonsville release data were provided by NYCDEP for the days in 2019 where mitigation was applied. The Cannonsville releases were compared against Stilesville gage data and it appears that the gage readings at Stilesville do not exactly mirror Cannonsville releases. As discussed earlier in the report, there is a disclaimer on the Stilesville gage by USGS that the data may not completely accurately reflect Cannonsville releases. During both events, the second day releases from Cannonsville were actually ~300 cfs. This discrepancy resulted in an overestimate of additional mitigation bank needed for 25 cfs-days for each event (50 cfs-days total) to fully implement the protocol. This discrepancy in flows also under-estimated how frequently flow criteria were met at the Stilesville gage for 48 and 72 hours post-event.

Flow discrepancies aside for day 2 of the events, it still appears there was a deviation in implementation of the Current Protocol, especially for day 1 of Event 2. For this event, flows being held at 500 cfs for a 24-hour period appears to have been skipped, but also no mitigation was used for that day. In discussion with NYCDEP about implementation of the Current Protocol on this event[13], their assessment was that the Current Protocol was fully implemented because RFC pre-event conditions were less than 700 cfs. NYCDEP, in knowing a change in directed releases was coming, attempted to bring down Cannonsville releases on 11/14/19 by re-directing directed releases to the Neversink. By increasing releases from the Neversink to reach the Montague target, Cannonsville releases were stepped down (100 cfs/hour) to get to a value below 700 cfs on 10/14/19 and not use any mitigation bank on that day. Therefore, when the Current Protocol was applied, starting on 10/15/19, the requirement was to hold flows at 300 cfs for 24 hours, which is what occurred (based on Cannonsville release data). This manipulation of flows to alter the starting conditions for mitigation contributed to lower flow conditions at the three USGS gages within the first 48 hours after the event than what might have happened if the 500 cfs step of the Current Protocol was implemented.

Full implementation of the Current Protocol for October 2019 RFC mitigated events

An evaluation was completed on the actual October 2019 data to determine how much additional water would have been required to fully implement the Current Protocol (including a full 24-hour hold at 500 cfs for day 1 of Event 2), and then how well subsequent flow criteria would have been achieved (Table 17). The total bank usage increased for both events with the full implementation of the Current Protocol, and ultimately, the two events would have exceeded the mitigation bank for 2019 by 20 cfs-days if they had been fully implemented. However, with the flow discrepancies between Stilesville and Cannonsville, the full implementation may have been ~30 cfs-days less than the available bank.

Table 17. Evaluation of performance of full implementation of Current Protocol on 2019 RFC events.

Criteria		Event 10/5/2019	Event 10/14/2019
% Stilesville Criteria Achieved	48-hr	100%	100%
% Hale Eddy Criteria Achieved	48-hr	100%	100%
% Callicoon Criteria Achieved	48-hr	46%	31%
% Callicoon >560 cfs Achieved	48-hr	100%	100%
% Stilesville Criteria Achieved	72-hr	72%	71%
% Hale Eddy Criteria Achieved	72-hr	100%	100%
% Callicoon Criteria Achieved	72-hr	64%	54%
% Callicoon >560 cfs Achieved	72-hr	100%	100%
Stilesville dropped <200 cfs after mitigation		Y	Y
Additional Mitigation Needed (cfs-days)		54	227
Total Mitigation by Event (cfs-days)		618	402

1) Event October 5, 2019 (Figure 10) – Fully implementing the Current Protocol would have improved achievement of all criteria. Stilesville and Hale Eddy criteria were fully met in the first 48 hours and the Hale Eddy criteria were also fully met in 72 hours. The Stilesville criteria were not fully met in 72 hours because mitigation ended and flows reduced to the Lower Rate, which

[13] B. Dramozos, NYCDEP personal communication, November 21, 2019.

was 185 cfs. Increased mitigation technically improved Callicoon meeting criteria during the first event, but the improvement was a small increase and decrease at Callicoon that likely wasn't a meaningful improvement in habitat and it did not eliminate the lowest flows of the event. Similar to the actual implementation of the Current Protocol, the releases of 500 cfs were not able to maintain flows at Callicoon at 930 cfs. The total bank usage increased by 54 cfs-days for this event and the resulting benefit was slight increases in flow at downriver gaging stations.

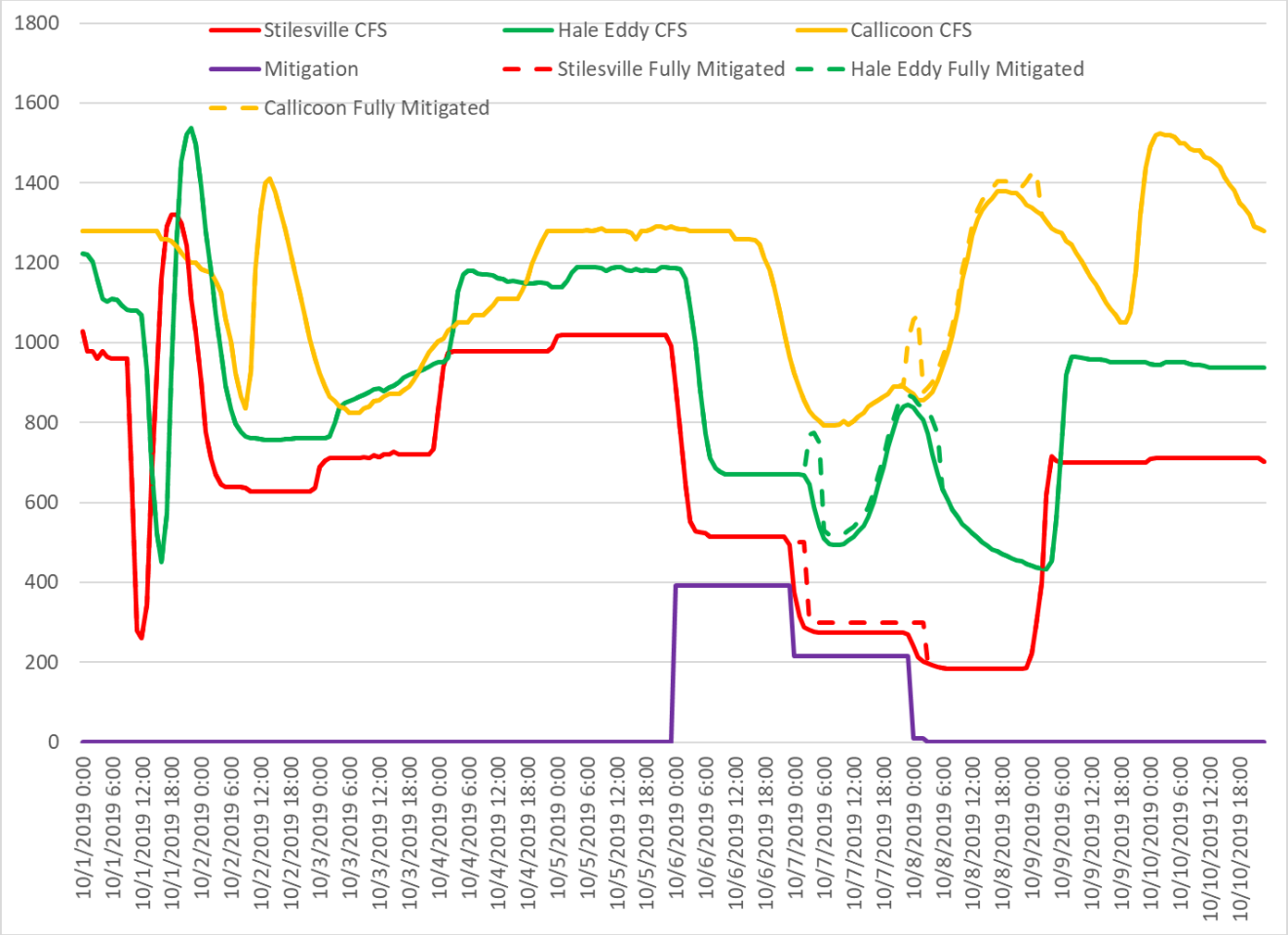


Figure 10. Full implementation of the Current Protocol on 2019 RFC Event 1, 10/5/2019.

2) Event October 14, 2019 (Figure 11) – There were improvements to the Stilesville and Hale Eddy criteria for this event, but no improvements for Callicoon. The Stilesville and Hale Eddy criteria were fully met in the first 48 hours and the Hale Eddy criteria were also fully met in 72 hours. The Stilesville criteria were not fully met in 72 hours because mitigation ended and flows reduced to the Lower Rate of 150 cfs. Similar to the actual implementation of the Current Protocol, the releases of 500 cfs were not able to maintain flows at Callicoon at 930 cfs. In addition, the Current Protocol was not long enough in duration during this event to span the flow gap of the event and still allowed Callicoon flows to drop below 600 cfs for a short period of time and also a temporary dip in flows at Hale Eddy. Full implementation of the Current Protocol for this event more than doubled the required mitigation for this event by requiring an additional 227 cfs-days.

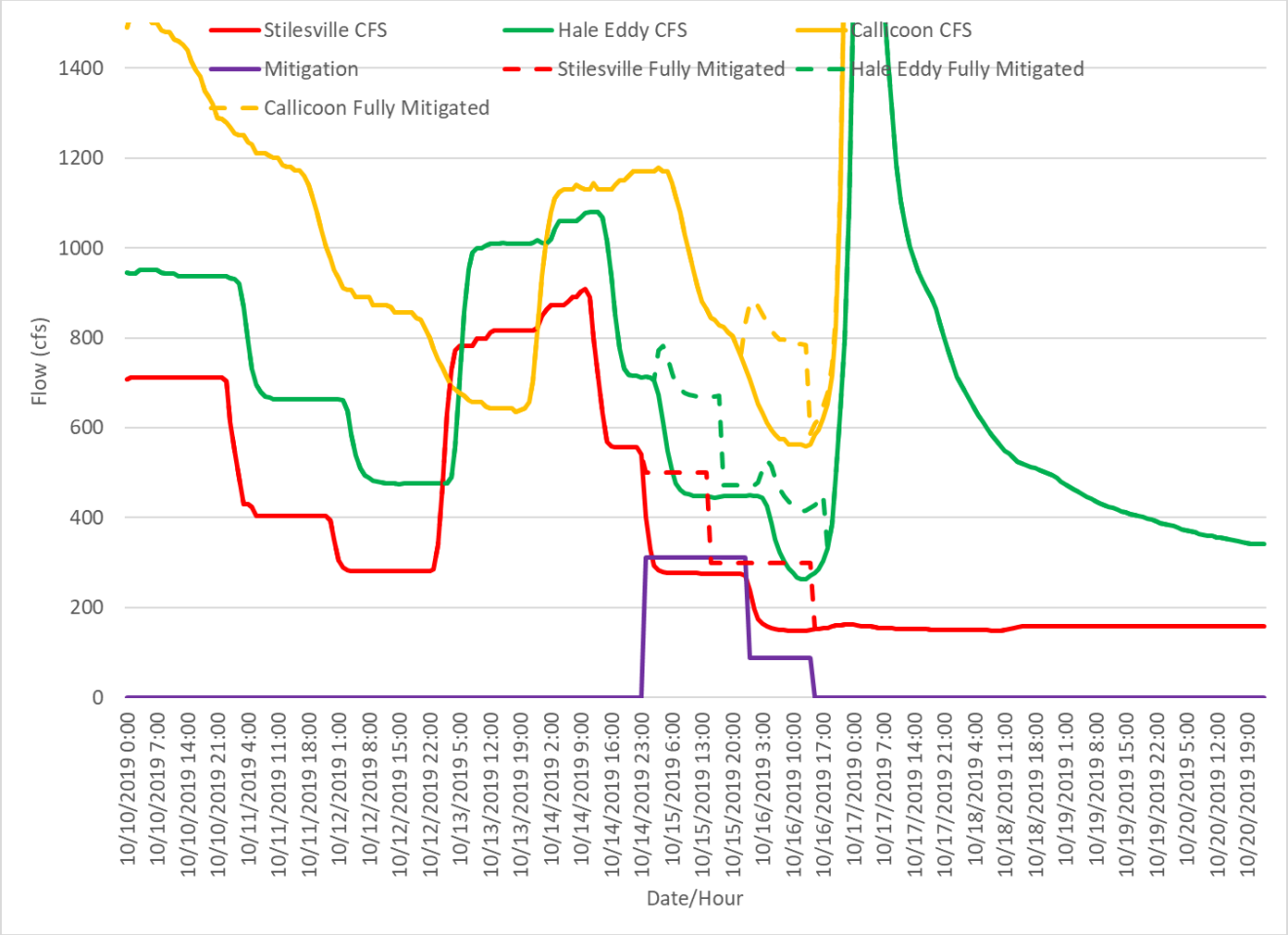


Figure 11. Full implementation of the Current Protocol on 2019 RFC Event 2, 10/14/2019.

Implementation of the Recommended Alternative Protocol for the 2019 RFC mitigated events

An evaluation of the Recommended Alternative Protocol (24 hrs @ 500 cfs, 24 hrs @ 400 cfs, 12 hrs @ 300 cfs) was implemented using the 2019 RFC events. The Alternative Protocol was the same or better under all downriver criteria evaluated. The Alternative Protocol would have used a total of 1,347 cfs, exceeding the available bank by nearly 350 cfs. Generally, the Alternative Protocol improved downriver conditions for a longer period of time (Table 18).

Table 18. Evaluation of performance of Recommended Alternative Protocol on 2019 RFC events.

Criteria		Event 10/5/2019	Event 10/14/2019
% Stilesville Criteria Achieved	48-hr	100%	100%
% Hale Eddy Criteria Achieved	48-hr	100%	100%
% Callicoon Criteria Achieved	48-hr	52%	33%
% Callicoon >560 cfs Achieved	48-hr	100%	100%
% Stilesville Criteria Achieved	72-hr	89%	88%
% Hale Eddy Criteria Achieved	72-hr	100%	100%
% Callicoon Criteria Achieved	72-hr	68%	56%
% Callicoon >560 cfs Achieved	72-hr	100%	100%
Stilesville dropped <200 cfs after mitigation		Y	Y
Additional Mitigation Needed (cfs-days)		211	397
Total Mitigation by Event (cfs-days)		775	572

1) Event October 5, 2019 (Figure 12) – Implementing the Recommended Alternative Protocol would have equaled or improved achievement of all criteria. As with other protocol evaluation, the Stilesville criteria were not fully met in 72 hours because mitigation ended and flows reduced to the Lower Rate. The increased mitigation allowed for the first flow gap at Hale Eddy to be reduced, but the lowest condition without mitigation would have still been a fully watered condition at Hale Eddy. Increased mitigation again technically improved Callicoon meeting criteria during the first event, but mitigation did not eliminate the lowest flows of the event. The total bank usage increased by 211 cfs-days for this event and the resulting benefit was slight increases in flow at downriver gaging stations.

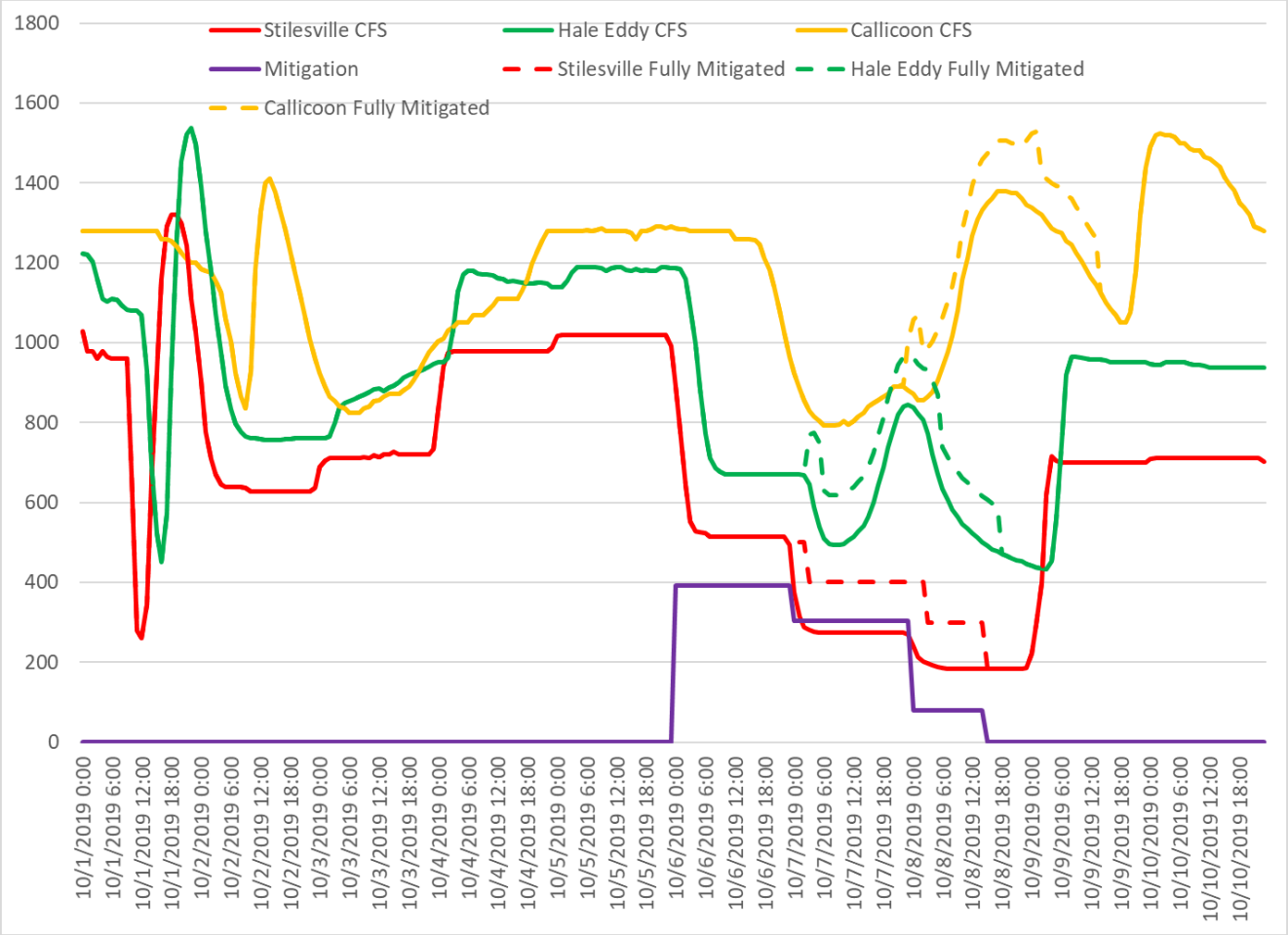


Figure 22. Implementation of the Recommended Alternative Protocol on 2019 RFC Event 1, 10/5/2019.

2) Event October 14, 2019 (Figure 13) – Implementing the Recommended Alternative Protocol would have equaled or improved achievement of all criteria. As with other protocol evaluation, the Stilesville criteria were not fully met in 72 hours because mitigation ended and flows reduced to the Lower Rate. The increased mitigation allowed for flows to remain higher during the flow gap event at Hale Eddy and Callicoon, reducing the drops in flows observed in other mitigation applications. Full implementation of the Current Protocol for this event more than doubled the required mitigation for this event by requiring an additional 397 cfs-days.

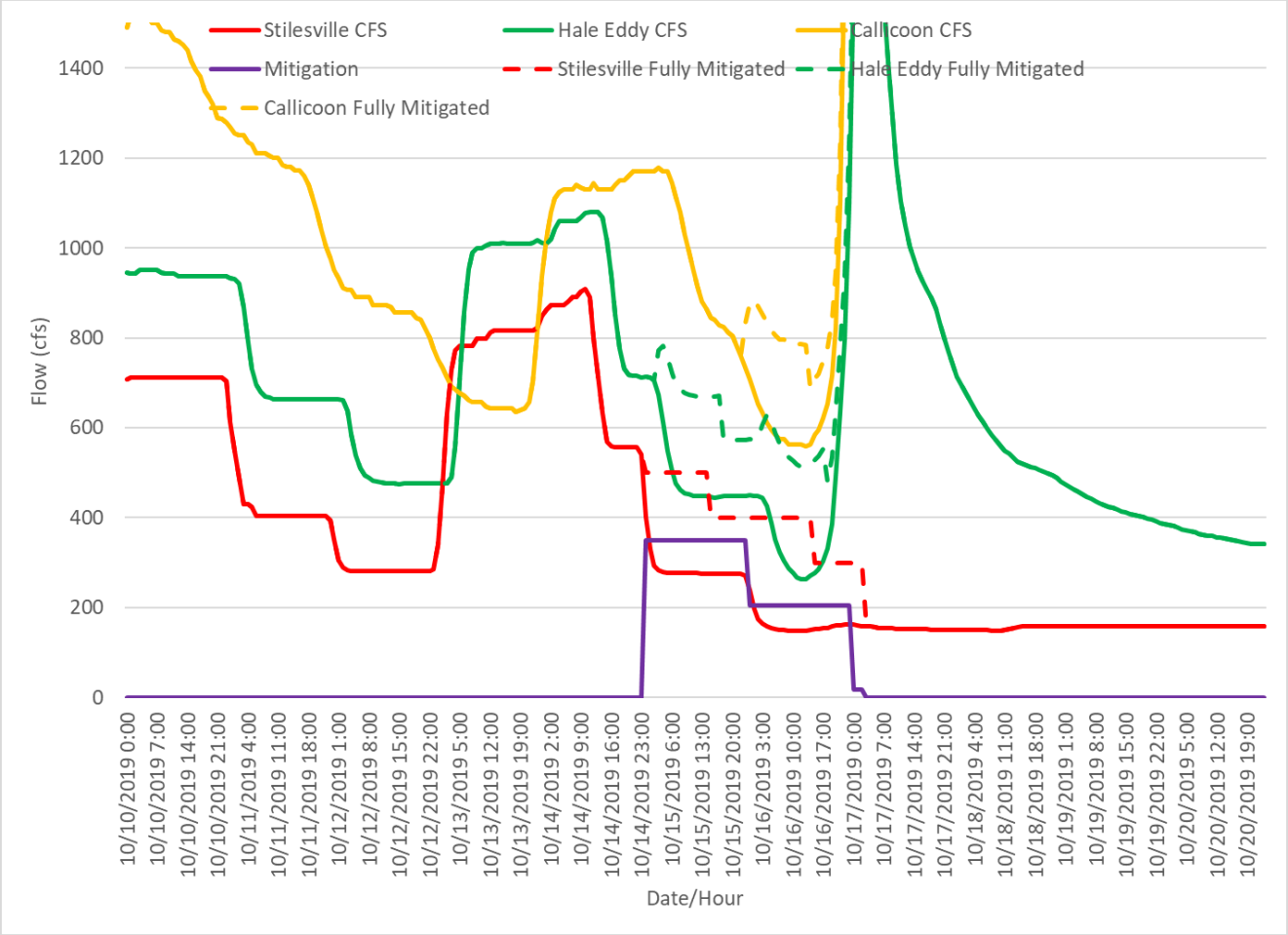


Figure 33. Implementation of the Recommended Alternative Protocol on 2019 RFC Event 2, 10/14/2019.

Evaluation of the non-mitigated RFC event in 2019

An additional event occurred in October 2019 that met the criteria to be considered as an RFC event, yet no mitigation was applied. The event occurred on 10/11/19 where flows dropped at Stilesville from ~700 cfs to ~430 cfs in a 5 hour period. This event qualified as an RFC event because it occurred during a change in directed releases, flows dropped below 500 cfs at Stilesville during the event, and a flow change of more than 250 cfs occurred in an 8 hour period. Based on correspondence with NYCDEP,[14] this event did not qualify for mitigation because it occurred when directed releases exceeded the conservation release value. Although that was true, that criteria is not explained in the Current Protocol, nor was that criteria conveyed to SEF prior to analysis of the Current Protocol against RFC events so SEF would still consider this event requiring RFC mitigation.

Mitigating this event would have increased the burden on the available mitigation bank by nearly 100 cfs-days if the Current Protocol was applied and nearly 200 cfs-days with the Recommended Alternative Protocol (Table 19). The Recommended Alternative Protocol did not improve achievement of downriver flow criteria compared to the Current Protocol for this event.

[14] B. Dramozos, NYCDEP email, November 26, 2019.

Table 19. Evaluation of performance of the Current Protocol and the Recommended Alternative Protocol on the unmitigated RFC event that occurred on 10/11/19.

Criteria		Current Protocol	Recommended Alternative Protocol
% Stilesville Criteria Achieved	48-hr	100%	100%
% Hale Eddy Criteria Achieved	48-hr	100%	100%
% Callicoon Criteria Achieved	48-hr	44%	44%
% Callicoon >560 cfs Achieved	48-hr	100%	100%
% Stilesville Criteria Achieved	72-hr	100%	100%
% Hale Eddy Criteria Achieved	72-hr	100%	100%
% Callicoon Criteria Achieved	72-hr	63%	63%
% Callicoon >560 cfs Achieved	72-hr	100%	100%
Stilesville dropped <200 cfs after mitigation		Y	Y
Additional Mitigation Needed (cfs-days)		99	196

Summary of 2019 mitigated RFC events and protocol implementation

Two mitigated RFC events that occurred in October 2019 that required significant amounts of water from the mitigation bank (~500 cfs-days each), and with full implementation of the Current Protocol, and would have slightly exceeded the available mitigation bank. The additional event that was not mitigated would have added another ~100 cfs-day demand on the bank. Actual implementation and full implementation of the Current Protocol for these events were not successful in fully achieving all evaluation criteria, particularly for Callicoon flows. This is likely a result of low rainfall conditions in the fall of 2019 that lead to high sustained ORDM directed releases to meet the flow targets at Montague and little tributary input. In many years, 500 cfs releases from Cannonsville is sufficient to maintain high flows (i.e. 930 cfs) at Callicoon, however, that was not the case in 2019. Similar flow conditions were experienced in the fall of 2016, preceding declared drought conditions. The RFC mitigation was at its highest demand during 2016 for the 10-year time series (2008-2019). It appears that 2019 was another high demand year, and if the Current Protocol was fully implemented for all three events, the demand on the mitigation bank (1,119 cfs-days) would have been higher than what was required during 2016 (934 cfs-days).

During periods of low rainfall, river conditions would likely have naturally been much lower than flows that are sustained by the ORDM to maintain the Montague flow target. These high flows interspersed with drops in flow of short duration do have a negative impact on carrying capacity of the aquatic community, but at the same time, the carrying capacity may have been lower during this time if the river were managed under more natural conditions. During periods of low rainfall, achievement of the Callicoon flow criteria based on releases from Cannonsville is not likely and should probably not be expected. The focus during these times should be to the gradual decreasing of flows in the West Branch (i.e. Stilesville and Hale Eddy) so that mobile aquatic species have the opportunity to vacate habitats that are likely to be dewatered.

Implementation of the Recommended Alternative Protocol for the three 2019 RFC events would have more greatly exceeded the available mitigation bank (1,543 cfs-days) compared to the Current Protocol (1,119 cfs-days). The Alternative Protocol did provide some increased downriver protections and prolonged the transition to lower flows in the West Branch, but did so at a higher water cost.

SUMMARY AND RECOMMENDATIONS

SEF implemented a set of criteria to identify an RFC event over the 10-year time series of data from 2008-2017. The criteria included identifying events where flows dropped below 500 cfs at Stilesville, flows changed more than 250 cfs over an 8-hour period, and association with a change or cessation in directed releases from the ODRM. Further refinement of the criteria eliminated events that had a very short-term (usually 2 days or less) increase and then decrease in flows, as establishment of aquatic communities into the newly available habitats would likely not occur that quickly. SEF recommends the following criteria be used to identify future RFC events requiring mitigation:

1) The event must occur during a change in an ODRM directed release, or within 2 days of the end of an ODRM directed release;
2) The flows at the USGS Stilesville gage dropped or will drop below 500 cfs in association with a change in ODRM directed release;
3) The rate of flow reduction is expected to be $\geq$250 cfs over an 8-hour period during a time associated with a change in ODRM directed release;
4) The minimum flow for the 24-hours post-RFC event (i.e. lower rate) will be less than 90% of the median 5-day flow prior to the event; and
5) The RFC event occurs during normal (non-drought) operating conditions.

Evaluation of RFC events that were identified using these criteria was completed using standardized post-event flow data based on the 2017 FFMP. The 2017 FFMP improved post-event flow conditions on more than half of the events and eliminated the need for mitigation on three previously identified RFC events during the 10-year time series, resulting in 2.7 RFC events on-average occurring annually. Evaluation of the Current Protocol described in the 2017 FFMP against downriver criteria established by the SEF, demonstrated improvement in meeting evaluation criteria over non-mitigated events, but did not achieve 100% satisfaction of all criteria, for all events, in the time series. The Current Protocol did remain within total the RFC Mitigation Bank allotment of 1,000 cfs-days annually during the entire time series. The Wait-for-the-Rain Protocol did show some improvements in achieving downriver criteria over the Current Protocol, but the protocol also allowed for significant drops in flow at Stilesville post-mitigation. The Wait-for-the-Rain Protocol also exceeded RFC Mitigation Bank allotment in 4 years, using about 50% more water than the Current Protocol. An alternative protocol was evaluated that was similar to the Current Protocol, but implemented 100 cfs drop after day 1 and day 2 and held flows on day 3 for 12 hours before dropping to the low flow condition. This alternative protocol improved achievement of downriver criteria over the Current Protocol and stayed within, or nearly so, the annual allotment of the RFC Mitigation Bank in all years. A second alternative protocol was evaluated that had high achievement for all evaluation criteria. To meet high achievement of all criteria, a protocol would require about 3,000 cfs annually in a RFC Mitigation Bank.

Based on the available mitigation bank of 1,000 cfs-days, SEF recommends the following mitigation (i.e., SS6) be implemented for future RFC events.

3. If the Cannonsville release is above or equal to 700 cfs
    a. The release shall be lowered to 500 cfs for the first day (0-24 hours)
    b. The release shall be lowered to 400 cfs for the second day (25-48 hours)
    c. The release shall be lowered to 300 cfs for the first half of the third day (49-60 hours)
    d. Normal operations would apply starting on the second half of the third day (hour 61 post-event) when the Lower Rate would be released.

e. If at any time during this procedure, the Lower Rate is higher than the specified mitigation rate, the Lower Rate should be applied.

4. If the Cannonsville release is above 450 cfs but less than 700 cfs
    a. The release shall be lowered to 300 cfs for the first day (0-24 hours)
    b. The release shall be lowered to 200 cfs for the second day (25-48 hours)
    c. The release shall be lowered to 100 cfs for the first half of the third day (49-60 hours)
    d. Normal operations would apply starting on the second half of the third day (hour 61 post-event) when the Lower Rate would be released.
    e. If at any time during this procedure, the Lower Rate is higher than the specified mitigation rate, the Lower Rate should be applied.

Evaluation of 2019 data was also conducted, and full implementation of the Current Protocol would have slightly exceeded the available mitigation bank and implementation of the recommended alternative protocol (below) would have exceeded the bank by ~500 cfs-days. Despite this potential exceedance, SEF continues to recommend the alternative protocol, as it could be fully implemented in most years based on available data.

SEF also recommends that the protocol be fully implementing beginning on the first RFC event of the year and continue to be fully implemented through the remaining RFC events, with priority on fully exhausting the available bank, versus preservation of the bank for potential future events.

STRATEGIC NEXT STEPS

Surface water elevation data is needed to better evaluate amount of habitat available under varying flow conditions. Fully-wetted conditions, used in this report as criteria for evaluating success of a given protocol, were established based on best professional judgement for the West Branch, and based on a dwarf mussel research paper for Callicoon. Fully-wetted flows are unknown for other locations in the West Branch and Delaware River main stems (i.e. between Stilesville and Lordville) and protecting the three locations identified in this report may or may not be sufficient to protect all habitats in the West Branch and Delaware River main stem. Also, the degree to which available habitat is lost under less than fully-wetted conditions may influence decision making on the best alternative protocol to apply in the future. A model should be developed incorporating surface water elevations at various locations under various flow conditions to better evaluate the ramifications of habitat loss under different RFC mitigation protocols. Capability exists within the original DSS and its successor, REFDSS, for inferring aquatic community habitat availability relative to flow rates. Further investigation is needed to get the DSS/REFDSS operational and potentially have supporting bathymetry address inundation of the Delaware tailwaters.

ATTACHMENTS AND APPENDICES

Attachment 1.

Regulated Flow Advisory Committee Charge to the Subcommittee on Ecological Flows

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Delaware River Basin Commission
25 Cosey Road
PO Box 7360
West Trenton, New Jersey
08628-0360
Phone: (609) 883-9500 Fax: (609) 883-9522
Web Site: http://www.drbc.net

Steven J. Tambini, P.E.
Executive Director

Regulated Flow Advisory Committee Charge to the Subcommittee on Ecological Flows

In accordance with Resolution 2018-2, the Regulated Flow Advisory Committee hereby tasks the Subcommittee on Ecological Flows with review of the guidelines for use of the Thermal Mitigation Bank and the Rapid Flow Change Mitigation Bank specified in the Flexible Flow Management Program of 2017. The guidelines were developed by the New York Department of Conservation and the Pennsylvania Fish and Boat Commission. The Commission seeks to provide information to inform the Decree Parties about the use of these banks in relation to ecological resources and whether potential adjustments to the proposed guidelines may be necessary. The reviews should consist of:

- collection and synthesis of information related to the habitat, flow, and temperature needs of fish and other species of concern in the tailwaters of Cannonsville, Pepacton, Neversink and the Delaware River above Lordville;
- documentation of the known relationships between flow characteristics (temperature, seasonality, velocity and depth), groundwater-surface water interactions, channel morphology, shade/tree cover and other parameters that may influence the health of the species;
- recommendations for adjustments to the guidelines as warranted; and
- if deemed necessary, exploration of alternate approaches for supporting ecological needs within the framework of the Rapid Flow Change and Thermal mitigation programs.

As the water resources of the DRB are finite, all recommendations should consider the many demands for their use. RFAC requests that SEF meet to develop a work plan and schedule, a list of experts to be consulted, and assignments for members of SEF. Such assignments may include, but not be limited to:

- conducting literature reviews (journal articles, published reports);
- developing annotated bibliographies of materials reviewed;
- soliciting expert opinions or participation of experts in SEF dialogue;
- modeling habitat with the DSS;
- writing report sections; and
- other tasks as identified.

RFAC requests that a draft assessment of the guidelines and proposed adjustments be completed no later than May 31, 2019. This charge represents the first task to SEF and it is anticipated that SEF will continue to explore additional topics after the completion of this charge. Future topics may potentially be derived from the findings of this charge.

Attachment 2

Interim Guidance for Rapid Flow Change Mitigation

Interim Guidance for Rapid Flow Change Mitigation

2017 Flexible Flow Management Program

Version 1: May 2018

During periods of low baseflow on the Delaware River, releases from the New York City reservoirs directed by the Office of the Delaware River Master (ODRM) to meet the Montague Flow Objective can be significantly higher than the base releases specified in the 2017 Flexible Flow Management Program (FFMP2017). Under these circumstances, when sudden increases in streamflow at Montague are projected, the directed release can be significantly reduced over very short periods of time, sometimes to zero. The implementation of such a rapid reduction of release from Cannonsville Reservoir can result in very abrupt reductions in streamflow and may have a negative effect on the aquatic habitat of the West Branch and main stem of the Delaware River. Section 3.c.iii of Appendix A of the 2017 FFMP designates a dedicated Rapid Flow Change Mitigation (RFCM) bank for the partial amelioration of these potentially negative effects. This document describes a procedure intended as an interim guidance and is expected to be replaced or updated after additional experience is gained and/or future studies on the subject are completed.

Use of the Rapid Flow Change Mitigation bank shall be made as follows, unless otherwise specified by the Decree Parties:

5. The application of the RFCM procedure shall not result in any release that is not sufficient to meet the Montague Flow Objective or maintain the minimum release required by the 2017 FFMP.

6. The term “Lower Rate” as used below means the higher of the applicable L1 or L2 release rate from Table 4 of the 2017 FFMP and the new release rate required to meet the Montague Flow Objective computed by the ODRM.

7. If the current Cannonsville release is above or equal to 700 cfs because of additional releases directed by the Office of the Delaware River Master for the purpose of meeting the Montague Flow Objective, then releases should not be immediately reduced to the Lower Rate. Instead:
    a. Normal operations would apply starting on the first day if the Lower Rate is above or equal to 500 cfs.
    b. If the Lower Rate is below 500 cfs, the release shall be lowered to 500 cfs for the first day after directed releases are discontinued or significantly reduced.
    c. Normal operations would apply starting on the second day if the Lower Rate is above or equal to 300 cfs.

d. If the Lower Rate is below 300 cfs, the releases will be reduced to 300 cfs for the second day. Normal operations would apply starting on the third day when the Lower Rate would be released.

8. If the current Cannonsville release is above 450 cfs and below 700 cfs because of additional releases directed by the Office of the Delaware River Master for the purpose of meeting the Montague Flow Objective, and the Lower Rate is below 300 cfs then releases should not be immediately reduced to the Lower Rate. The release shall be reduced to 300 cfs for the first day after directed releases are discontinued or significantly reduced. Normal operations would apply starting on the second day when the Lower Rate would be released.

9. Only the actual quantity of water required to be released to meet the intermediate reduction(s) in release rate in excess of the Lower Rate shall be debited from the Rapid Flow Change Mitigation bank.

10. The quantity of water and ramping schedule will be calculated by the New York City Department of Environmental Protection and reported to ODRM. ODRM will provide regular reporting to the Decree Parties and the Delaware River Basin Commission on the status and availability of the RFCM bank.

11. The total volume of the RFCM releases shall not exceed the total volume of the RFCM bank. RFCM releases shall cease when the volume of the bank is exhausted. If Step 3 (or 4) above would otherwise apply to a release reduction but there is insufficient water remaining in the RFCM bank to meet the target release(s), then the Step 3 (or 4) target release(s) shall be made until the volume of the bank is exhausted.

Appendix A. Rapid Flow Change (RFC) events that occurred at the Cannonsville Reservoir as identified by the Stilesville USGS gaging station from 2008-2017. A total of five days following the peak flow at the start of the RFC event are listed to illustrate daily flow reductions. Median flow for 5 days prior to the event compared to minimum flows within 24 hours after the event are also included (*).

RFC Event #	RFC Event Start Date	RFC Event Start Hour	RFC Event Start CFS	Actual CFS +24Hr Post Event	Actual CFS +48Hr Post Event	Actual CFS +72Hr Post Event	Actual CFS +96Hr Post Event	Median CFS 5-days prior	Min. CFS within 24Hr Post Event	Event Flow Change*
1	6/14/2008	23:00	507	259	259	259	256	418	259	-38%
2	7/5/2008	23:00	507	262	321	262	283	256	259	1%
3	7/12/2008	23:00	822	266	259	259	259	285	259	-9%
4	7/19/2008	23:00	851	312	330	259	263	259	303	17%
5	9/4/2008	17:00	863	100	105	101	101	642	100	-84%
6	9/12/2008	17:00	518	104	102	103	102	102	104	2%
7	9/26/2008	18:00	462	112	115	110	111	763	112	-85%
8	10/23/2008	18:00	976	89	92	89	103	824	89	-89%
9	10/8/2009	18:00	709	336	336	557	413	336	336	0%
10	10/22/2009	17:00	703	341	355	345	345	456	336	-26%
11	7/2/2010	22:00	773	510	350	372	478	423	510	21%
12	8/22/2010	23:00	734	354	304	304	300	860	354	-59%
13	9/26/2010	15:00	969	134	138	134	163	936	134	-86%
14	9/1/2012	18:00	716	350	350	350	350	471	350	-26%
15	9/16/2012	16:00	1190	326	345	326	326	511	326	-36%
16	10/6/2013	15:00	1300	259	227	322	232	910	247	-73%
17	10/17/2013	23:00	601	313	417	267	332	478	307	-36%
18	11/3/2013	19:00	671	177	145	143	149	567	177	-69%
19	11/10/2013	16:00	609	145	145	145	266	221	145	-34%
20	11/25/2013	19:00	504	139	144	143	143	232	139	-40%
21	8/31/2014	14:00	897	458	737	588	396	567	450	-21%
22	10/15/2014	22:00	885	172	168	168	168	1100	172	-84%
23	11/4/2014	15:00	780	138	522	750	897	380	138	-64%
24	11/20/2014	0:00	923	490	631	556	332	936	482	-49%
25	9/8/2015	23:00	956	394	407	407	413	763	394	-48%
26	9/28/2015	10:00	1245	320	326	269	135	1260	313	-75%
27	10/26/2015	10:00	876	309	129	138	132	898	157	-83%
28	9/16/2016	23:00	1388	494	363	296	1070	1230	479	-61%
29	9/28/2016	16:00	715	290	542	419	639	515	273	-47%
30	10/4/2016	11:00	512	188	136	300	211	536	123	-77%
31	10/19/2016	23:00	810	164	1093	687	703	1070	164	-85%
32	10/25/2016	23:00	834	150	1113	284	555	719	150	-79%
33	10/27/2016	22:00	1120	278	562	504	471	687	278	-59%
34	11/27/2016	10:00	589	108	89	80	80	594	108	-82%
35	9/16/2017	18:00	677	293	223	566	335	299	293	-2%
36	10/7/2017	23:00	1010	150	540	810	770	1050	149	-86%
37	10/22/2017	23:00	776	303	709	657	768	969	303	-69%
38	10/26/2017	23:00	768	299	167	166	154	683	299	-56%

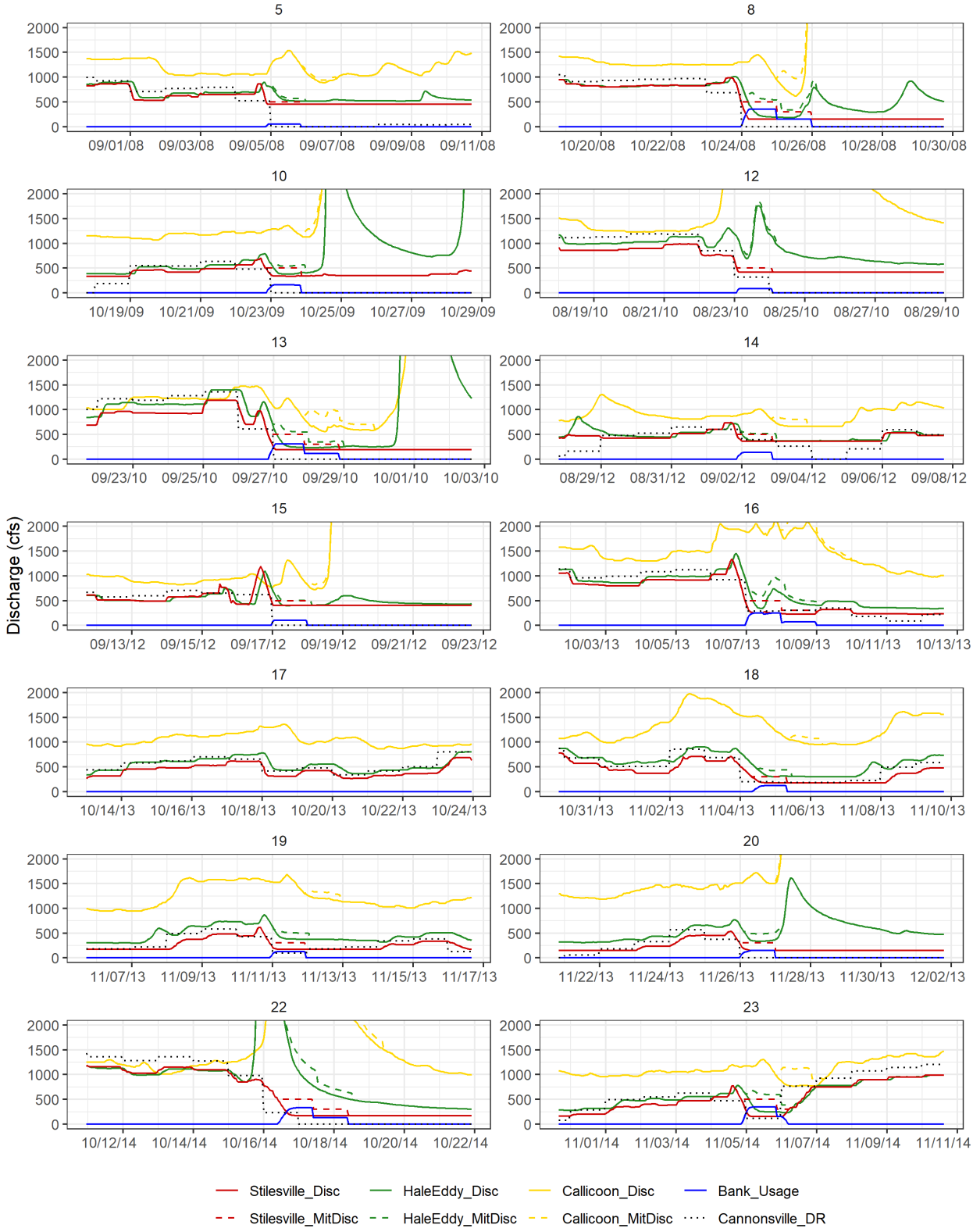
Appendix B. Application of the current RFC protocol to the 39 identified RFC events and their subsequent predicted bank usage and hours of achievement of downriver mitigation criteria during the first 48 hours post-RFC event.

RFC Event #	Required Mitigation (cfs)	Proportion of hours Stilesville achieved within 48 hours	Proportion of hours Hale Eddy achieved within 48 hours	Proportion of hours Callicoon achieved within 48 hours	Proportion of hours Callicoon >560 within 48 hours
1	39	56%	77%	100%	100%
2	35	100%	100%	10%	100%
3	259	100%	100%	100%	100%
4	179	100%	100%	100%	100%
5	538	100%	100%	50%	100%
6	164	100%	100%	100%	100%
7	170	56%	56%	100%	100%
8	572	100%	100%	96%	100%
9	149	100%	100%	100%	100%
10	146	100%	100%	100%	100%
11	131	100%	100%	52%	100%
12	139	100%	100%	100%	100%
13	490	100%	100%	23%	100%
14	139	100%	100%	0%	100%
15	165	100%	100%	67%	100%
16	305	100%	100%	100%	100%
17	0	100%	100%	100%	100%
18	111	75%	75%	90%	100%
19	137	63%	100%	100%	100%
20	143	58%	100%	100%	100%
21	26	100%	100%	98%	100%
22	406	100%	100%	100%	100%
23	359	100%	98%	92%	100%
24	7	100%	100%	100%	100%
25	107	100%	100%	8%	100%
26	173	100%	100%	92%	100%
27	398	100%	100%	100%	100%
28	60	100%	100%	100%	100%
29	195	100%	100%	44%	100%
30	129	54%	54%	0%	60%
31	270	100%	94%	85%	100%
32	277	100%	98%	100%	100%
33	64	58%	100%	67%	100%
34	153	58%	100%	100%	100%
35	6	67%	79%	17%	100%
36	269	100%	100%	92%	100%
37	35	100%	100%	50%	100%
38	204	100%	100%	67%	100%
39	302	100%	100%	67%	100%

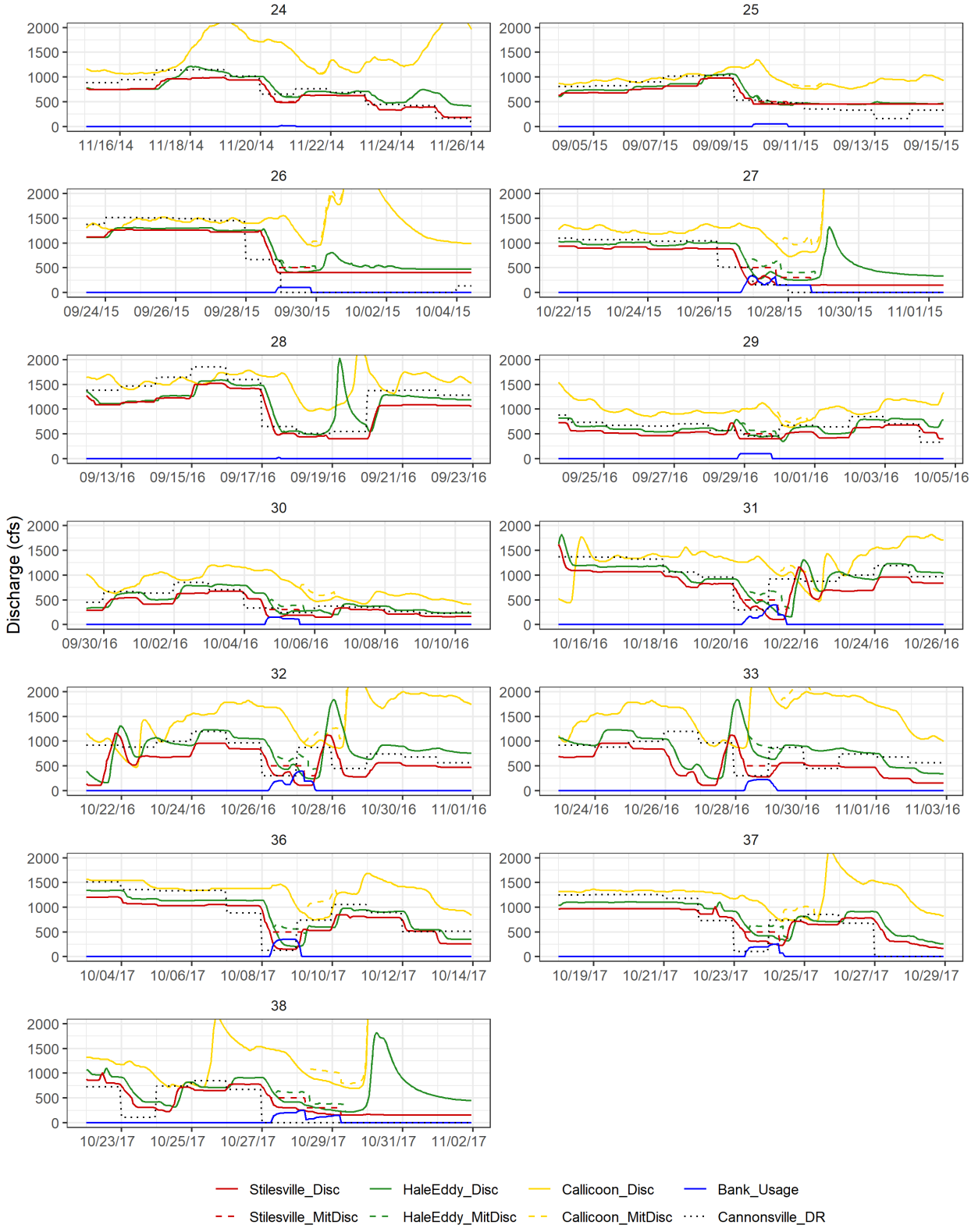
Appendix C. Performance of Alternate Mitigation Protocol SS18 using the 2017 FFMP standardized flow data from 2008-2017.

Event	% Stilesville Criteria Achieved 48-hr	% Hale Eddy Criteria Achieved 48-hr	% Callicoon Criteria Achieved 48-hr	% Callicoon 560 cfs Achieved 48-hr	% Stilesville Criteria Achieved 72-hr	% Hale Eddy Criteria Achieved 72-hr	% Callicoon Criteria Achieved 72-hr	% Callicoon 560 cfs Achieved 72-hr	Stilesville dropped <200 cfs after mitigation	Mitigatio by Event (cfs-days
5	100%	100%	100%	100%	100%	100%	100%	100%	Y	1473
8	100%	100%	100%	100%	100%	100%	100%	100%	Y	3162
10	100%	100%	100%	100%	100%	100%	100%	100%	N	2015
12	100%	100%	100%	100%	100%	100%	100%	100%	Y	1694
13	100%	100%	**98%**	100%	100%	100%	**99%**	100%	Y	2944
14	100%	100%	100%	100%	100%	100%	100%	100%	N	1758
15	100%	100%	100%	100%	100%	100%	100%	100%	Y	1723
16	100%	100%	100%	100%	100%	100%	100%	100%	Y	2547
17	100%	100%	100%	100%	100%	100%	100%	100%	N	1883
18	100%	100%	100%	100%	100%	100%	100%	100%	N	2604
19	100%	100%	100%	100%	100%	100%	100%	100%	N	2788
20	100%	100%	100%	100%	100%	100%	100%	100%	N	3233
22	100%	100%	100%	100%	100%	100%	100%	100%	Y	2910
23	100%	100%	100%	100%	100%	100%	100%	100%	N	849
24	100%	100%	100%	100%	100%	100%	100%	100%	Y	1442
25	100%	100%	100%	100%	100%	100%	100%	100%	Y	1401
26	100%	100%	100%	100%	100%	100%	100%	100%	Y	1687
27	100%	100%	100%	100%	100%	100%	100%	100%	Y	3075
28	100%	100%	100%	100%	100%	100%	100%	100%	Y	719
29	100%	100%	**98%**	100%	100%	100%	**99%**	100%	Y	1077
30	100%	100%	100%	100%	100%	100%	**96%**	100%	N	2902
31	100%	100%	100%	100%	100%	100%	100%	100%	Y	620
32	100%	100%	100%	100%	**82%**	100%	100%	100%	Y	647
33	100%	100%	100%	100%	100%	100%	100%	100%	Y	1852
36	100%	100%	**96%**	100%	100%	100%	**97%**	100%	Y	608
37	100%	100%	**85%**	100%	100%	100%	**90%**	100%	Y	531
38	100%	100%	100%	100%	100%	100%	100%	100%	Y	2969
Avg	100%	100%	99%	100%	99%	100%	99%	100%	70%	1893
Min	100%	100%	85%	100%	82%	100%	90%	100%		531
Max	100%	100%	100%	100%	100%	100%	100%	100%		3233

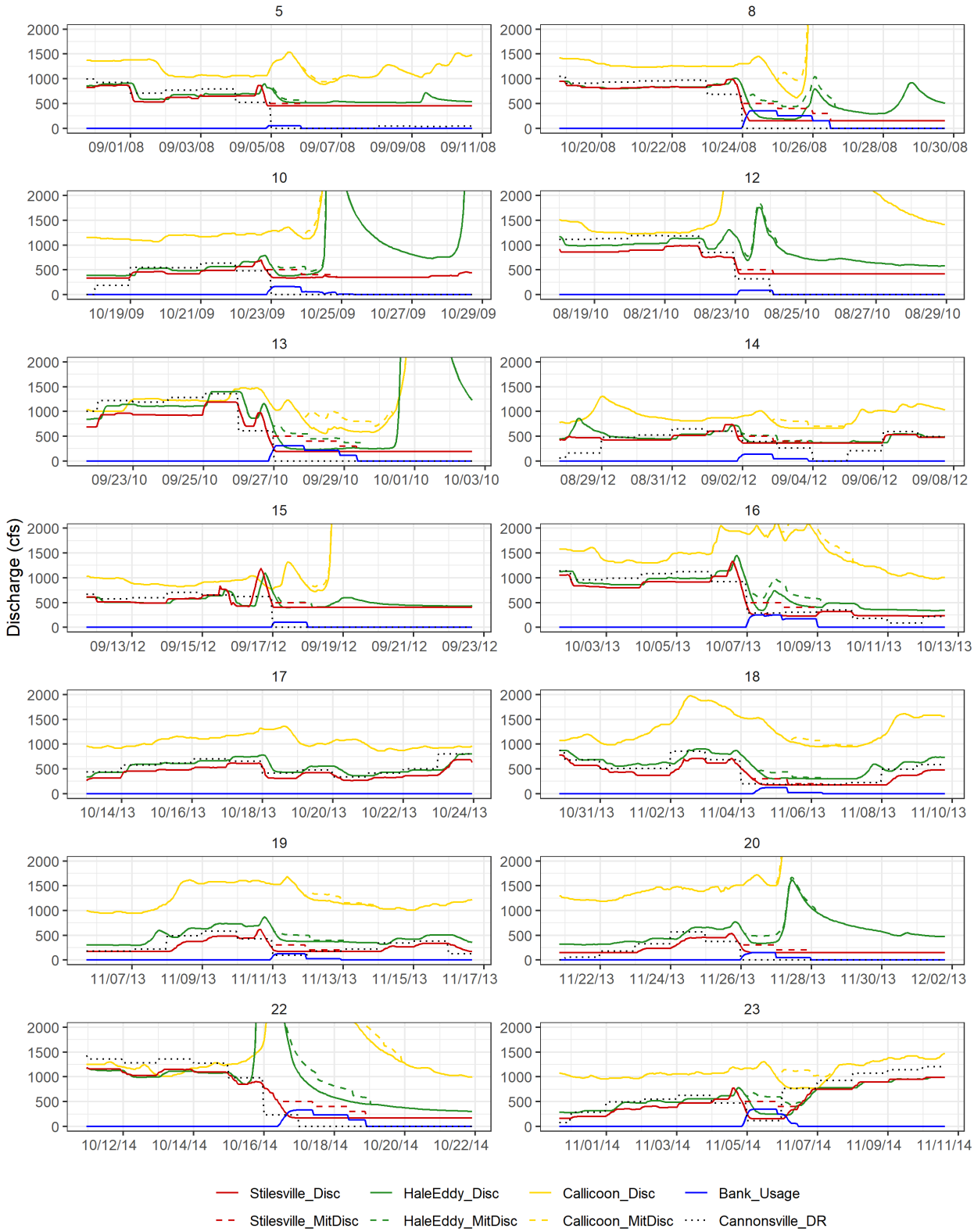
Appendix D. Current Protocol (SS1) applied to 27 RFC events using 2017 FFMP standardized flows.



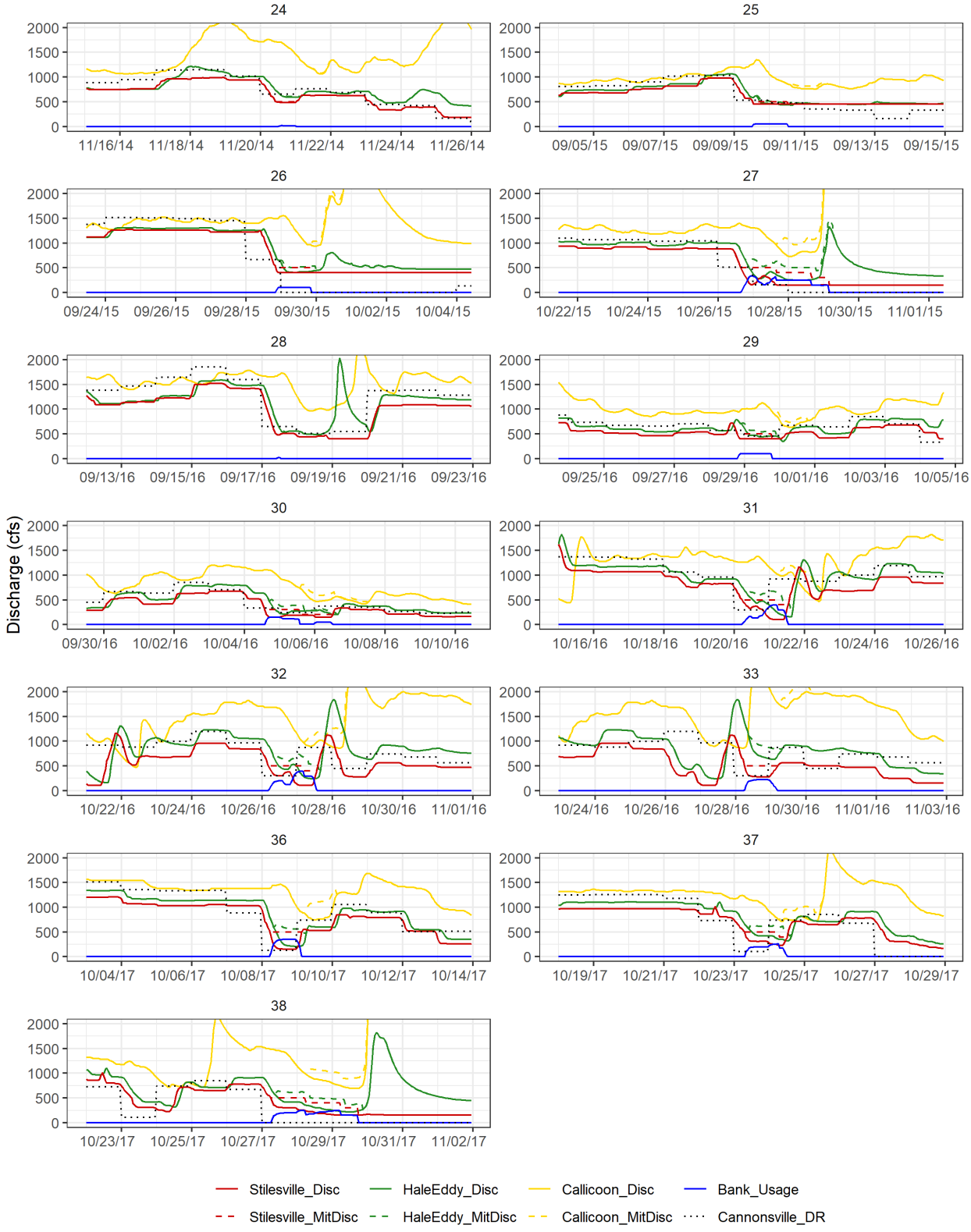
Appendix D. Continued.



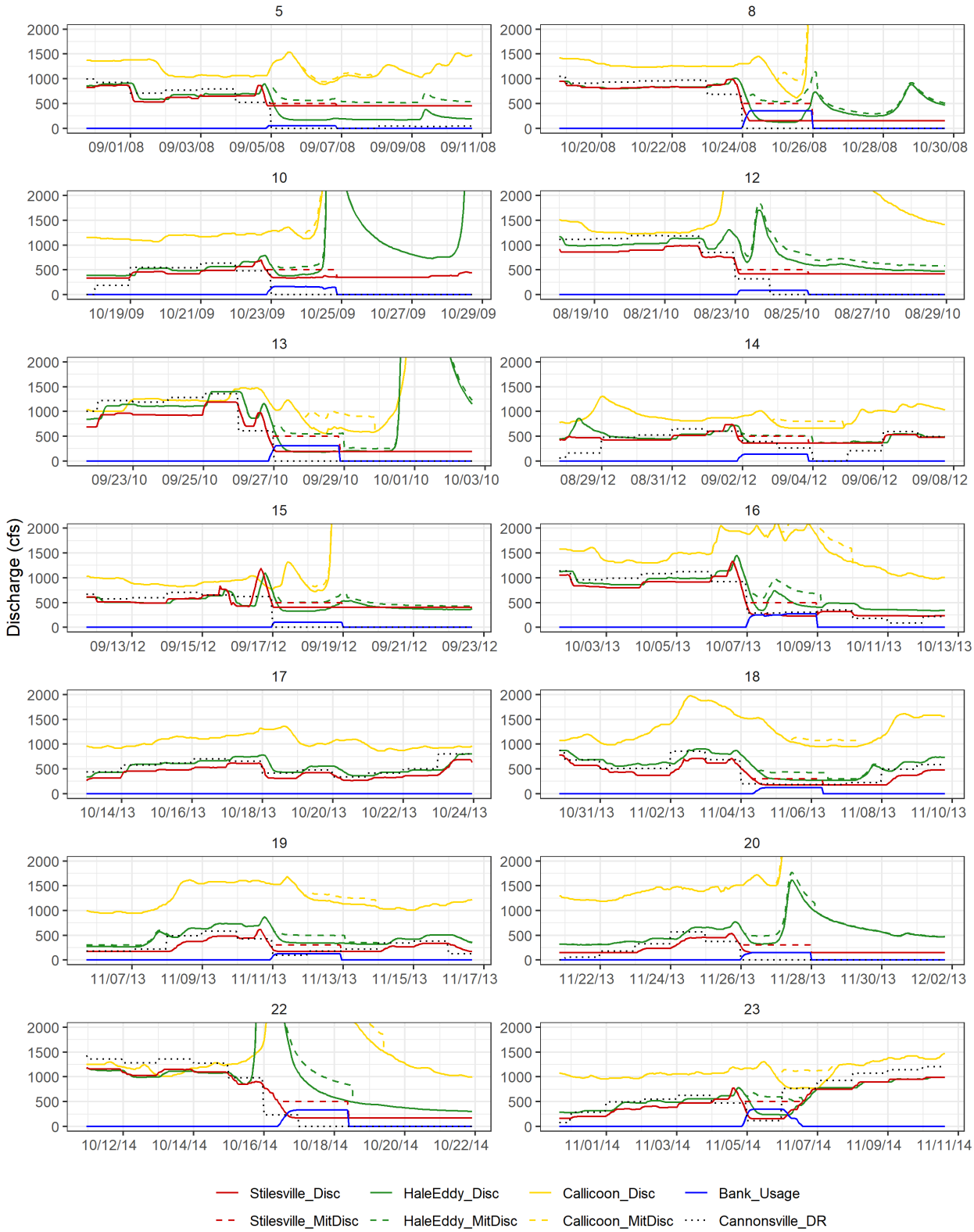
Appendix E. Best protocol for the available mitigation bank size (Protocol SS6) applied to 27 RFC events using updated 2017 FFMP standardized flows.



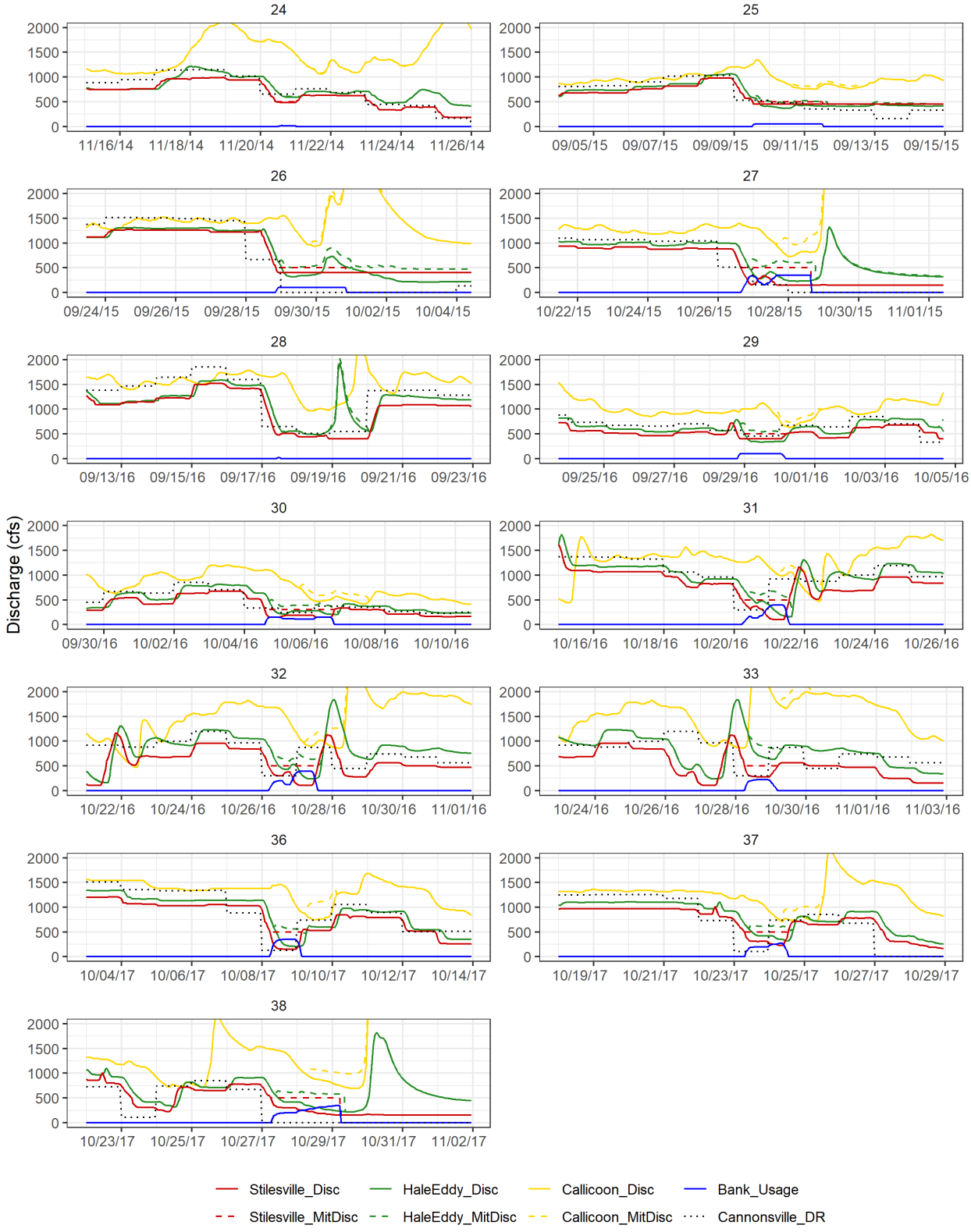
Appendix E. Continued.



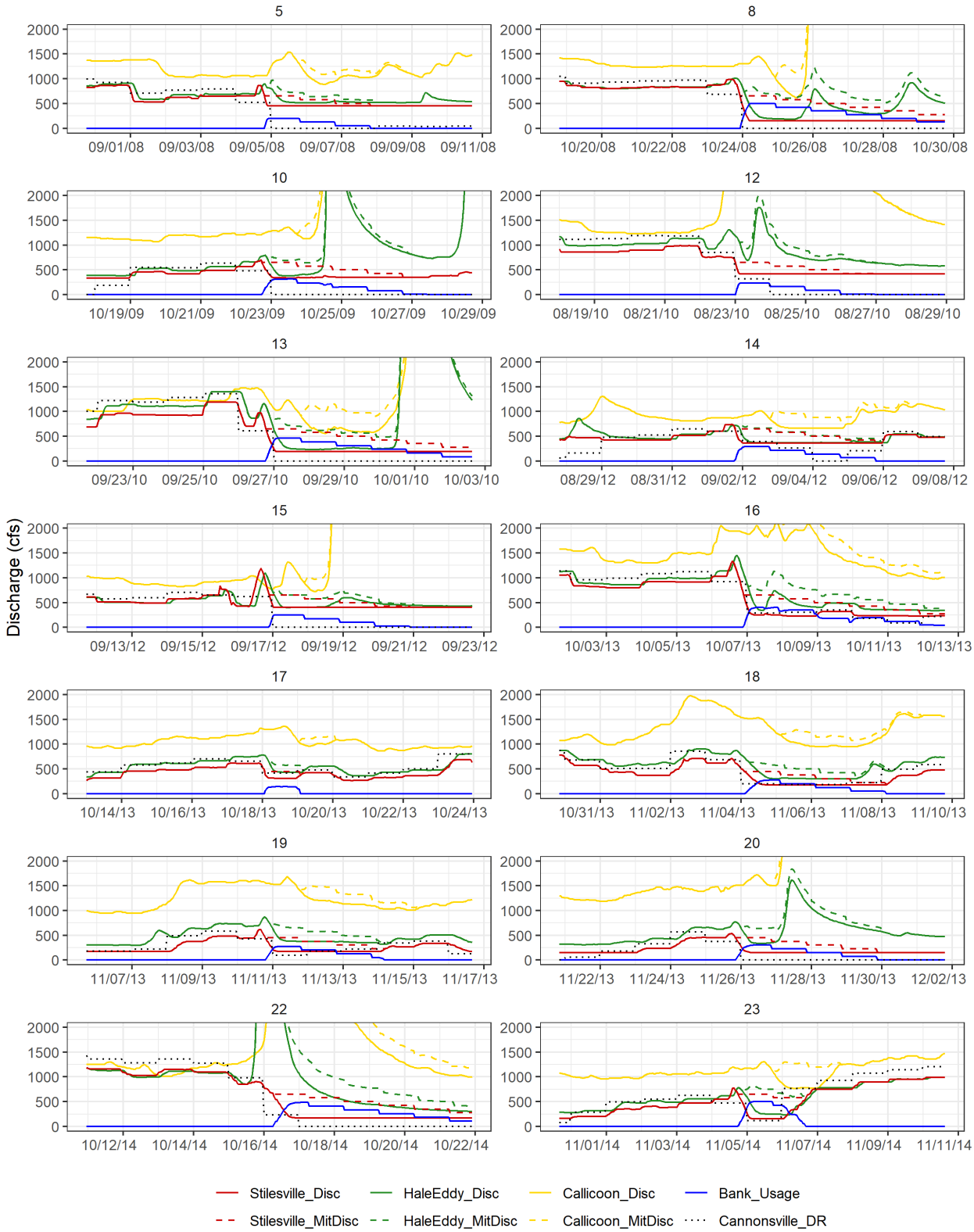
Appendix F. Wait-for-the-Rain Protocol (SS2) applied to 27 RFC events using updated 2017 FFMP standardized flows.



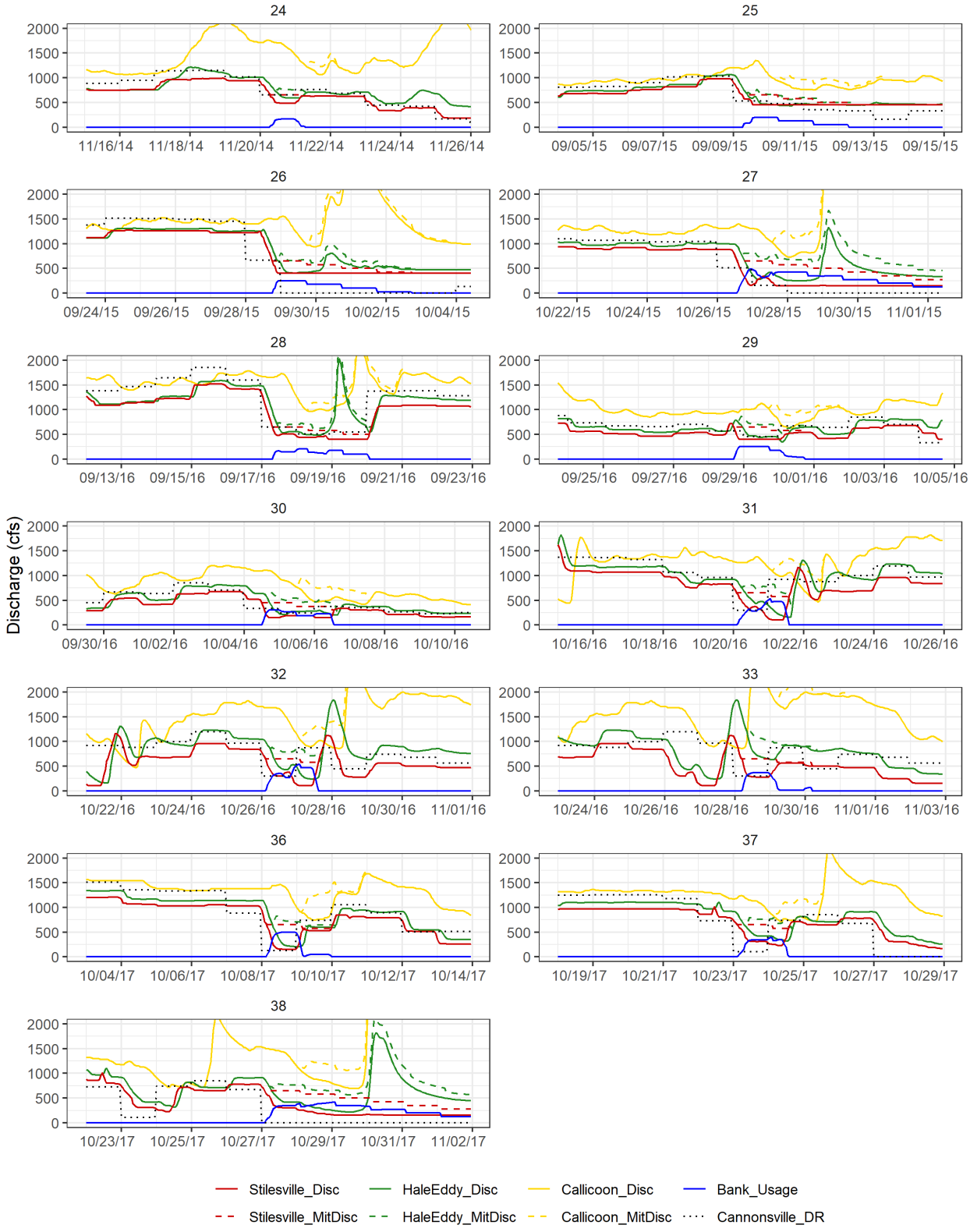
Appendix F. Continued.



Appendix G. Best protocol for achieving evaluation criteria (Protocol SS17) applied to 27 RFC events using updated 2017 FFMP standardized flows.



Appendix G. Continued.



Appendix H. Comparison of downriver criteria achievement by event for the Current Protocol (SS1), the WFTR Protocol (SS2), the best protocol for the available mitigation bank (SS6) and the best protocol for achieving evaluation criteria (SS17).

Protocol	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17
Downriver Criteria		**Event 8**				**Event 13**				**Event 14**		
% hrs Stilesville achieved in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Hale Eddy achieved in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Callicoon achieved in 48 hrs	100%	100%	100%	100%	***35%***	***48%***	***35%***	***98%***	***0%***	***0%***	***0%***	***48%***
% hrs Callicoon >560 in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Stilesville achieved in 72 hrs	***74%***	***74%***	***90%***	100%	***74%***	***74%***	***90%***	100%	100%	100%	100%	100%
% hrs Hale Eddy achieved in 72 hrs	100%	100%	100%	100%	***74%***	***74%***	***90%***	100%	100%	100%	100%	100%
% hrs Callicoon achieved in 72 hrs	100%	100%	100%	100%	***33%***	***42%***	***38%***	***93%***	***18%***	***18%***	***18%***	***58%***
% hrs Callicoon >560 in 72 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Stilesville dropped >200 cfs post-mitigation	N	***Y***	N	N	N	***Y***	N	N	N	N	N	N
Mitigation by Event (cfs)	469	669	644	1806	397	597	552	1572	132	272	172	684

Protocol	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17
Downriver Criteria		**Event 15**				**Event 16**				**Event 18**		
% hrs Stilesville achieved in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	***75%***	100%	***75%***	100%
% hrs Hale Eddy achieved in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	***75%***	100%	100%	100%
% hrs Callicoon achieved in 48 hrs	***75%***	***75%***	***75%***	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Callicoon >560 in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Stilesville achieved in 72 hrs	100%	100%	100%	100%	***97%***	***97%***	100%	100%	***50%***	***83%***	***50%***	100%
% hrs Hale Eddy achieved in 72 hrs	100%	100%	100%	100%	100%	100%	100%	100%	***50%***	***83%***	***83%***	100%
% hrs Callicoon achieved in 72 hrs	***83%***	***83%***	***83%***	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Callicoon >560 in 72 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Stilesville dropped >200 cfs post-mitigation	N	N	N	N	N	***Y***	N	N	N	N	N	N
Mitigation by Event (cfs)	99	199	99	535	305	505	407	1229	106	231	131	589

Appendix H. Continued

Protocol	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17
Downriver Criteria		**Event 19**				**Event 20**				**Event 22**		
% hrs Stilesville achieved in 48 hrs	***63%***	100%	***63%***	100%	***58%***	100%	***58%***	100%	100%	100%	100%	100%
% hrs Hale Eddy achieved in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Callicoon achieved in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Callicoon >560 in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Stilesville achieved in 72 hrs	***42%***	***75%***	***42%***	100%	***39%***	***72%***	***39%***	100%	***82%***	***82%***	***99%***	100%
% hrs Hale Eddy achieved in 72 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Callicoon achieved in 72 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Callicoon >560 in 72 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Stilesville dropped >200 cfs post-mitigation	N	N	N	N	N	N	N	N	N	***Y***	N	N
Mitigation by Event (cfs)	118	243	143	586	137	287	187	711	406	606	572	1624

Protocol	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17
Downriver Criteria		**Event 23**				**Event 25**				**Event 27**		
% hrs Stilesville achieved in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Hale Eddy achieved in 48 hrs	***98%***	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Callicoon achieved in 48 hrs	***83%***	100%	100%	100%	***17%***	***17%***	***17%***	***92%***	100%	100%	100%	100%
% hrs Callicoon >560 in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Stilesville achieved in 72 hrs	100%	100%	100%	100%	100%	100%	100%	100%	***74%***	***74%***	***90%***	100%
% hrs Hale Eddy achieved in 72 hrs	***99%***	100%	100%	100%	100%	100%	100%	100%	***96%***	***96%***	100%	100%
% hrs Callicoon achieved in 72 hrs	***89%***	100%	100%	100%	***11%***	***11%***	***11%***	***64%***	100%	100%	100%	100%
% hrs Callicoon >560 in 72 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Stilesville dropped >200 cfs post-mitigation	N	N	N	N	N	N	N	N	N	***Y***	N	N
Mitigation by Event (cfs)	350	465	400	673	50	100	50	346	379	579	553	1703

Appendix H. Continued.

Protocol	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17
Downriver Criteria		**Event 29**				**Event 30**				**Event 31**		
% hrs Stilesville achieved in 48 hrs	100%	100%	100%	100%	***54%***	100%	***54%***	100%	100%	100%	100%	100%
% hrs Hale Eddy achieved in 48 hrs	100%	100%	100%	100%	***54%***	100%	***60%***	100%	***94%***	100%	***96%***	100%
% hrs Callicoon achieved in 48 hrs	***46%***	***48%***	***46%***	***79%***	***0%***	***0%***	***0%***	***6%***	***85%***	***88%***	***85%***	***98%***
% hrs Callicoon >560 in 48 hrs	100%	100%	100%	100%	***60%***	100%	***63%***	100%	100%	100%	100%	100%
% hrs Stilesville achieved in 72 hrs	100%	100%	100%	100%	***67%***	100%	***67%***	100%	100%	100%	100%	100%
% hrs Hale Eddy achieved in 72 hrs	100%	100%	100%	100%	***65%***	***96%***	***69%***	***96%***	***96%***	100%	***97%***	100%
% hrs Callicoon achieved in 72 hrs	***47%***	***49%***	***47%***	***69%***	***0%***	***0%***	***0%***	***4%***	***90%***	***92%***	***90%***	***99%***
% hrs Callicoon >560 in 72 hrs	100%	100%	100%	100%	***68%***	***94%***	***69%***	***94%***	100%	100%	100%	100%
Stilesville dropped >200 cfs post-mitigation	N	N	N	N	N	N	N	N	N	N	N	N
Mitigation by Event (cfs)	95	130	95	335	123	250	153	466	268	328	296	502

Protocol	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17	SS1	SS2	SS6	SS17
Downriver Criteria		**Event 32**				**Event 36**				**Event 37**		
% hrs Stilesville achieved in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Hale Eddy achieved in 48 hrs	***98%***	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Callicoon achieved in 48 hrs	100%	100%	100%	100%	***92%***	***92%***	***92%***	***96%***	***67%***	***75%***	***69%***	***83%***
% hrs Callicoon >560 in 48 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Stilesville achieved in 72 hrs	***82%***	***82%***	***82%***	***82%***	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Hale Eddy achieved in 72 hrs	***99%***	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% hrs Callicoon achieved in 72 hrs	100%	100%	100%	100%	***94%***	***94%***	***94%***	***97%***	***78%***	***83%***	***79%***	***89%***
% hrs Callicoon >560 in 72 hrs	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Stilesville dropped >200 cfs post-mitigation	N	N	N	N	N	N	N	N	N	N	N	N
Mitigation by Event (cfs)	276	349	311	531	269	269	269	449	204	249	224	418

Appendix H. Continued.

Protocol	SS1	SS2	SS6	SS17
Downriver Criteria		**Event 38**		
% hrs Stilesville achieved in 48 hrs	100%	100%	100%	100%
% hrs Hale Eddy achieved in 48 hrs	100%	100%	100%	100%
% hrs Callicoon achieved in 48 hrs	***67%***	100%	***73%***	100%
% hrs Callicoon >560 in 48 hrs	100%	100%	100%	100%
% hrs Stilesville achieved in 72 hrs	***75%***	***75%***	***92%***	100%
% hrs Hale Eddy achieved in 72 hrs	***81%***	***81%***	***97%***	100%
% hrs Callicoon achieved in 72 hrs	***78%***	100%	***82%***	100%
% hrs Callicoon >560 in 72 hrs	100%	100%	100%	100%
Stilesville dropped >200 cfs post-mitigation	N	***Y***	N	N
Mitigation by Event (cfs)	302	502	477	1595