7. POTENTIAL IMPACTS AND BENEFITS OF THE PROPOSED ACTION ON LOWER ESOPUS CREEK

This section evaluates how operation of Ashokan Reservoir in the future with the Proposed Action (IRP: use of the Ashokan Release Channel in accordance with the Interim Ashokan Release Protocol) has the potential to benefit and impact lower Esopus Creek as compared to operation of Ashokan Reservoir in the future without the Proposed Action (no use of the Ashokan Release Channel).[1] The water resources and water quality assessment is presented first, as this analysis formed the basis for the other technical area assessments that follow. The other technical area assessments presented within this section include: public policy, land use and zoning; socioeconomic conditions; open space and recreation; historic and cultural resources; aesthetic (visual) resources; natural resources (including aquatic resources, wetlands, and terrestrial and wildlife resources); hazardous materials; and infrastructure and energy. These assessments were conducted in accordance with the methods outlined in Section 5, "EIS Methodology."

7.1 WATER RESOURCES AND WATER QUALITY

A water resources and water quality assessment was conducted to determine the potential benefits or impacts of the Proposed Action to streamflow and water quality conditions within the lower Esopus Creek study area. Specifically, this section considers potential differences between the future without and with the Proposed Action on the magnitude, duration, frequency, and seasonality of streamflow (flow regime), and turbidity levels, temperature, dissolved oxygen, and pH (water quality) within lower Esopus Creek. Baseline conditions are presented alongside the future without and with the Proposed Action assessments to provide complete context for the analysis of potential future water resources and water quality conditions.

7.1.1 FLOW REGIME AND WATER QUALITY IN LOWER ESOPUS CREEK

As noted in Section 5.2, "Lower Esopus Creek Modeling Methodology," operation of Ashokan Reservoir in the future with the Proposed Action would be influenced by the region's dynamic hydrologic conditions. Hydrologic conditions vary based on season, storm events, and climatic conditions. Therefore, to provide a comprehensive understanding of the potential streamflow and water quality conditions in the future without and with the Proposed Action, this section includes an evaluation of how a range of anticipated future hydrologic conditions (i.e., during wet, normal, and dry years) would affect flows from Ashokan Reservoir (spills and releases) and streamflow within lower Esopus Creek. From these analyses, seasonal patterns in flow regime in the future without and with the Proposed Action were also identified.

Different streamflow characteristics, such as the total amount of streamflow at any given time (magnitude), how often streamflow of a given magnitude occurs over a given time period (frequency) and for how long it lasts within a stream (duration) are commonly used to describe flow regimes. Another important component of a flow regime is the seasonality of streamflow. The lower Esopus Creek flow

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[1] As described, the Proposed Action would modify the Catalum SPDES Permit to incorporate: (1) Turbidity control measures, including operation of Ashokan Reservoir in accordance with the IRP; and (2) Delay of dredging accumulated material (alum floc) from Kensico Reservoir until the completion of certain infrastructure projects. The Lower Esopus Creek Study Area assessment focuses on operation of Ashokan Reservoir in accordance with the IRP.

regime encompasses the relative contributions of the portion of streamflow attributable to flow from Ashokan Reservoir, direct surface water runoff from surrounding sub-watersheds, and sub-surface flows (background streamflow).

This section also presents potential differences in turbidity levels of flows from Ashokan Reservoir, which were considered in combination with measured background turbidity in lower Esopus Creek. Finally, a complete understanding of the flow regime of lower Esopus Creek required evaluation of less frequent, higher magnitude streamflow events – specifically potential differences in the frequency and magnitude of flood and episodic turbidity events between the future without and with the Proposed Action.

Information gathered from the below analysis of flow regime and water quality in lower Esopus Creek was ultimately used to determine how and whether identified differences have the potential to affect various parameters such as water depth, water velocity, erosion, sediment deposition, inundation and turbidity levels within the different valley reaches of lower Esopus Creek (see Section 7.1.4, "Parameters Evaluated for the Technical Area Assessments").

FLOWS FROM ASHOKAN RESERVOIR

SPILLS

Spills are the uncontrolled flow of water over Ashokan Reservoir's spillway located at the southern end of the east basin. Spills occur when storage capacity in Ashokan Reservoir is exceeded. In the future without the Proposed Action, water from Ashokan Reservoir would be conveyed to lower Esopus Creek through spills only. In the future with the Proposed Action, spills would be comparatively less frequent and smaller in magnitude due to the increased storage capacity of the Reservoir created by releases (which maintain the CSSO, providing a seasonal storage void in the Reservoir). **Figure 7.1-1** shows the magnitude and seasonality of spills in the future without and with the Proposed Action.[2] As shown on the figure, the seasonality of spills between the future without and with the Proposed Action would largely be the same (occurring mostly in the spring).

Table 7.1-1 shows the difference in the magnitude of spill events between the future without and with the Proposed Action in wet, normal, and dry years. The table also shows the number of spill events and total days of spill (duration) as modeled by OST. As shown in the table, the average magnitude and duration of spill events would be lower in the future with the Proposed Action as compared to the future without the Proposed Action. Maximum spill magnitudes would be comparable; however, the duration of these events would be shorter in the future with the Proposed Action.

As shown in **Table 7.1-1**, while Ashokan Reservoir provides attenuation of storm events in both the future without and with the Proposed Action, operation of Ashokan Reservoir in accordance with the IRP has the potential to provide enhanced flood attenuation by maintaining the CSSO and managing Reservoir water levels through releases.

Figure 7.1-2 and **Figure 7.1-3** show the modeled spill turbidity levels that would occur in the future without and with the Proposed Action. As illustrated, when spills occur, their turbidity levels would be similar between the future without and with the Proposed Action.

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[2] As stated in Section 5, "Methodology," for this EIS, some periods of analysis start and end with complete water years. A water year is defined as the flow period between June 1st and May 31st (e.g., Water Year 2016/2017 runs from June 1, 2016 through May 31, 2017), in conformance with the starting period for DEP's reservoirs being full.

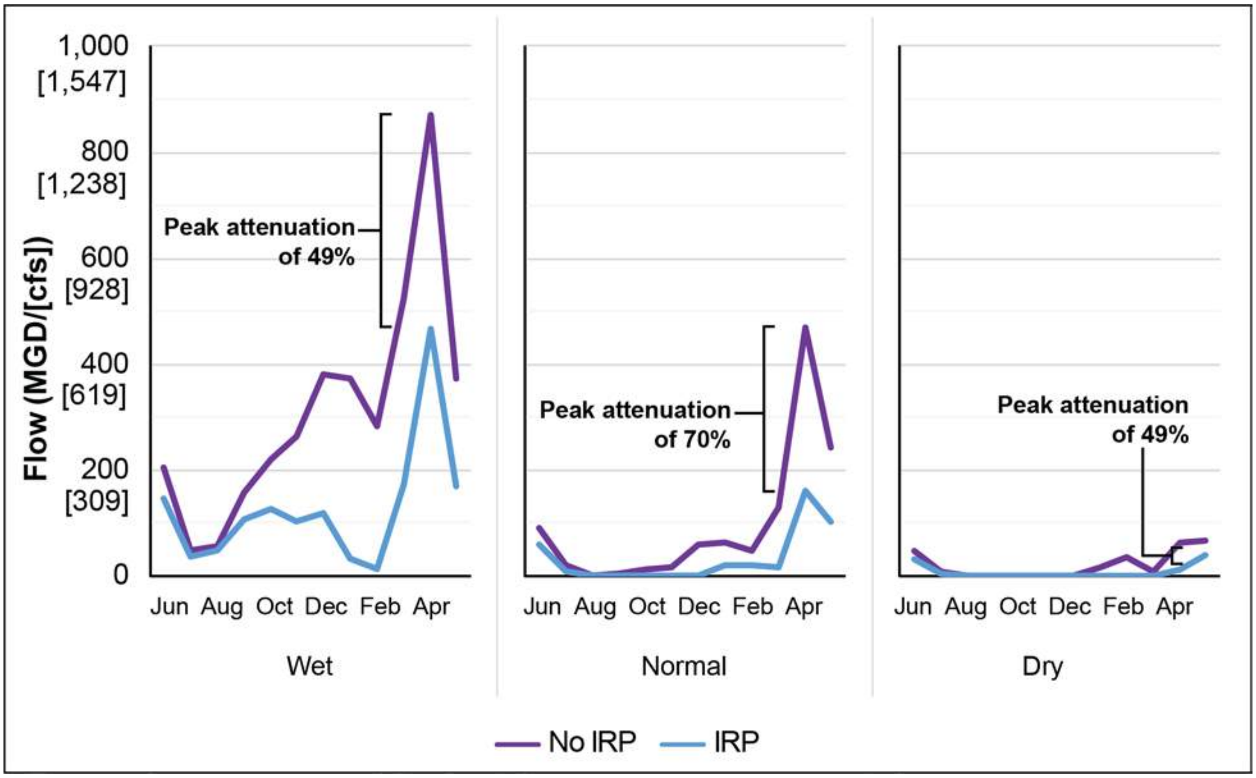

Figure 7.1-1. Modeled Annualized Ashokan Reservoir Spills for the Future Without the Proposed Action and the Future With the Proposed Action

Table 7.1-1. Magnitude and Duration of Spills in the Future Without and With the Proposed Action[1]

	Binned					Full Record	
	Year Type	**Average Magnitude of Spills (MGD [cfs])**	**Average Duration of Spill Events (Days)**	**Maximum Magnitude of Spills (MGD [cfs])[2]**	**Duration of Maximum Spill Event (Days)**	**Number of Spill Events**	**Total Days of Spill**
Future Without the Proposed Action	Wet	610 [944]	55	14,900 [23,053]	243	170	6,200
	Normal	490 [758]	28	9,300 [14,389]	96		
	Dry	370 [572]	19	6,200 [9,593]	27		
Future With the Proposed Action	Wet	550 [851]	24	14,300 [22,125]	163	149	2,600
	Normal	450 [696]	14	8,800 [13,616]	45		
	Dry	370 [572]	11	3,400 [5,261]	19		

Notes:

[1] Data are modeled and shown based on the OST simulation period (1948 -2017).

[2] Spill events of 3,000 MGD (4,642 cfs) or higher occur less than one percent of the time.

Number of Days Per Year

Turbidity (NTU)	Wet	Normal	Dry
0-5	86	51	18
5-10	52	14	2
10-15	21	5	1
15-20	9	1	0
20-25	4	1	0
25-30	4	0	0
30-40	4	1	0
40-50	2	0	0
50-60	1	0	0
60-100	0	0	0
> 100	0	0	0
No Spill	183	292	345
Total	**365**	**365**	**365**

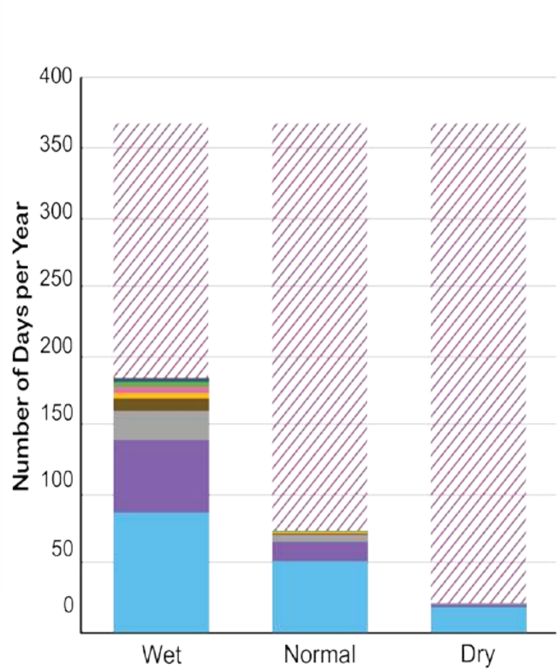

Figure 7.1-2. Modeled Occurrence of Spill Turbidity Levels by Type of Year in the Future Without the Proposed Action

Number of Days Per Year

Turbidity (NTU)	Wet	Normal	Dry
0-5	31	15	6
5-10	17	5	1
10-15	15	2	1
15-20	7	1	0
20-25	5	1	0
25-30	4	0	0
30-40	3	0	0
40-50	2	1	0
50-60	1	0	0
60-100	0	0	0
> 100	0	0	0
No Spill	281	340	358
Total	**365**	**365**	**365**

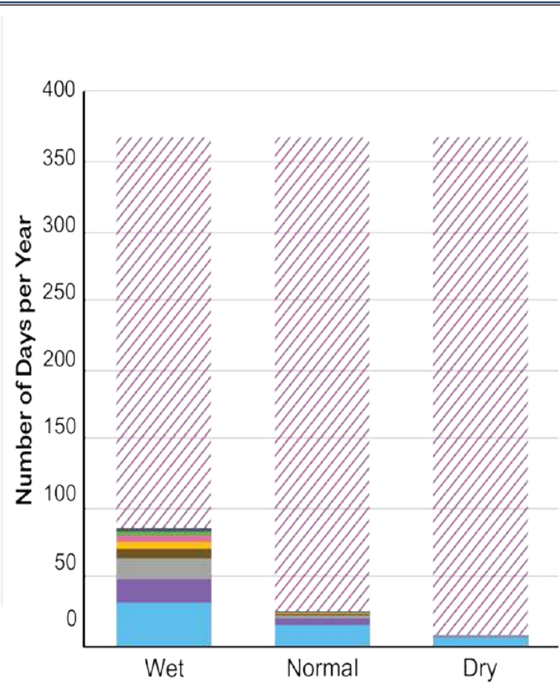

Figure 7.1-3. Modeled Occurrence of Spill Turbidity Levels by Type of Year in the Future With the Proposed Action

RELEASES

Figure 7.1-4 through **Figure 7.1-7** provides information on releases from Ashokan Reservoir, which would only occur in the future with the Proposed Action. As reflected in **Figure 7.1-4**, which shows molded annualized releases, wet years would require higher releases to maintain the CSSO due to higher inflow to the Reservoir. For the same reason, releases would be of higher magnitude in the early spring in all years, similar to the seasonality of spills in the future without the Proposed Action.

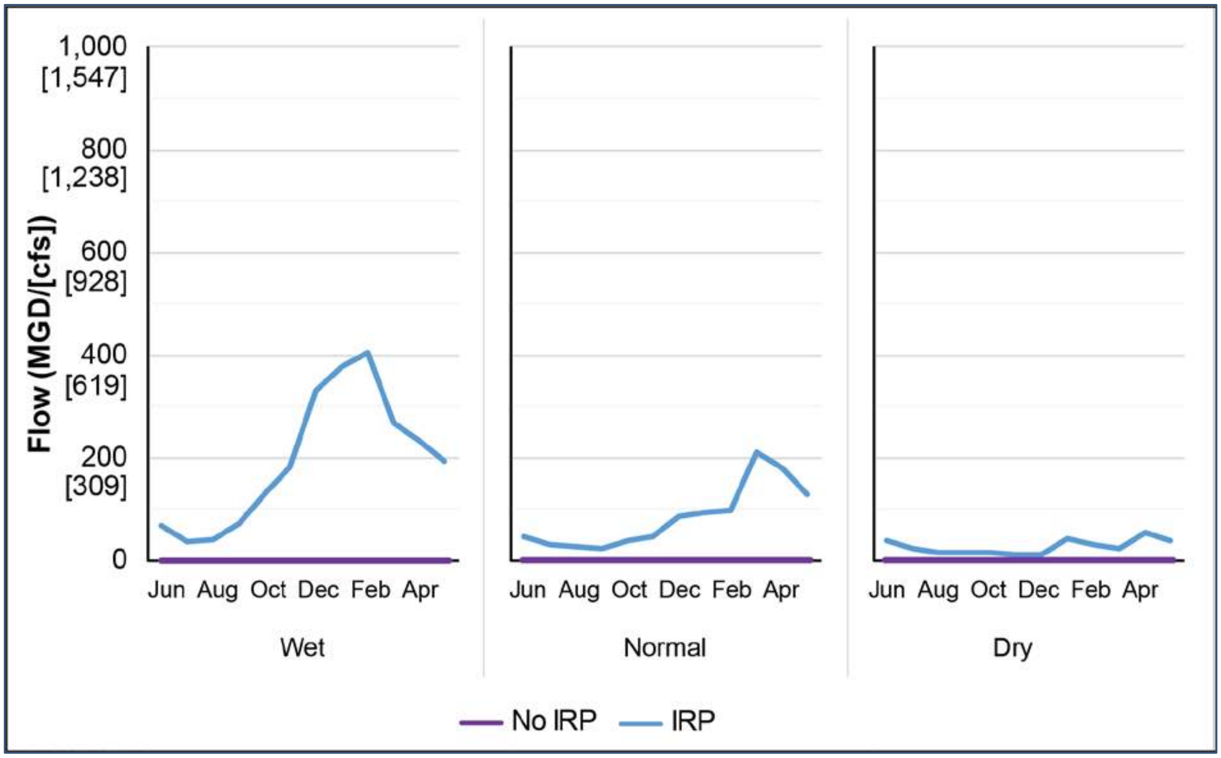

Figure 7.1-4. Modeled Annualized Releases in the Future Without and With the Proposed Action

Figure 7.1-5 shows the anticipated frequency and average magnitude of each type of release in wet, normal, and dry years.

- As shown on the left side of the figure, the community release would occur for the highest percentage of days in all years. In wet years, the percentage of days the community release would occur is lower as compared to normal and dry years because additional spill mitigation releases would be required to maintain the CSSO.
- Likewise, spill mitigation releases make up a greater percentage of days during wet years as compared to normal and dry years. As shown on the right side of the figure, while the maximum release from Ashokan Reservoir is 600 MGD (928 cfs), the average magnitude of spill mitigation releases would range from approximately 230 to 380 MGD (356 to 588 cfs). The IRP prescribes ramping rates at the beginning and end of a release. Ramping of releases would be conducted in a controlled manner that gradually increases flow to lower Esopus Creek.
- Operational releases would occur infrequently, from one to seven percent of days for dry and wet years, respectively. These releases would occur most often in the spring when the Reservoir is full or close to full and storm events are more likely. The median duration of operational releases

would be three days and the 10th to 90th percentile range in duration is one to nine days. The average magnitude of operational releases is approximately 315 to 465 MGD (487 to 719 cfs), which would be less than the maximum release of 600 MGD (928 cfs) for the reasons described above for spill mitigation releases.

- The potential need for flushing would be very infrequent with an average flow of 150 MGD (232 cfs).

The percentage of days without any releases would be higher in wet years than in normal and dry years because DEP would be required to throttle releases as necessary so that the combined flow from Ashokan Reservoir (spill and release) does not exceed 1,000 MGD (1,547 cfs) or when the Mount Marion gage is within one foot of the flood “Action Stage” and is forecasted to reach the flood Action Stage. The percentage of days without any releases would be higher in dry years as compared to normal years due to low inflow or drought conditions that would suspend the community release.

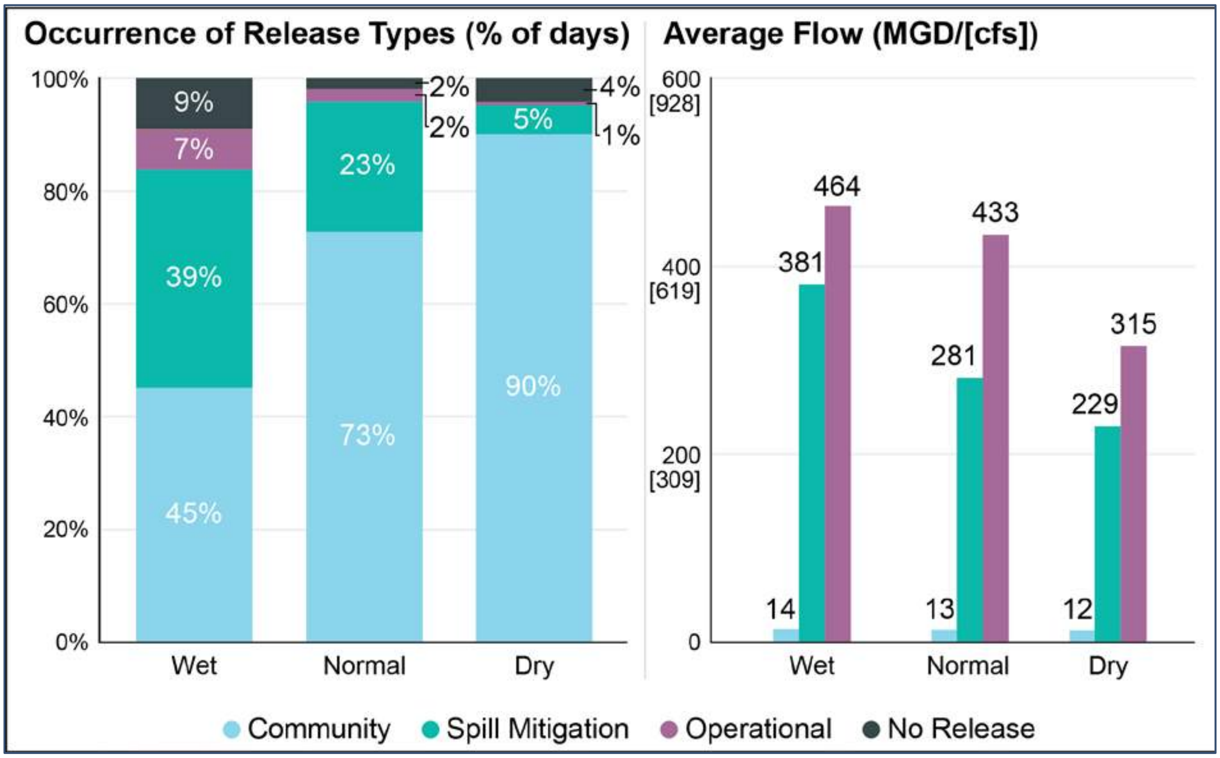

Figure 7.1-5. Modeled Occurrence and Average Annual Flow of Releases in the Future With the Proposed Action

The turbidity level of releases would vary depending on conditions in Ashokan Reservoir but is anticipated to be at or below 5 NTU approximately 70 percent of the days based on OST modeling.

Based on OST modeling, the majority of releases from Ashokan Reservoir are anticipated to have low levels of turbidity.

Figure 7.1-6 shows average turbidity levels in wet, normal, and dry years by type of release. As discussed in Section 5.3.1, “Water Resources and Water Quality” methodology, various ranges of turbidity levels were evaluated for their occurrence in wet, normal, and dry years. Additional information on the occurrence of turbidity levels by release type is as follows:

- The median turbidity levels of the community release would be 1.8 NTU and the 10^{th} to 90^{th} percentile turbidity levels would range from 0 to 5 NTU, respectively.
- Turbidity levels of spill mitigation releases would range from 3 to 16 NTU (10^{th} to 90^{th} percentile), with a median turbidity level of 6.6 NTU.
- Operational release turbidity levels would range from 4 to 26 NTU (10^{th} to 90^{th} percentile), with a median turbidity level of 15 NTU.

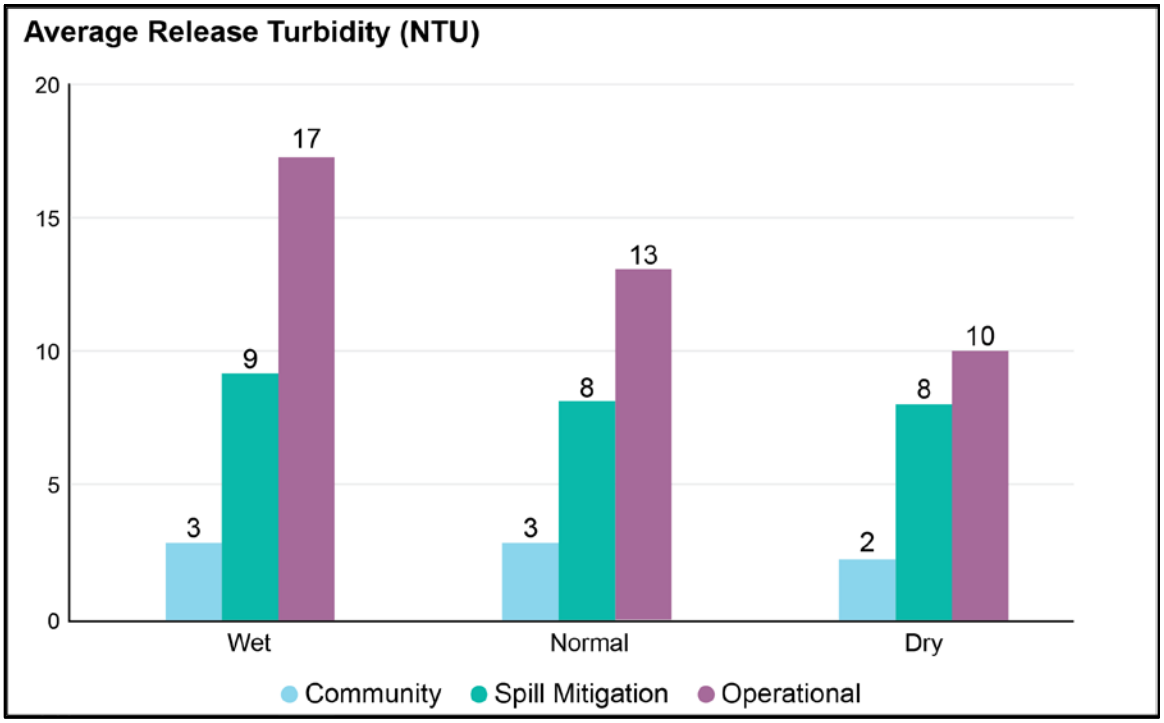

Figure 7.1-6. Modeled Average Release Turbidity in the Future With the Proposed Action

Figure 7.1-7 characterizes turbidity levels in releases combining all release types (community, spill mitigation and operational) and spills in the future with the Proposed Action as compared to spills in the future without the Proposed Action (spills would be the only flow from Ashokan Reservoir to lower Esopus Creek in the future without the Proposed Action). **Table 7.1-2** shows the breakdown of the average number of days per year of turbidity levels in flow in the future without and with the Proposed Action. As shown, compared to the future without the Proposed Action, in future with the Proposed Action:

- there would be more days with flow from Ashokan Reservoir and in general, this water would have low levels of turbidity (ranging between 5 and 25 NTU);
- release turbidity levels would be below 5 NTU for a majority of days (approximately 70 percent of the days);
- the number of days of flow from Ashokan Reservoir with turbidity levels greater than 25 NTU would be similar between the future without and with the Proposed Action; and,
- there would be no flow or turbidity contribution from Ashokan Reservoir on days without spill or release.

As presented below in the "Streamflow within Lower Esopus Creek" section, observed turbidity levels in flow through the Ashokan Release Channel since 2013 (when the IRP was implemented) are consistent with OST modeling results – they remained below 5 NTU for 68 percent of the time. For the same period, release turbidity levels were below 10 NTU for 90 percent of the time.[3]

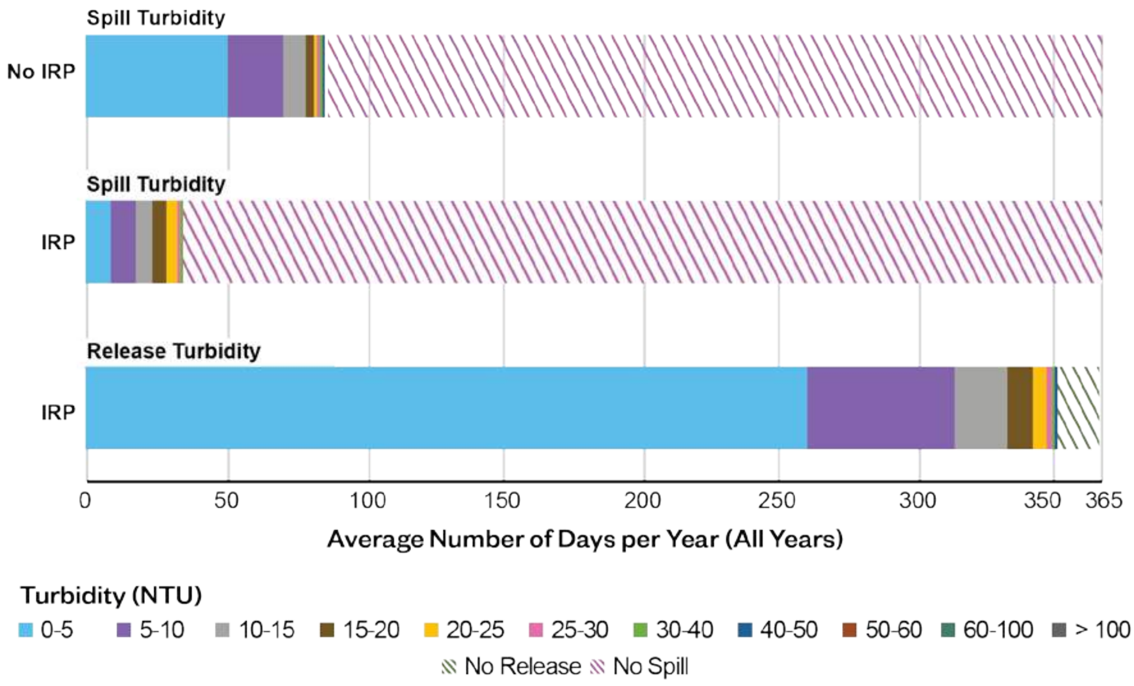

Figure 7.1-7 Modeled Comparison of Turbidity Levels between the Future Without and With the Proposed Action

[3] The highest observed turbidity of releases since 2013 was 17 NTU.

Table 7.1-2. Average Number of Days Per Year of Modeled Turbidity Levels of Flow between the Future Without and With the Proposed Action

Turbidity Level (NTU)[1]	Number of Days			
	Future without the Proposed Action (Spill)	**Future with the Proposed Action (Releases)**	**Future with the Proposed Action (Spill)**	**Future with the Proposed Action (Releases and Spill)** [2]
0-5	**51**	259	17	**263**
5-10	**20**	54	7	**55**
10-15	**8**	18	5	**20**
15-20	**3**	10	2	**10**
20-25	**1**	5	1	**6**
25-30	**1**	2	1	**2**
30-40	**1**	1	1	**2**
40-50	**1**	1	1	**1**
50-60	**0**	<1	<1	**<1**
60-100	**0**	<1	<1	**<1**
>100	**0**	0	0	**0**
No Release	**NA**	15		**0**
No Spill	**279**		330	**5**
Total Days	**365**	**365**	**365**	**365**

Notes:
1 Turbidity level ranges are from the lower number up to but not including the higher number within each bin. The exception is 0 NTU, which is included in the no spill/no release lines.
2 The total number of days considering releases and spill is not additive because there are 25 days where modeled releases and spills occur simultaneously).
NA - Not Applicable

STREAMFLOW WITHIN LOWER ESOPUS CREEK

STREAMFLOW MAGNITUDE, DURATION, AND FREQUENCY

Figure 7.1-8 shows similar seasonal streamflow patterns for wet, normal, and dry years for the future without and with the Proposed Action (i.e., higher streamflow occurs in the spring) at the spillway confluence. There are two primary differences in the lower Esopus Creek flow regime between the future without and with the Proposed Action: (1) in the spring, the Proposed Action would reduce peak streamflow in lower Esopus Creek as compared to the future without the Proposed Action through operation of Ashokan Reservoir in accordance with the IRP to maintain the CSSO; and (2) the community release would provide sustained flow to lower Esopus Creek year-round (see inset on **Figure 7.1-8**).

These two differences – reductions in peak streamflow and sustained flow from the community release – would also be evident further downstream at Mount Marion; however, these effects would be muted at this downstream location in both the future without and with the Proposed Action (see **Figure 7.1-9**). This pattern is consistent with the diminishing contributions of the Ashokan releases to the overall streamflow in lower Esopus Creek demonstrated in Section 6.2, "Operation of Ashokan Reservoir in Accordance With the IRP."

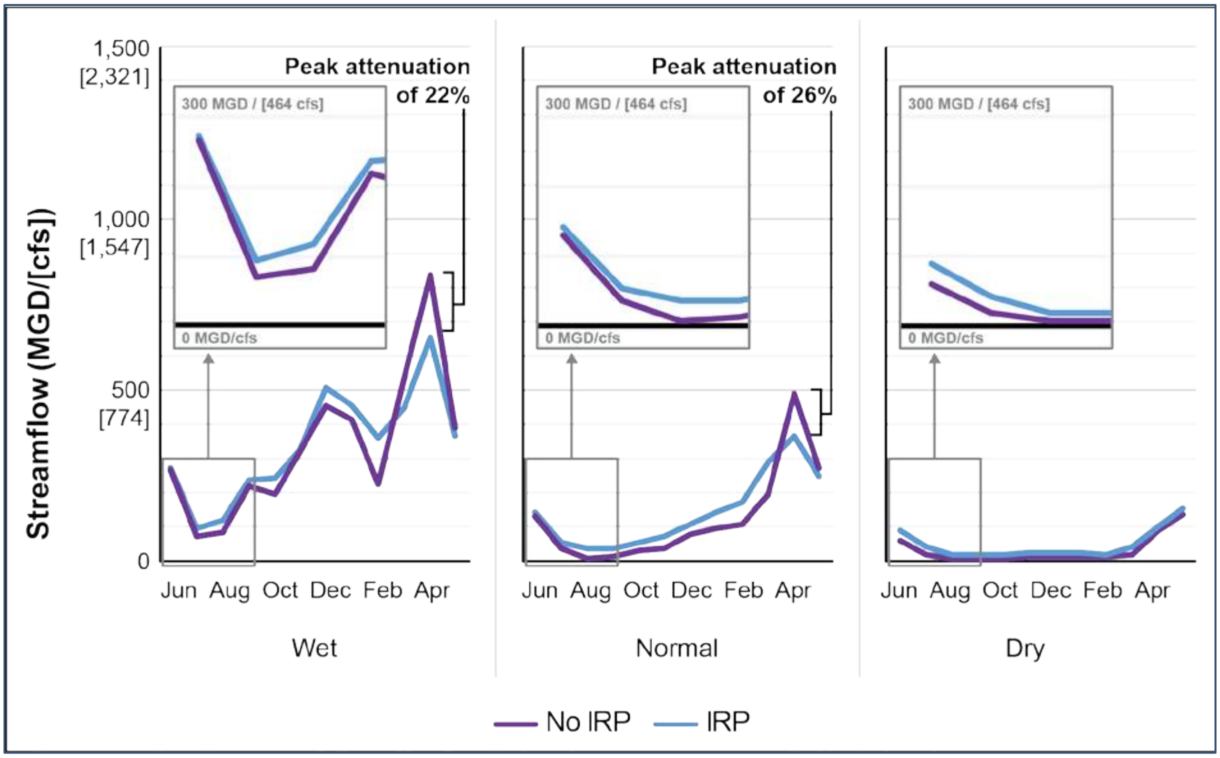

Figure 7.1-8. Modeled Annualized Streamflow for the Future Without and Future With the Proposed Action at the Spillway Confluence

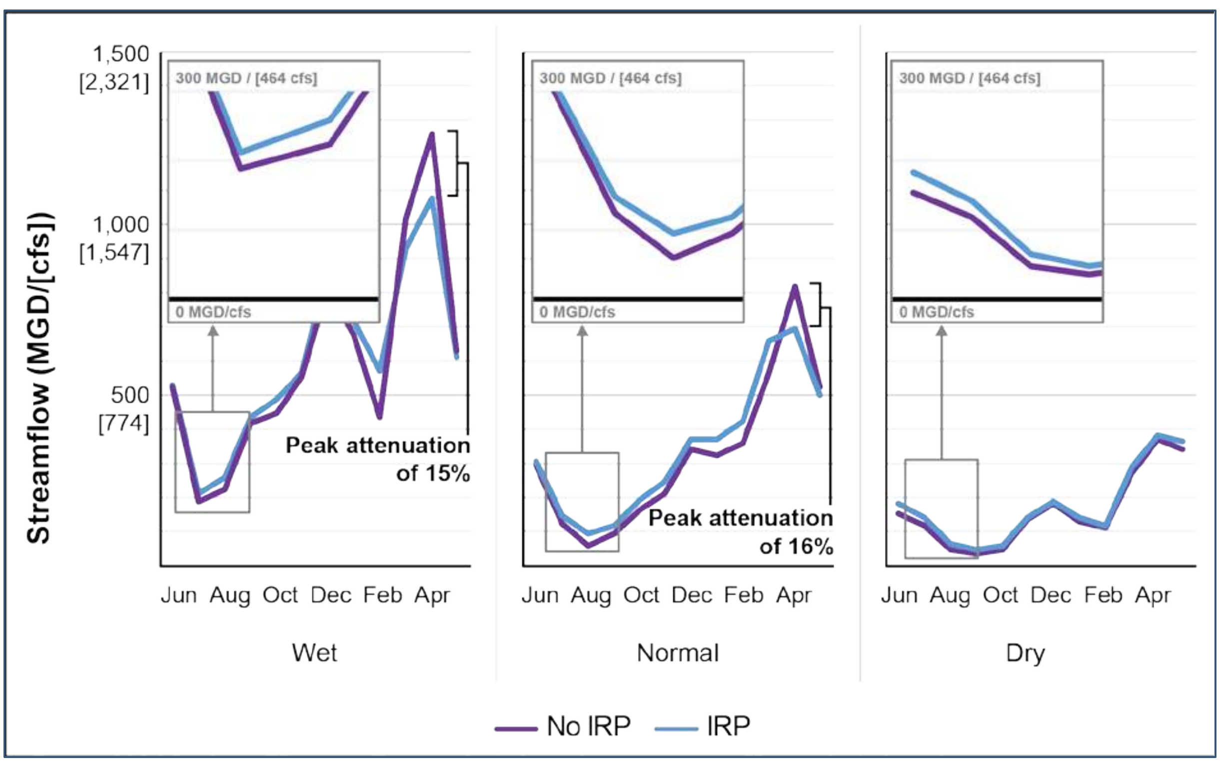

Figure 7.1-9. Modeled Annualized Streamflow for the Future Without and Future With the Proposed Action at Mount Marion

The IRP converts shorter duration, higher flow spill events into longer duration, lower flow release events, reducing variability of streamflow in lower Esopus Creek.

In addition to evaluating the difference in streamflow magnitude and seasonality between the future without and with the Proposed Action, the difference in duration of various magnitudes of streamflow was also assessed. **Figure 7.1-10** and **Figure 7.1-11** show the 50th and 75th percentile water years, as modeled by OST.[4] To illustrate this difference, **Figure 7.1-10** shows that for the 75th percentile water year (a wet year), the Proposed Action would change the flow regime of lower Esopus Creek by converting a sequence of spill events that would occur in the future without the Proposed Action (on the order of weeks) to a single release event (on the order of a month or longer). As a result, and as illustrated by the inset in **Figure 7.1-10**, for the 75th percentile year, the Proposed Action would reduce the variability of flows. Since releases would be higher in years of high streamflow to maintain the CSSO, these differences would be more pronounced during wet years as compared to dry years. These periods of longer duration, lower flow releases would follow the same seasonal pattern presented above and would occur more often in the winter and spring in the future with the Proposed Action. **Figure 7.1-11** shows that similar patterns would occur moving further downstream, although they would be less pronounced due to the diminishing contribution of flows from Ashokan Reservoir to streamflow in lower Esopus Creek.

Finally, flow duration curves at various points along lower Esopus Creek were developed to determine the frequency that certain streamflow would occur within lower Esopus Creek in the future without and with the Proposed Action (**Figure 7.1-12)**. The curves show the percent of time (the x-axis) a certain streamflow (the y-axis) would occur. The frequency of occurrence of streamflow in the range of 600 MGD (928 cfs) would be similar in both the future without and with the Proposed Action. The community release would provide additional flow to lower Esopus Creek in the range of 15 MGD (23 cfs) more frequently in the future with the Proposed Action. This indicates the community release would provide a potential benefit of sustained flow to lower Esopus Creek year-round and would enhance the flood attenuation benefit provided by Ashokan Reservoir by helping to maintain the CSSO. This would result in the most pronounced difference in streamflow between the future without and with the Proposed Action for Valley Reach 1A, which does not receive flow from Ashokan Reservoir in the future without the Proposed Action. In Valley Reach 1A, a 15 MGD (23 cfs) streamflow or greater would occur in lower Esopus Creek 90 to 95 percent of the time in the future with the Proposed Action, whereas the same streamflow would occur only 25 percent of the time in the future without the Proposed Action.

Potential differences in the frequency of occurrence of streamflow in the range of 600 MGD (928 cfs) would diminish moving downstream. This is consistent with the determination that flow from Ashokan Reservoir has a diminishing contribution to the overall streamflow in lower Esopus Creek moving downstream (see Section 6.2, "Operation of Ashokan Reservoir in Accordance With the IRP").

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[4] The 50th and 75th percentile water years were identified by ranking water years over the Mount Marion period of record from wettest (100 percent) to driest (0 percent). The 50th percentile year is water year 1998. The 75th percentile year is water year 1976.

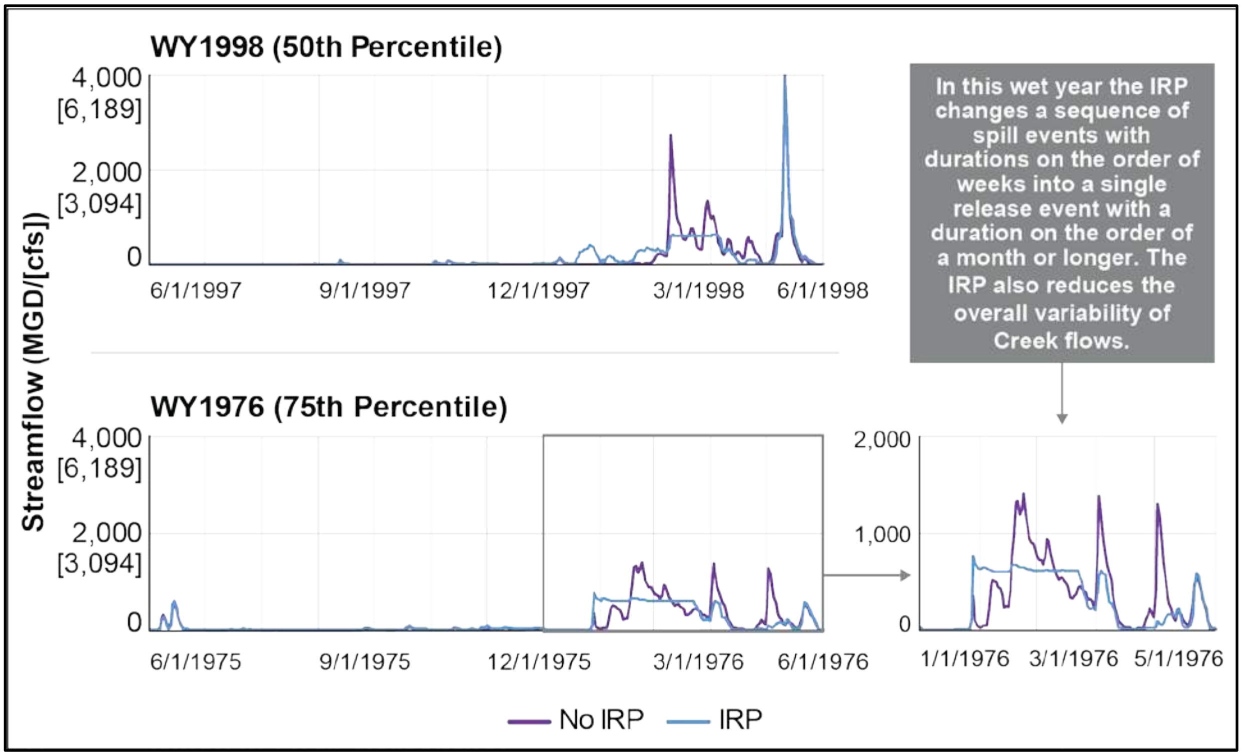


Figure 7.1-10. Modeled Streamflow for the 50th and 75th Percentile Water Year at the Spillway Confluence

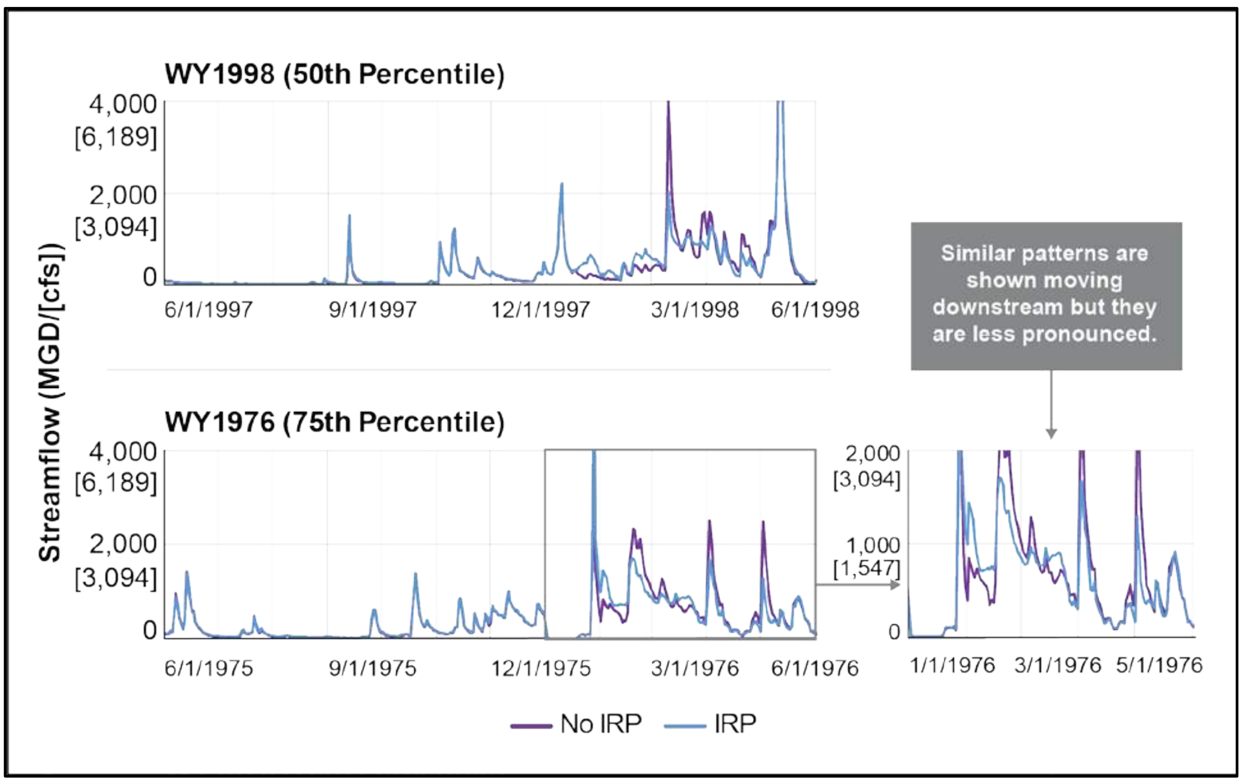
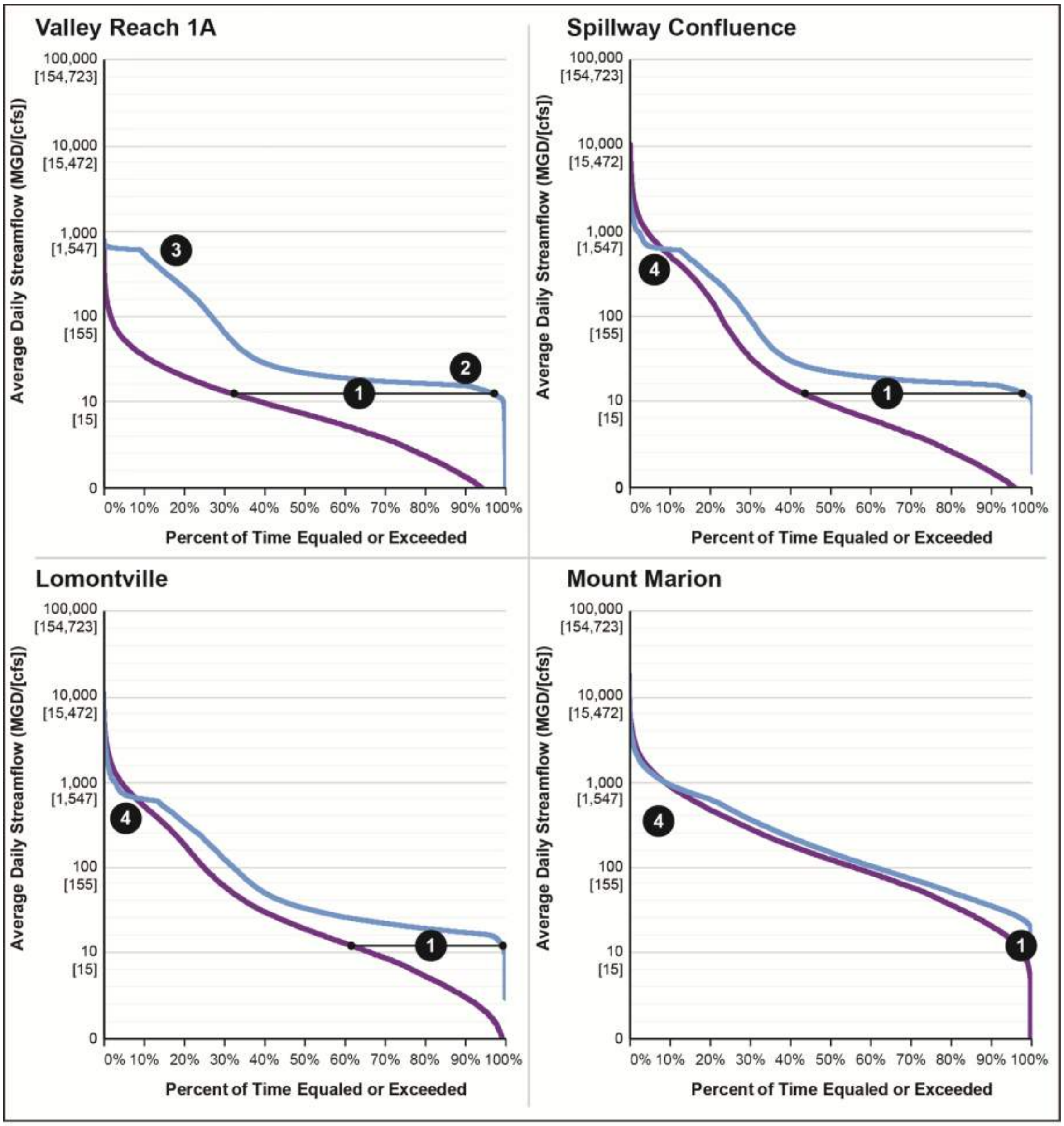


Figure 7.1-11. Modeled Streamflow for the 50th and 75th Percentile Water Year at Mount Marion



No IRP — IRP

1. The community release would provide additional flow to lower Esopus Creek, with streamflow between 10 and 15 MGD (15 and 23 cfs) occurring more frequently in the future with the Proposed action than in the Future without the Proposed Action.
2. In Valley Reach 1A, which does not receive flow from Ashokan Reservoir in the future without the Proposed Action, the community release would provide the benefit of additional streamflow. The frequency of occurrence of streamflow in the range of 15 MGD (23 cfs) would occur 90 to 95 percent of the time in the future with the Proposed Action as compared to 25 to 30 percent of the time in the future without the Proposed Action.
3. Flows up to 600 MGD (928 cfs) would occur more frequently in the future with the Proposed Action in Valley Reach 1A.
4. The frequency of occurrence of streamflow in the range of 600 MGD (928 cfs) would be similar in the future without and with the Proposed Action downstream of the spillway confluence and this difference would diminish moving downstream.

Figure 7.1-12
Modeled Streamflow Duration Curves along Lower Esopus Creek
(Mount Marion Period of Record)

TURBIDITY

Turbidity levels within lower Esopus Creek streamflow were evaluated by reviewing observed data. The relationship between observed streamflow and turbidity in lower Esopus Creek is illustrated in **Figure 7.1-13** and **Figure 7.1-14**.[5] In general, changes in turbidity levels and streamflow followed a similar pattern within lower Esopus Creek; observed peaks in streamflow coincided with observed peaks in turbidity levels at both Lomontville and Mount Marion.[6]

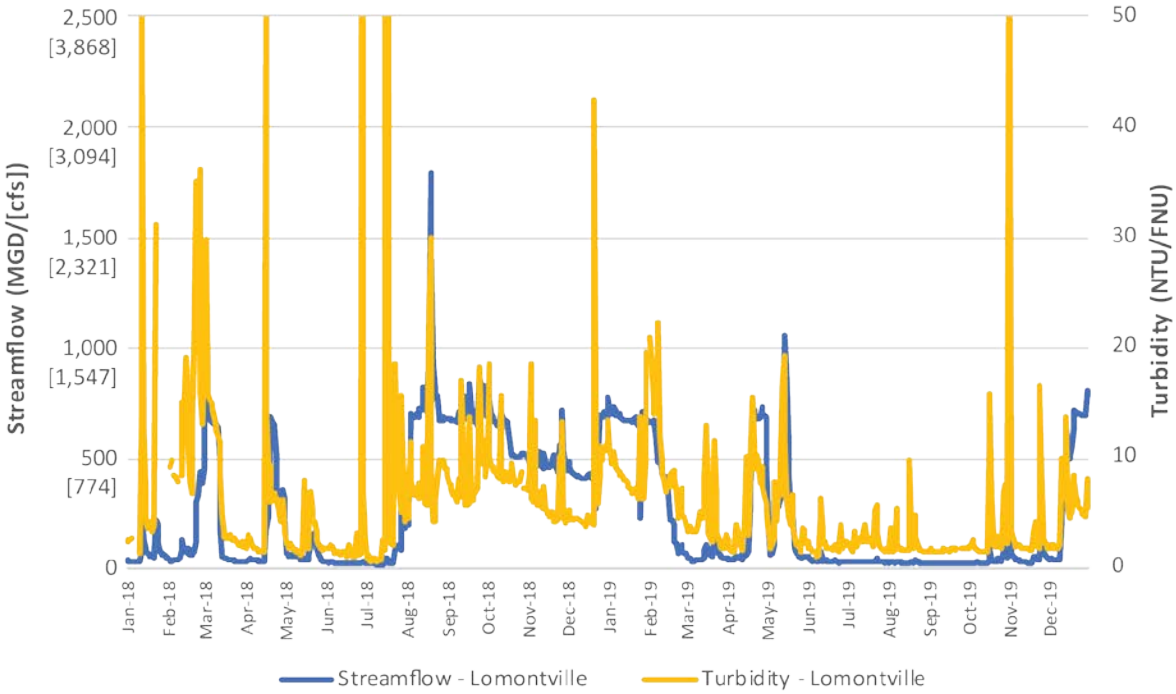


Figure 7.1-13. Observed Streamflow and Turbidity Levels at Lomontville for 2018-2019

[5] NTU and FNU are considered equivalent measurements of turbidity for the EIS. Both measure light using a 90-degree detection angle – the only difference is the source of light. According to ISO7027-1:2016, which sets the international standard for measuring turbidity, these measurement units are numerically equivalent (https://www.iso.org/standard/62801.html).

[6] Turbidity and streamflow are compared for 2018, the most recent complete year available at the time of analysis.

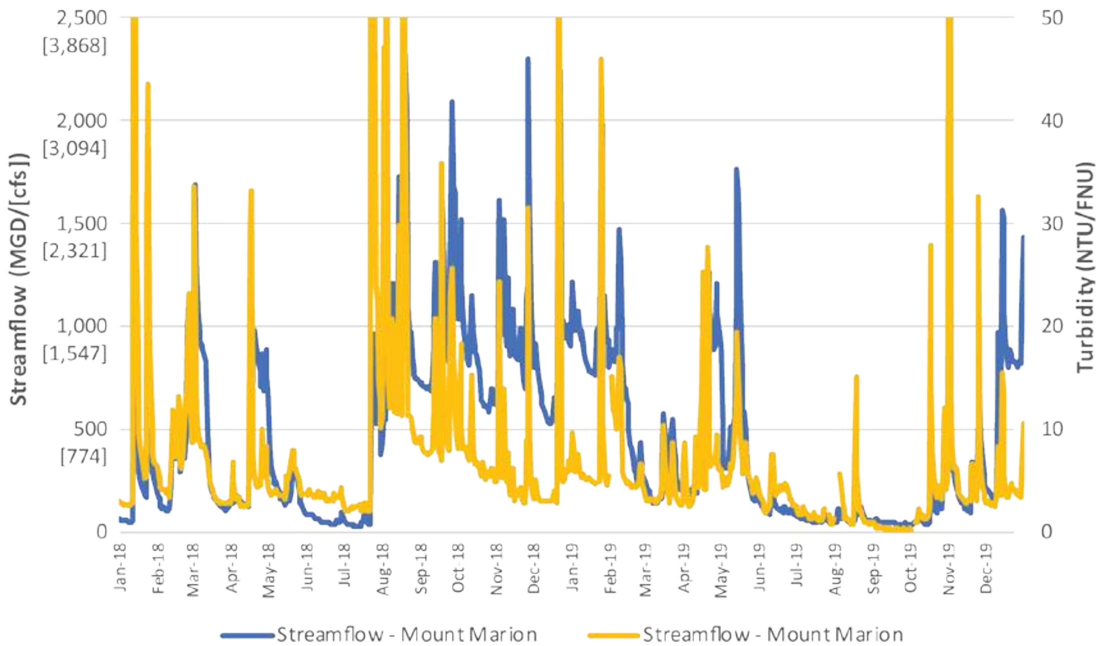


Figure 7.1-14. Observed Streamflow and Turbidity Levels at Mount Marion for 2018-2019

Figure 7.1-15 shows the range and variability of observed turbidity levels at Mount Marion and Lomontville alongside observed turbidity levels of flows in the Ashokan Release Channel since 2013. The 25th to 75th percentile range of turbidity levels are similar along lower Esopus Creek and remained below 10 NTU. Outlier points, shown as an inset within **Figure 7.1-15**, indicate that higher turbidity levels of streamflow within lower Esopus Creek occurred while Ashokan Release Channel turbidity levels were lower and less variable.[7]

Water quality sampling sites that were used to describe baseline water quality conditions in lower Esopus Creek are shown in **Figure 7.1-16**. Turbidity data in lower Esopus Creek were collected at the Ashokan Release Channel (M-1), lower Esopus Creek above Saugerties (LEC AS) and Saugerties Beach (LEC Saugerties Beach) when the release channel was operating and at the spillway (ASP) and spillway confluence (ASP-M1 Conf) when the Reservoir was spilling in accordance with the Water Quality Monitoring Plan incorporated into the IRP. Turbidity level data for the Saw Kill and Plattekill tributaries were collected weekly since 2013 to support the EIS assessments and are comparable to those at Lomontville and Mount Marion.[8] Therefore, increases in observed turbidity levels moving downstream appear to be due, in part, to inputs of turbidity from the Saw Kill and Plattekill tributaries and potential other surface water runoff to lower Esopus Creek.

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[7] Data in the box plots present observations that occur simultaneously (i.e., on the same days) at each location. There are no data available for Lomontville until 2016 when the gage became active.

[8] The 25th to 75th percentile ranges for Saw Kill and Plattekill were 1.3 to 4.2 NTU and 1.4 to 2.7 NTU, respectively. Turbidity levels in the Saw Kill have been recorded up to 1,000 NTU and in the Plattekill up to 140 NTU. DEP no longer conducts weekly water quality monitoring of the Saw Kill and Plattekill.

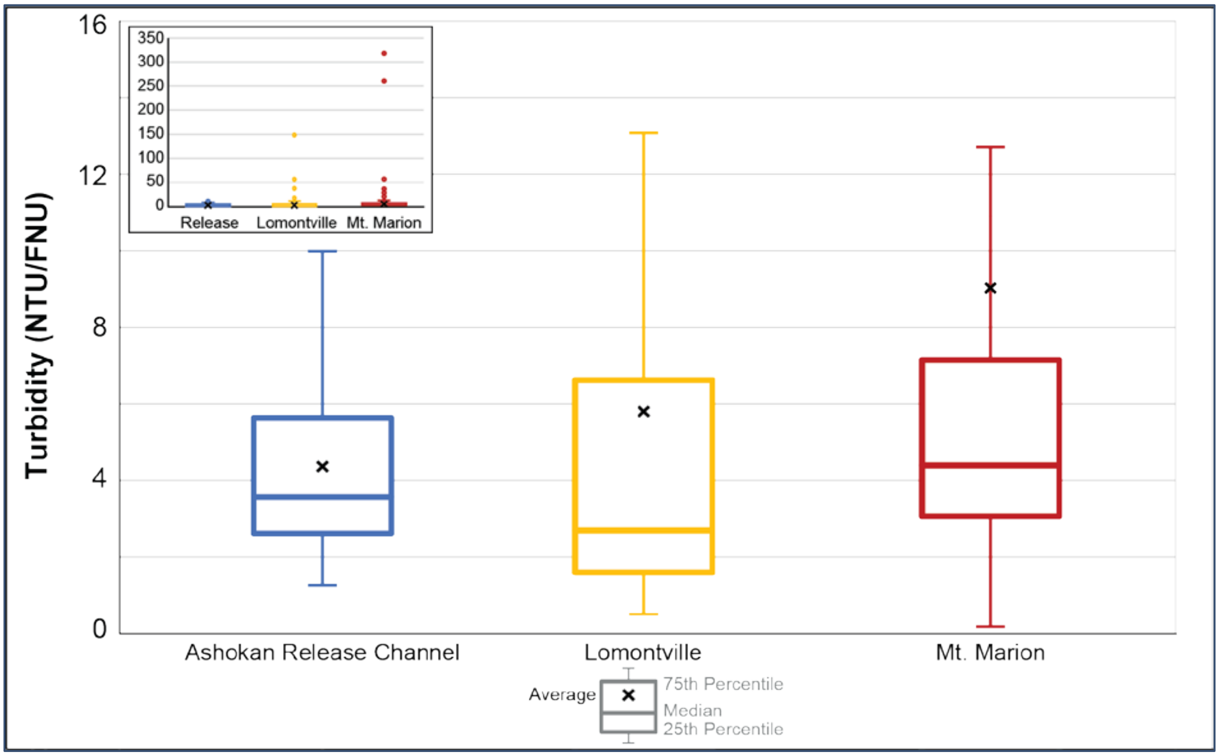

Figure 7.1-15. Box Plots of Observed Turbidity Level Data Collected at the Release Channel (2013-2019), Lomontville (2016-2019), and Mount Marion (2013-2019)

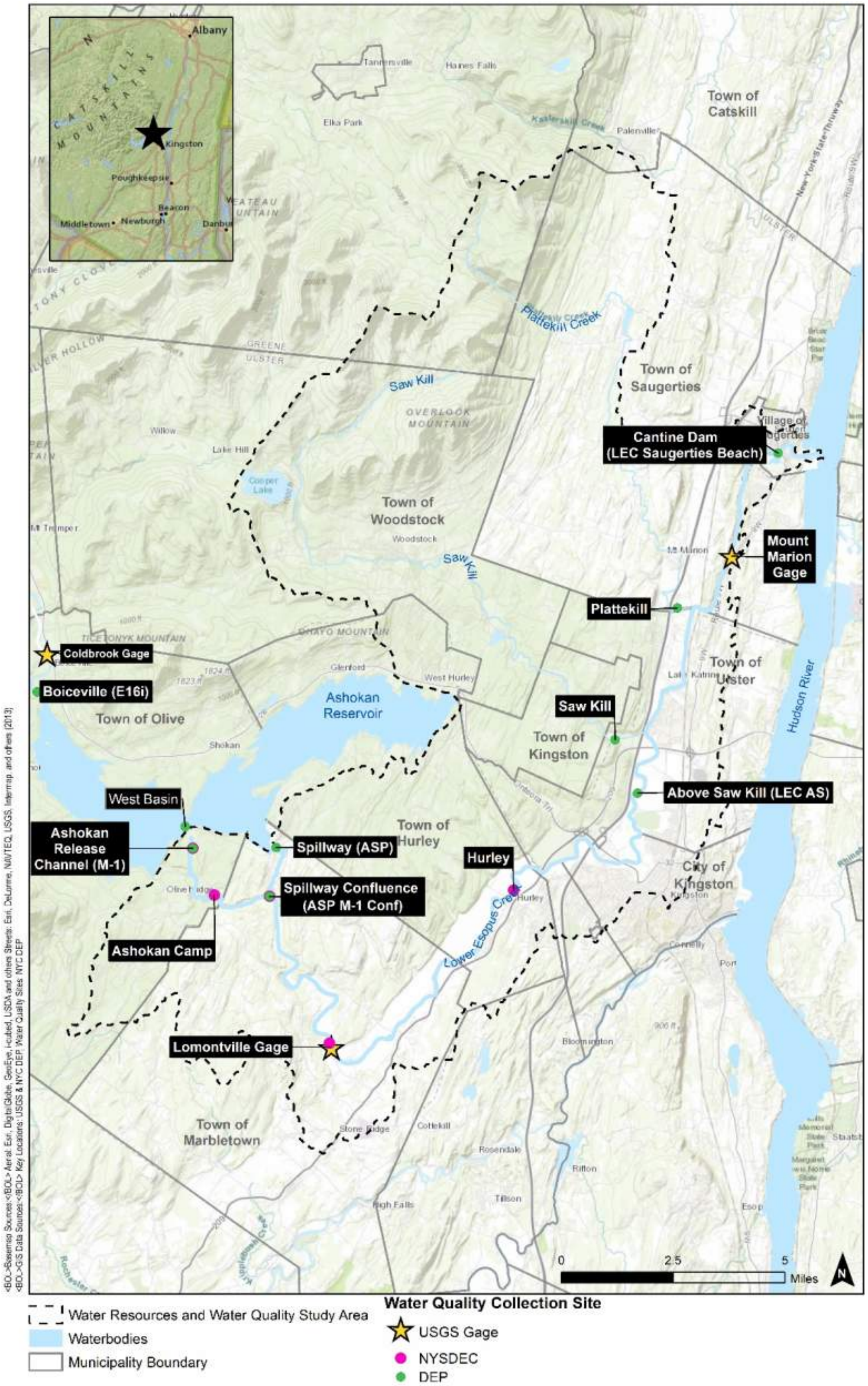

Figure 7.1-16
Water Quality Data Collection Sites

Flows from Ashokan Reservoir are one of several inputs of flow and turbidity to lower Esopus Creek.

To further investigate how turbidity levels in lower Esopus Creek streamflow vary in relationship to flows from Ashokan Reservoir, time series plots of streamflow and turbidity data for 2016 and 2018 were evaluated. These time periods are illustrative of a long duration community release (2016) and a long duration spill mitigation release to support shutdown of the Catskill Aqueduct to conduct repairs (2018). As shown in **Figure 7.1-17**, during the community release that was maintained for most of the year in 2016, turbidity levels were typically below 5 NTU with an increase to 15 NTU in the fall. During local storm events over this time period, release turbidity levels remained relatively constant and low, while turbidity levels at Mount Marion fluctuated, indicating turbidity levels at Mount Marion were influenced by other inputs of flow and turbidity.

As shown in **Figure 7.1-18**, for a period of sustained 600 MGD (928 cfs) releases in the latter part of the year, there were several periods where turbidity levels at Mount Marion spiked while turbidity levels of the releases remained low (see **Figure 7.1-18**). During this period, flow from the Ashokan Release Channel and turbidity levels of the releases remained relatively constant while streamflow magnitude and turbidity levels of streamflow at Mount Marion followed increases (spikes) in streamflow (with turbidity levels ranging from less than 10 NTU to greater than 50 NTU). Therefore, it appears that turbidity levels in streamflow at Mount Marion are influenced by the localized conditions of the lower Esopus Creek watershed (e.g., flows into lower Esopus Creek from contributing sub-watersheds, including those that encompass the Saw Kill and Plattekill tributaries) as opposed to flow from Ashokan Reservoir. **Figure 7.1-19** shows observed streamflow and turbidity at the Lomontville gage for 2018. A similar pattern was observed to the one that was presented above for Mount Marion: turbidity and streamflow spiked at the Lomontville gage due to local contributions of flow while turbidity levels of the releases remained low.

As shown in **Figure 7.1-17** through **Figure 7.1-19** turbidity levels of streamflow within lower Esopus Creek varied over the observation period.

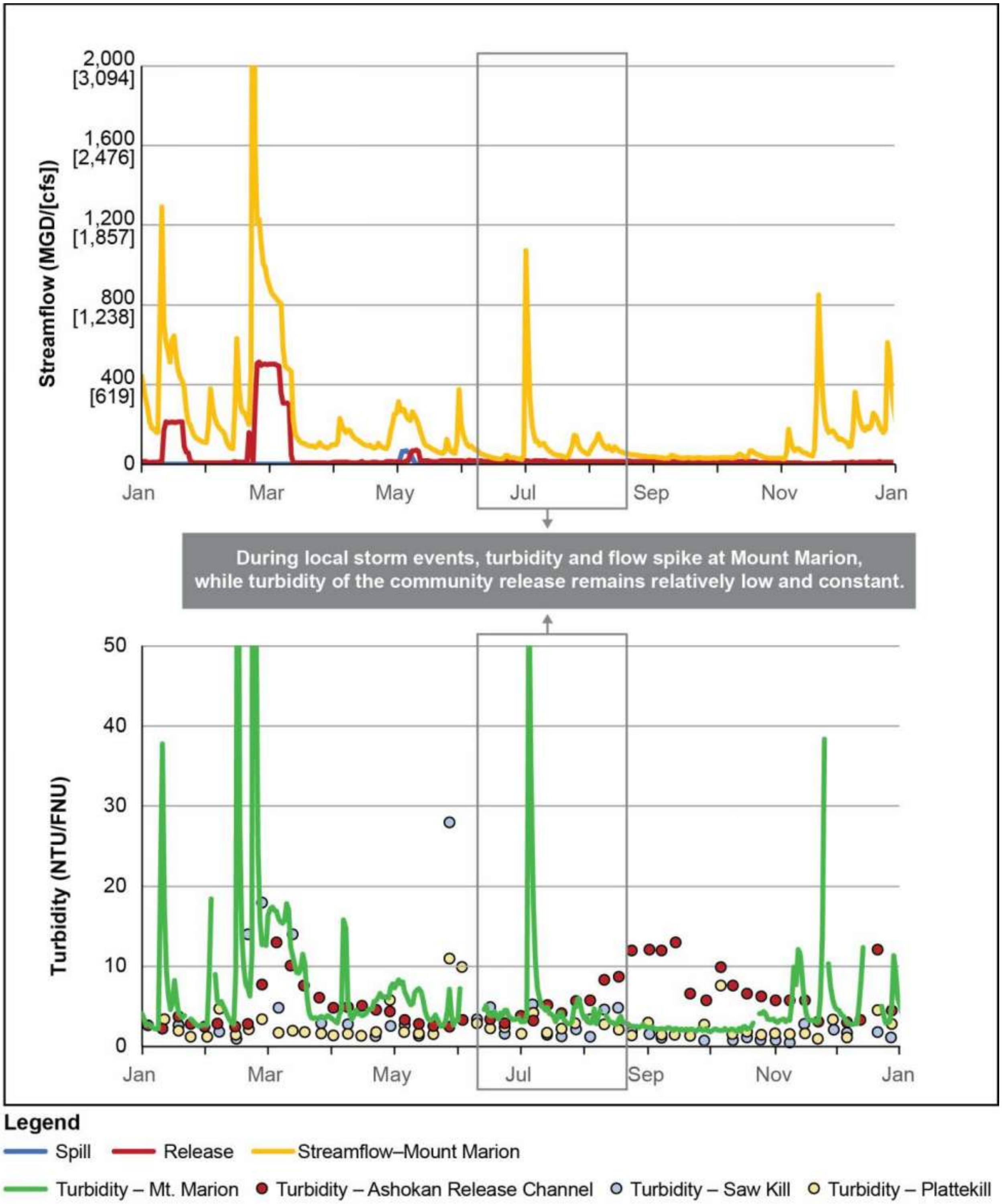

Figure 7.1-17. Observed Streamflow and Turbidity Levels at Mount Marion (2016-2017)

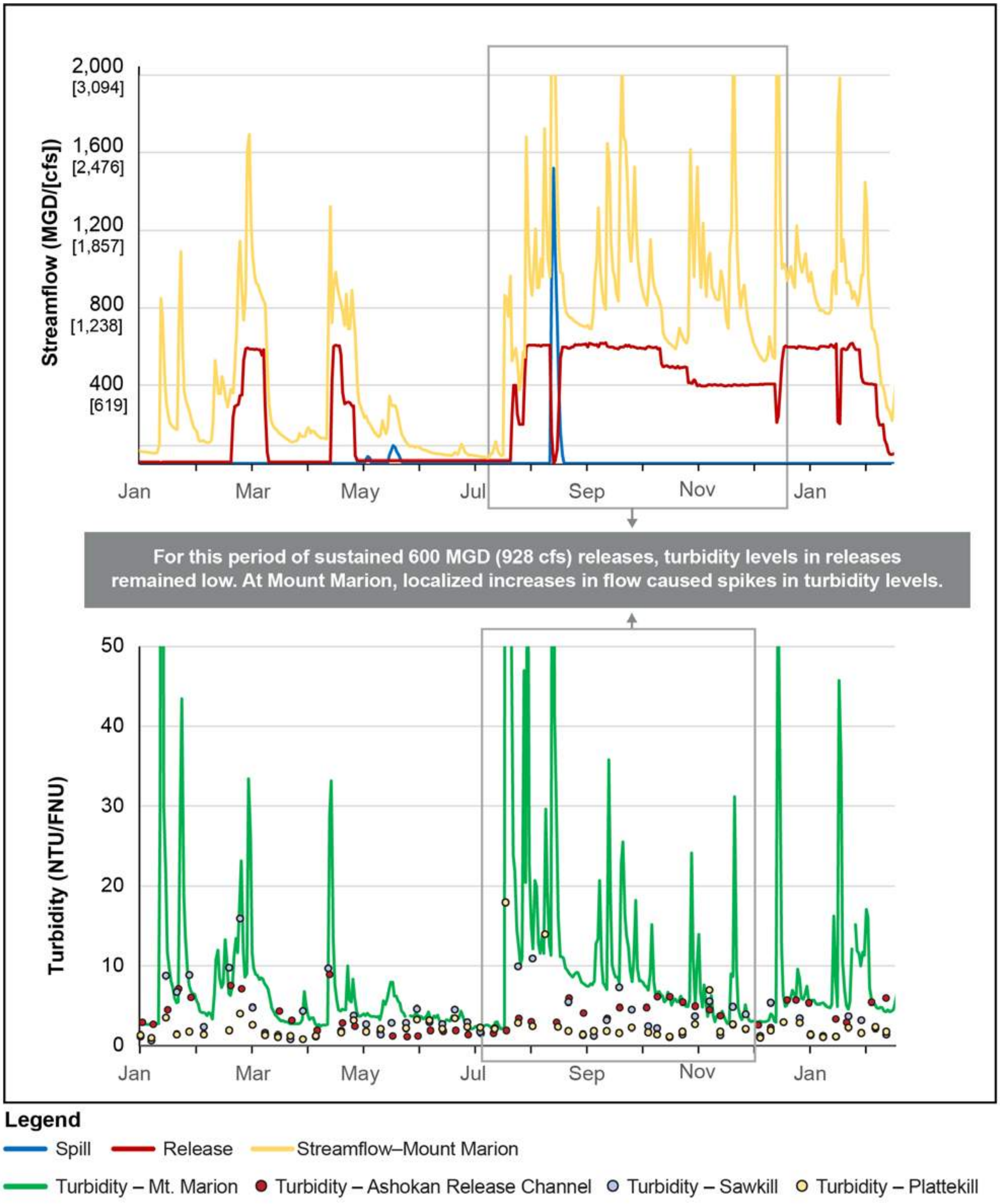

Figure 7.1-18. Observed Streamflow and Turbidity Levels at Mount Marion (2018-2019)

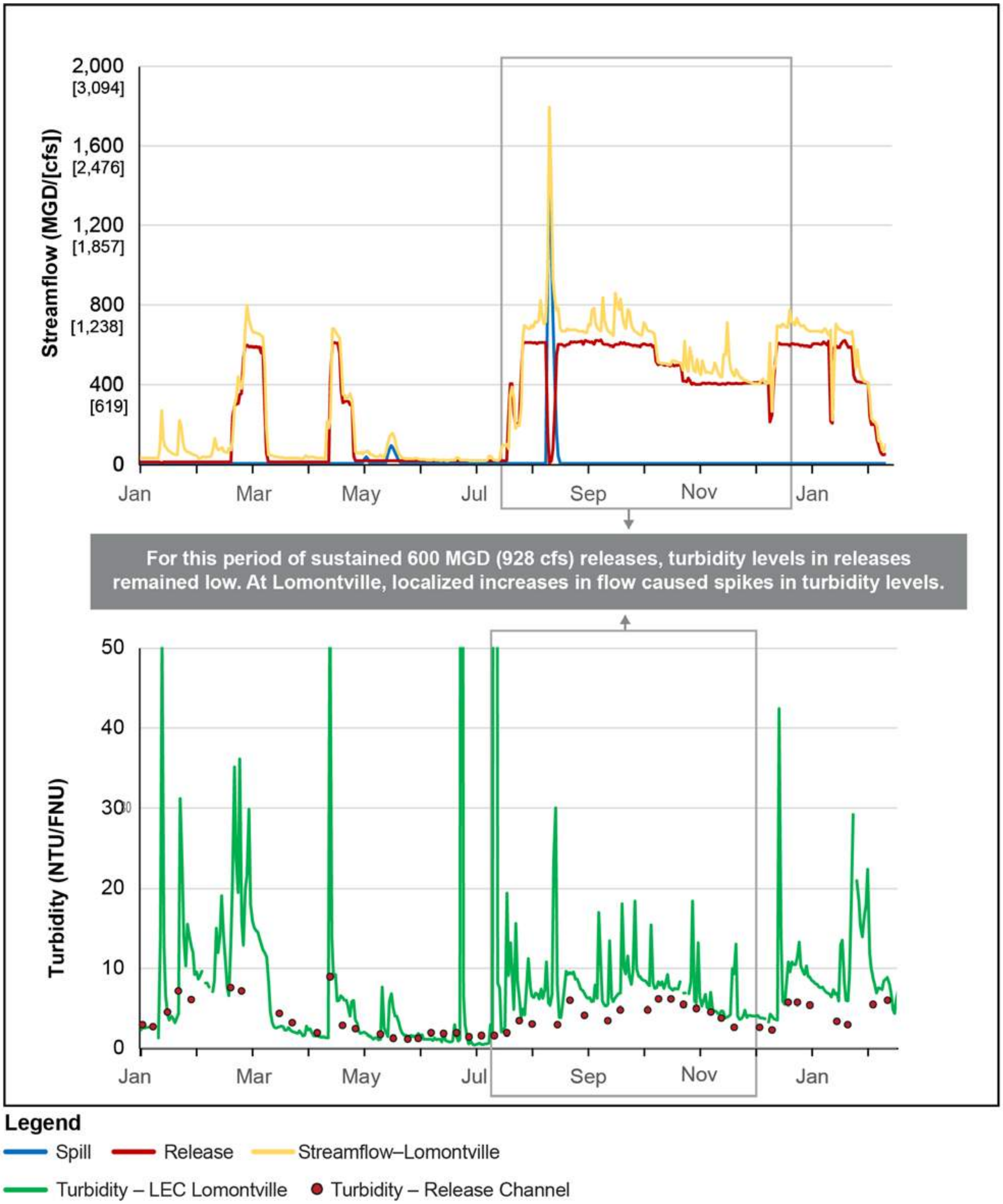

Figure 7.1-19. Observed Streamflow and Turbidity Levels at Lomontville (2018-2019)

TEMPERATURE

In addition to turbidity, the EIS considered potential changes to water temperature within lower Esopus Creek that could occur in the future with the Proposed Action. Observed temperatures in lower Esopus Creek from 2011 through 2018 fluctuated seasonally, reaching highs of 77°F or more during the summer months and dipping to lows of about 32°F (and occasionally freezing) during winter months. Observed average temperatures within Ashokan Reservoir and lower Esopus Creek by season are shown in **Table 7.1-3.**

Table 7.1-3. Observed Average Water Temperatures in Ashokan Reservoir and Lower Esopus Creek by Season

Location	Average Water Temperature (°F)			
	Winter	Spring	Summer	Fall
Hurley Mountain Road	38	54	73	62
Ashokan Reservoir Spills[1]	--	52	69	66
Ashokan East Basin (surface)	37	46	74	61
Ashokan Reservoir Releases	37	42	56	57

Note:
[1] Because spill temperature is only collected when the Reservoir is spilling, water temperatures near the surface of the east basin are also provided. There were no spill data available for winter.

Figure 7.1-20 shows ranges of observed concurrent temperature data at seven locations along lower Esopus Creek during the community release in the summer months of 2013 to 2016 (the only time period where temperature is available at all sites along lower Esopus Creek). For context, temperatures in lower Esopus Creek's two main tributaries, the Saw Kill and Plattekill, are also shown. All of the plots show measured weekly data over the same time period. As shown on the figure, temperatures were lowest in the Ashokan Release Channel, somewhat higher at the spillway confluence, and were generally equal to background temperatures when flows reached Lomontville, indicating that for this period, temperatures of the release did not affect temperatures of streamflow in lower Esopus Creek.

Releases in the future with the Proposed Action are anticipated to lower stream temperatures in summer. The extent of these effects would depend on flow magnitude and would diminish moving downstream.

The effect of releases on temperatures in lower Esopus Creek would vary depending on the time of year. Since releases consist of water from deep beneath the Reservoir surface, they can be cooler than ambient creek temperatures in the summer as compared to the temperature of spills, which occur from the surface of the Reservoir. Therefore, during the warmer summer months, releases have the potential to lower ambient water temperatures for certain portions of lower Esopus Creek, depending on the magnitude of the release, as compared to spills in the future without the Proposed Action. For higher releases, the influence of the lower water temperature of releases in the summer could extend farther downstream, but temperature differences are still anticipated to have less of an effect downstream as the percent contribution of flow from Ashokan Reservoir to streamflow within lower Esopus Creek diminishes (see Section 6.2, "Operation of Ashokan Reservoir in Accordance with the IRP").

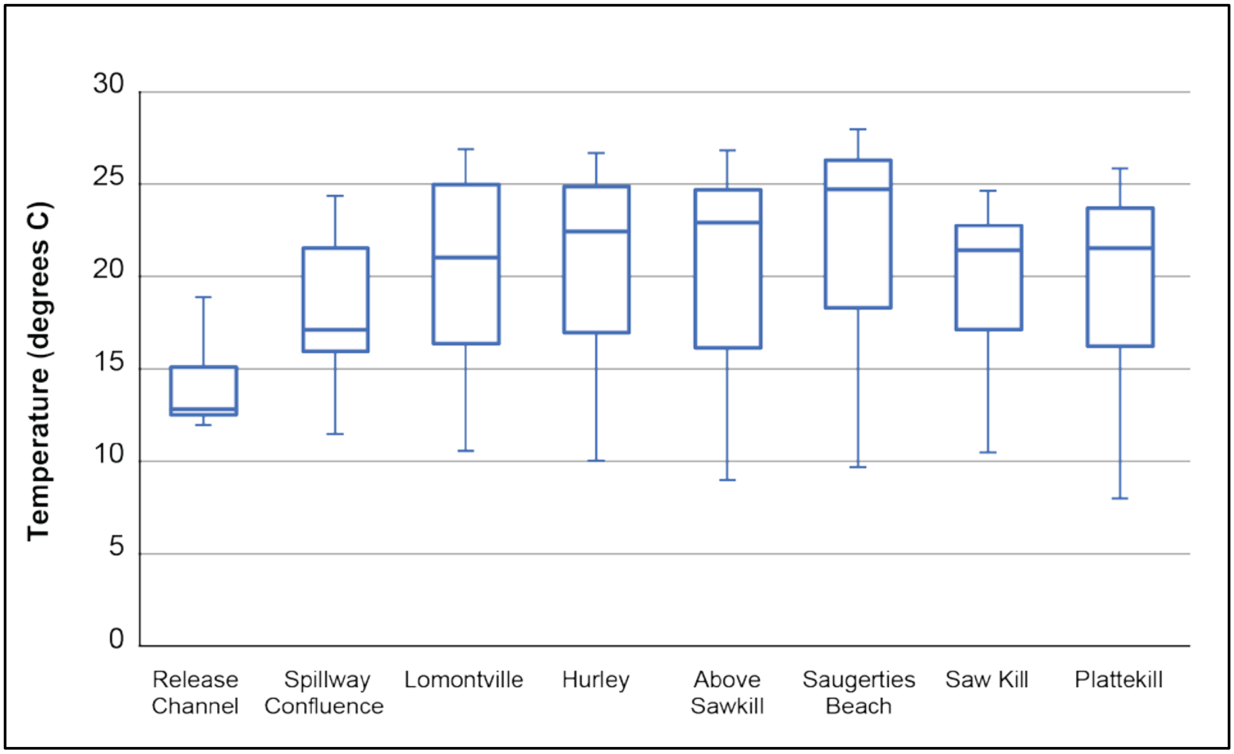

Figure 7.1-20. Observed Temperature Profile Along Lower Esopus Creek (21 concurrent measurements)

DISSOLVED OXYGEN (DO) AND PH

DEP collected intermittent data on dissolved oxygen (DO) and pH at lower Esopus Creek monitoring sites in 2011. Graphs of these observed data are shown on **Figure 7.1-21** and **Figure 7.1-22**, respectively, which also includes data from Boiceville and the west basin of Ashokan Reservoir for context.[9] Relative to DO, which is inversely related to water temperature, seasonal patterns were clearly apparent but are not anticipated to change as a result of summertime releases since temperature changes would diminish downstream of Valley Reach 1B. There were no distinguishable patterns or trends for pH during the monitoring period. Therefore, there is no anticipated difference in DO and pH within lower Esopus Creek between the future without and with the Proposed Action.

[9] DEP maintains a monitoring point for influent turbidity to Ashokan Reservoir from upper Esopus Creek at Boiceville. The point is located at the point where upper Esopus Creek enters the Reservoir. The period of record is 1990 through the present.

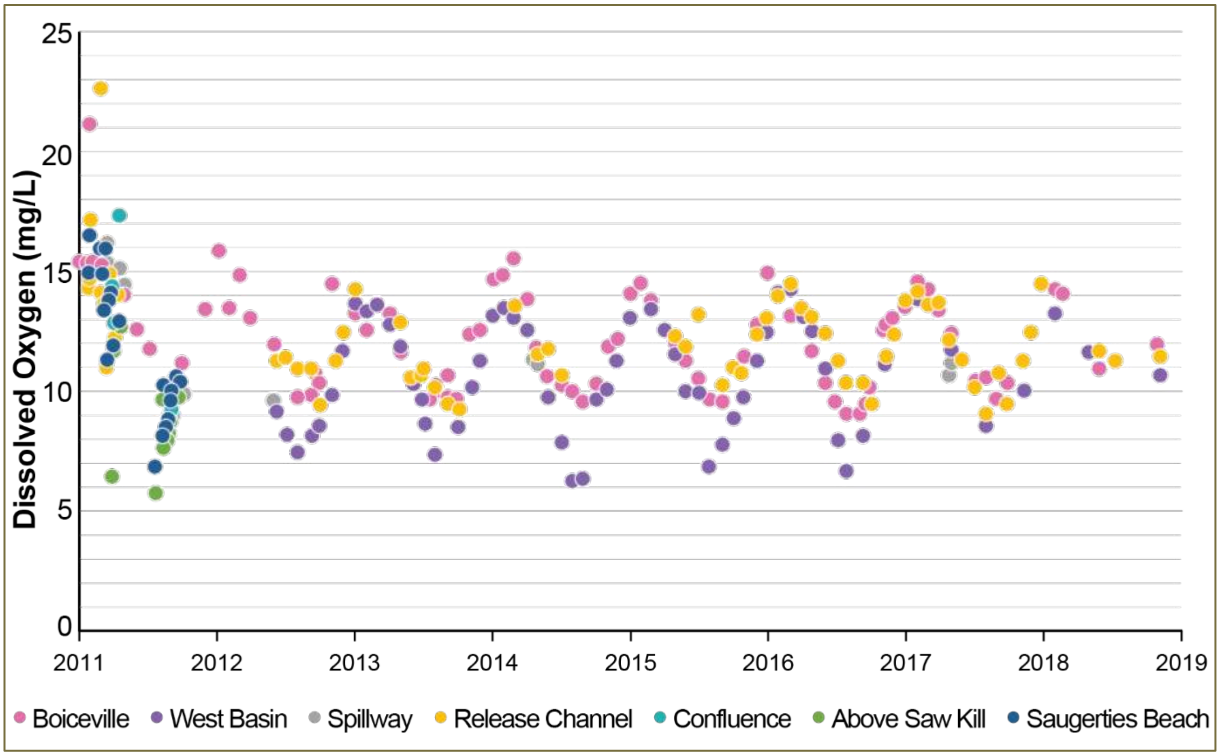

Figure 7.1-21. Observed Dissolved Oxygen for Points Along Esopus Creek, 2011–2018

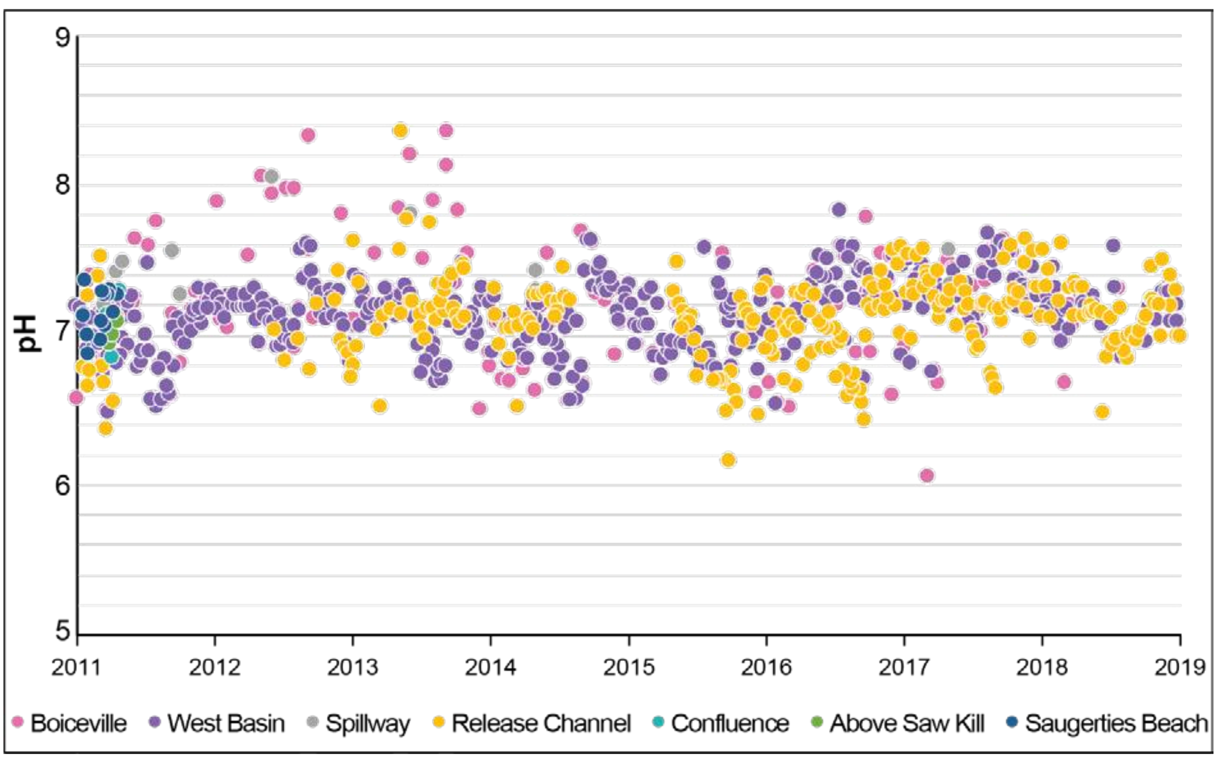

Figure 7.1-22. Observed pH for Points Along Esopus Creek, 2011–2018

FLOOD FREQUENCY AND EPISODIC TURBIDITY EVENTS

FLOOD RECURRENCE

High streamflow can occur within lower Esopus Creek during any season of the year but is most likely to occur in the late winter to early spring months when extreme (in magnitude and/or duration) precipitation events can combine with melting snow. High streamflow events in late summer have also historically occurred as a result of thunderstorms, tropical storms, and hurricanes carrying abundant amounts of rain as they travel up the eastern seaboard. The National Weather Service (NWS) sets various flood levels (stages) which are associated with specific water levels in relation to the Mount Marion gage, as well as a corresponding streamflow. Historical streamflow records at Mount Marion were analyzed to determine peak streamflow return periods and are presented alongside the NWS flood levels in **Figure 7.1-23**. Since the streamflow frequency estimates are based on observed streamflow, they inherently account for flood attenuation provided by Ashokan Reservoir.[10]

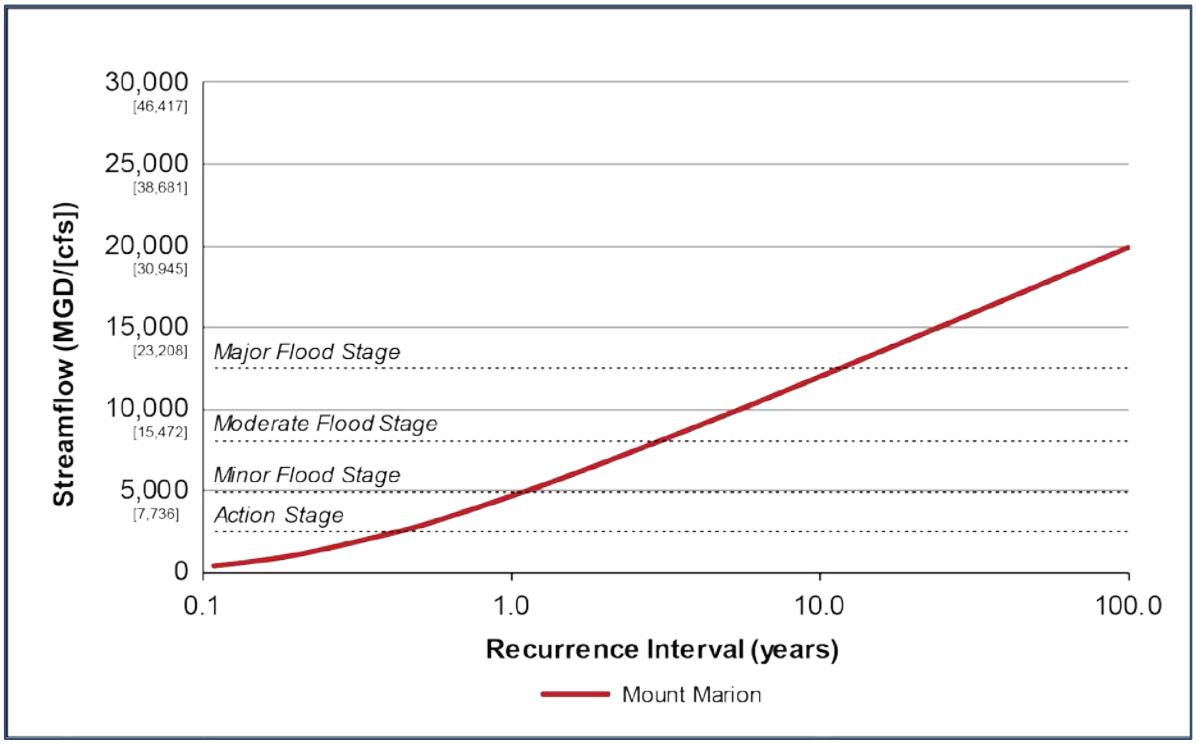

Figure 7.1-23. Observed Flood Magnitudes at Mount Marion for 2-Month to 100-Year Recurrence Intervals

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[10] The water level in Ashokan Reservoir at the time of peak streamflow events affects the level of attenuation provided; however, prior studies have demonstrated that reservoirs reduce flood peaks even when they are full and spilling. The Major Flood Stage upstream of Ashokan Reservoir at Coldbrook is 24,900 MGD (38,526 cfs), almost twice the Major Flood Stage at Mount Marion, 12,500 MGD (19,340 cfs), highlighting the Reservoir's flood attenuation capacity.

Figure 7.1-24 shows estimated peak streamflow frequencies for the future without and with the Proposed Action up to the 100-year recurrence interval based on the methods of USGS Bulletin 17B.[11] **Figure 7.1-25** shows the same data with a focus on peak streamflow recurrence intervals up to ten years. In general, in the future with the Proposed Action, as compared to the future without the Proposed Action, peak streamflow would be approximately 20 percent lower for all recurrence intervals. For example, as shown in **Figure 7.1-25**, the streamflow associated with a 1-year streamflow event would be approximately 3,800 MGD (5,879 cfs) in the future without the Proposed Action, and in the future with the Proposed Action, the streamflow for a 1-year event would be approximately 3,000 MGD (4,642 cfs). The same information is presented in **Figure 7.1-26** to show how magnitudes of 2 to 100-year streamflow events differ between the future without and with the Proposed Action for Valley Reach 1B (between the spillway confluence and the Lomontville gage) and at the Mount Marion gage. For all streamflow events, magnitudes increase moving downstream but are lower in the future with the Proposed Action as compared to the future without the Proposed Action.

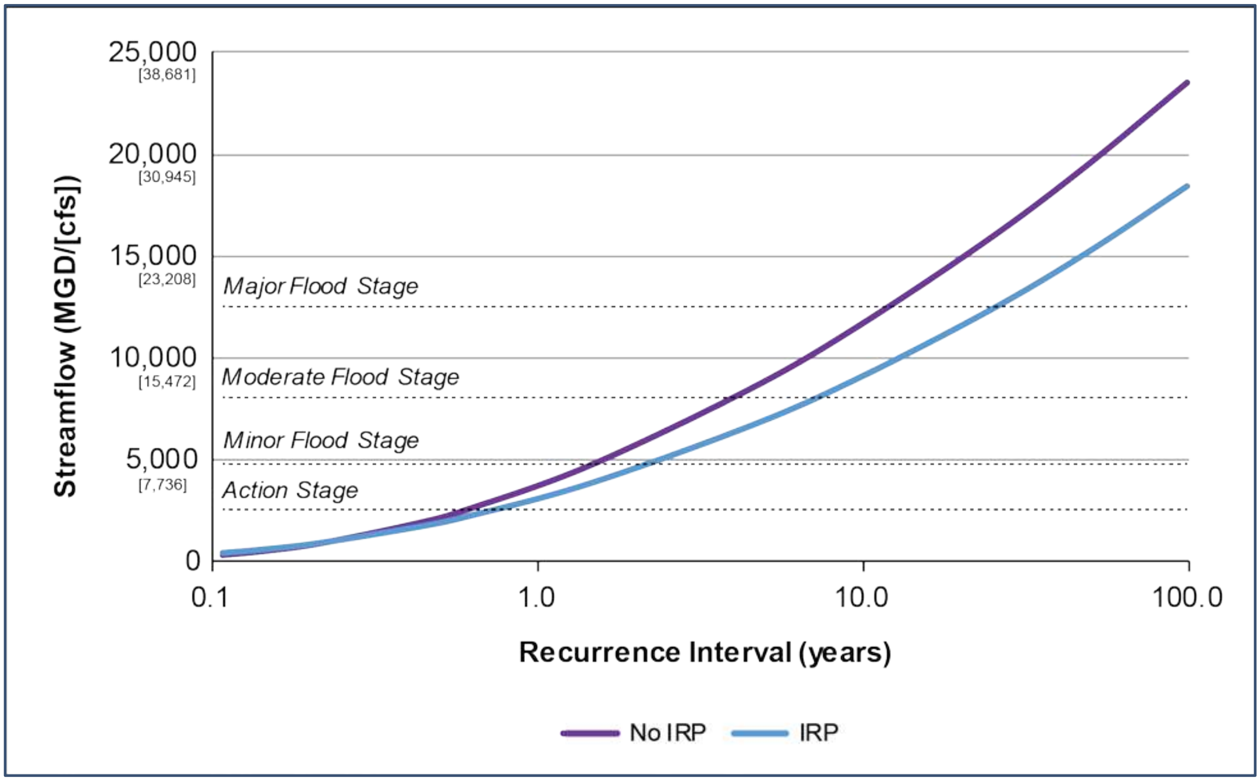

Figure 7.1-24. Modeled Flood Magnitudes at Mount Marion for 2-Month to 100-Year Recurrence Intervals

[11] USGS Bulletin 17B is a traditional federal method for performing flood frequency analysis in the United States and has been used for numerous unregulated and regulated flood frequency studies since its publication in 1982. The methodology uses historical streamflow observations to develop a Log-Pearson Type III distribution for determining flood recurrence intervals (e.g., 100-year, 500-year) at a given location (i.e. Mount Marion). USGS. "Guidelines for Determining Flood Flow Frequency." *Bulletin 17B of the Hydrology Subcommittee*. 1982.

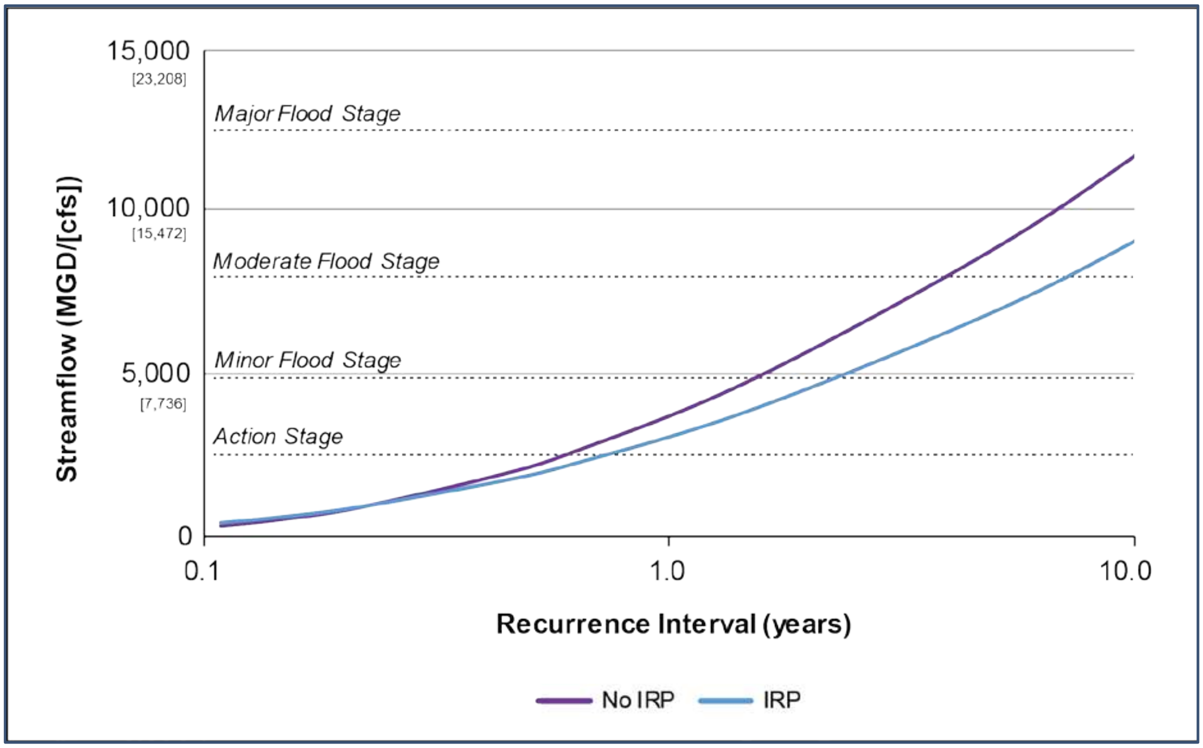

Figure 7.1-25. Modeled Flood Magnitudes at Mount Marion for 2-Month to 10-Year Recurrence Intervals

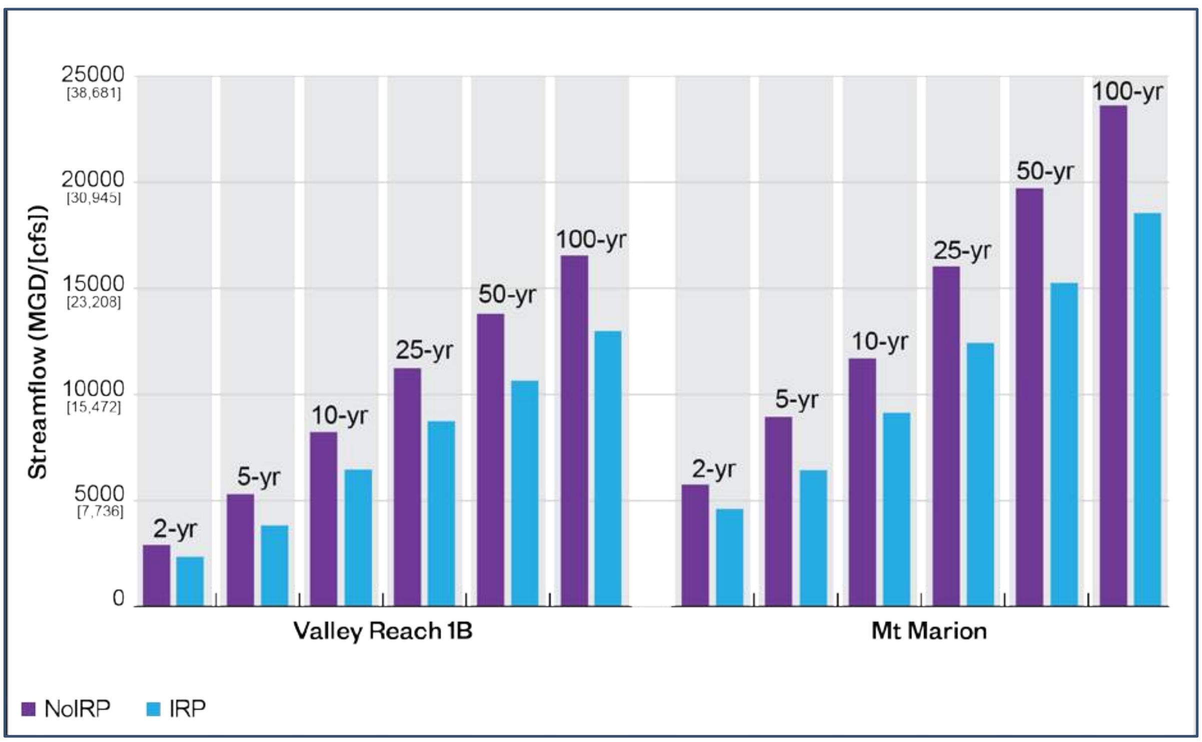

Figure 7.1-26. Modeled Flood Magnitudes for Various Streamflow Events Along Lower Esopus Creek

To provide context for this portion of the assessment, peak streamflow estimates that were calculated for the EIS were compared to flood frequency estimates from the Federal Emergency Management Agency (FEMA). Estimates conducted for the EIS indicate a 100-year streamflow of approximately 20,000 MGD (30,945 cfs) at Mount Marion. FEMA's Ulster County Flood Insurance Study #36111CV001B report dated November 18, 2016 (2016 FEMA FIS) indicates a 100-year streamflow of approximately 35,500 MGD (54,927 cfs) for the same location, which the 2016 FEMA FIS refers to as Glasco Turnpike (see **Table 7.1-4).**

Table 7.1-4. Flood Frequency Estimates for the 100-year Recurrence Interval

Analysis	100-year Streamflow	Location
EIS Analysis (Observed Streamflow)	20,000 MGD (30,945 cfs)	Mount Marion
2016 FEMA FIS	35,500 MGD (54,927 cfs)	Glasco Turnpike

Table 7.1-5 provides the streamflow associated with all reported flood recurrence intervals from the 10- to 500-year streamflow event from the 2016 FEMA FIS through Glasco Turnpike (end of Valley Reach 3E). A map of these locations in relationship to the valley reaches assessed in the EIS is presented in **Figure 7.1-27.** Peak streamflow frequencies derived for the EIS were developed based on a methodology focused on identifying the potential for incremental differences in streamflow between the future without and with the Proposed Action. The EIS is not intended to provide flood frequency estimates for other uses such as floodplain mapping, for which FEMA is the sole authority.

Table 7.1-5. FEMA FIS Summary of Discharges[1]

Location	Discharge Area (square miles)	Peak Discharges (MGD [cfs])			
		10-year storm	50-year storm	100-year storm	500-year storm
Upstream of the confluence with Ashokan East Spillway Channel	11.6	1,015 [1,570]	1,764 [2,730]	2,139 [3,310]	3,186 [4,930]
From Hurley Mountain Road upstream to confluence with Ashokan East Spillway Channel	256.0	6,851 [10,600]	19,551 [30,250]	28,600 [44,250]	65,278 [101,000]
350 feet downstream Hurley Mount Road	297.7	6,851 [10,600]	19,803 [30,640]	28,890 [44,700]	69,156 [107,000]
At Interstate Route 587/State Route 28	319.0	6,762 [10,462][2]	19,760 [30,573][2]	29,376 [45,452]	70,597 [109,230]
At Glasco Turnpike	419.0	8,928 [13,814]	22,149 [34,270]	35,491 [54,913]	96,820 [149,802]

Notes:

1 FEMA defines discharge as the volume of water that passes a given location within a given period of time. Usually expressed in cubic feet per second (cfs).

2 Peak discharges decrease due to widening of lower Esopus Creek upstream of this location, increasing the storage within the stream channel.

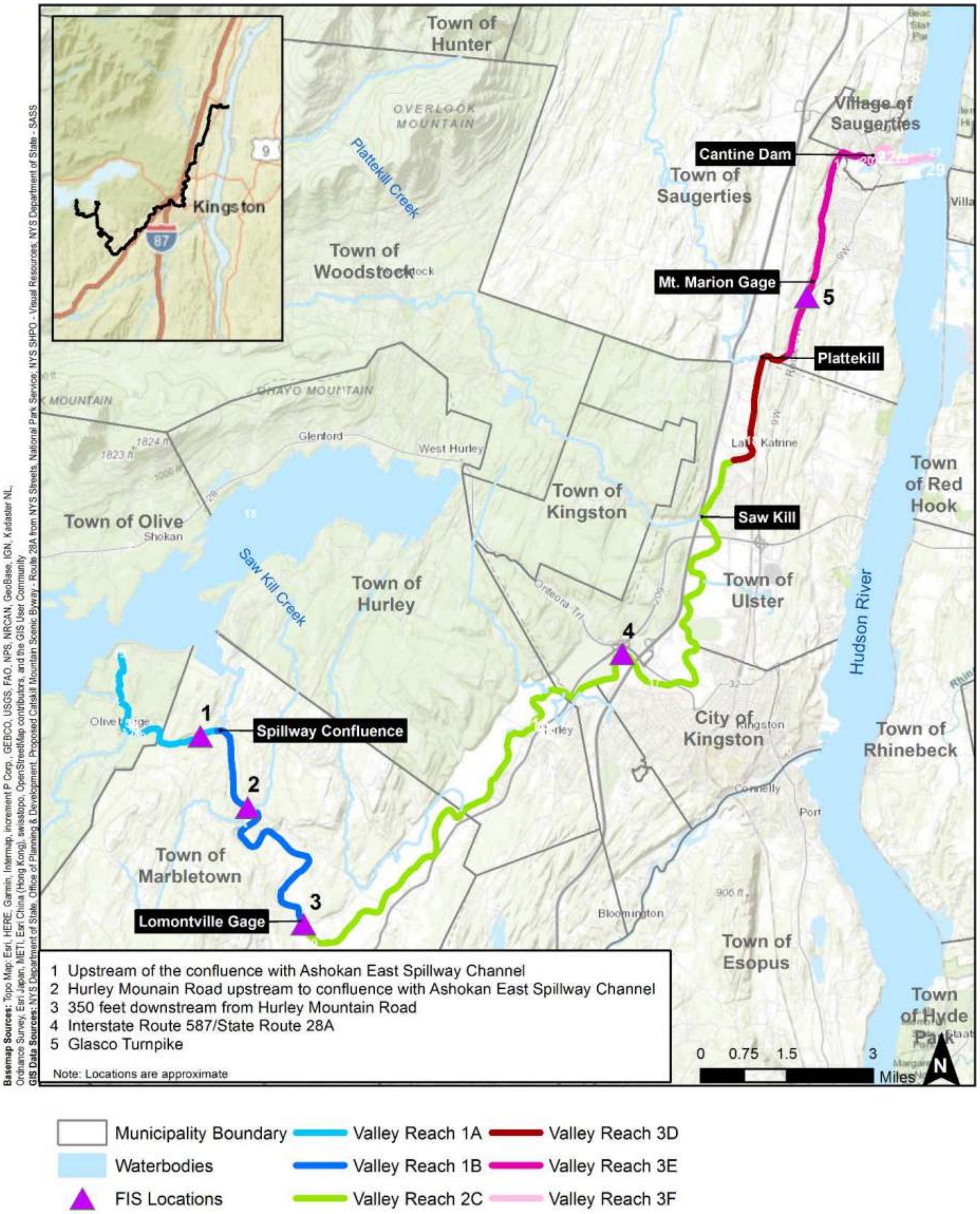

Figure 7.1-27
2016 FEMA FIS Locations along Lower Esopus Creek

EPISODIC TURBIDITY EVENTS

Turbidity in flows from Ashokan Reservoir would generally be low. However, at times, flows from the Reservoir can transfer turbidity downstream via the Catskill Aqueduct and to lower Esopus Creek (**Figure 7.1-28)**. Eleven episodic turbidity events requiring alum application occurred over the past 37 years and all were driven by turbidity originating in the upper Esopus Creek watershed. These events are infrequent and would occur in the future without or with the Proposed Action. Historical episodic turbidity events requiring application of alum to water in the Catskill Aqueduct upstream of Kensico Reservoir were reviewed for inflow of turbidity to Ashokan Reservoir and spills to lower Esopus Creek (see Section 1.2.4, "Alum Application and Ashokan Release Channel Use"). **Table 7.1-6** shows observed data for the turbidity levels of inflows from upper Esopus Creek, Reservoir turbidity levels, and average, maximum, and minimum spill volumes for each of the historical alum events where these data are available. For events where data are available, average spills ranged from 200 to 700 MGD (309 to 1,083 cfs) with maximum spills to lower Esopus Creek reaching 6,300 MGD (9,748 cfs). As shown, even under these historical events requiring alum application, Ashokan Reservoir provided some reduction in turbidity as compared to inflows from upper Esopus Creek for several of the events.

Table 7.1-6. Summary of Spills, Influent Turbidity Levels, and Ashokan Turbidity Levels for Alum Events (Observed)

Alum Event		Spill (MGD [cfs])		Boiceville Turbidity Levels (NTU)[1]			Ashokan West Basin Turbidity Levels (NTU)[2]		
Start	**Days**	**Max**	**Avg**	**No. of Measurements**	**Max**	**Avg**	**No. of Measurements**	**Max**	**Avg**
2/21/1981	72	0	0	0	NA	NA	0	NA	NA
4/9/1984	44	2,890 [4,471]	720 [1,114]	0	NA	NA	0	NA	NA
4/6/1987	43	6,200 [9,593]	700 [1,083]	0	NA	NA	6	150	90
1/22/1996	151	2,150 [3,327]	345 [534]	118	710	52	43	346	150
1/14/1997	15	15 [23]	2 [3]	9	16	7	2	10	9
1/10/2001	23	0	0	16	33	26	3	32	29
4/5/2005	76	2,500 [3,868]	200 [309]	16	140	60	24	225	166
10/13/2005	294	6,250 [9,670]	475 [735]	69	761	56	44	110	24
1/31/2011	11	0	0	3	16	13	4	45	44
3/2/2011	79	3,870 [5,988]	530 [820]	11	60	25	28	160	55
8/29/2011[3]	262	6,340 [9,809]	200 [309]	38	360	38	60	1,600	251

Notes:
[1] The DEP Boiceville gage provides turbidity data for upper Esopus Creek inflows to Ashokan Reservoir.
[2] Ashokan West Basin turbidity levels are measured in the West Basin of Ashokan Reservoir at the gatehouse window.
[3] Note that some of the turbidity level gages became inoperable during Tropical Storm Irene.
NA - Not applicable

Flows and turbidity levels from the 11 historical alum events were analyzed in the future without and with the Proposed Action to compare potential turbidity conditions in lower Esopus Creek and alum application to water in the Catskill Aqueduct upstream of Kensico Reservoir. The analysis was performed with stop shutters, the Catskill/Delaware Interconnection at Shaft 4, and the Croton Water Filtration Plant online. Results of this analysis are presented in **Table 7.1-7**.

Use of stop shutters, Shaft 4, and the Croton WFP provide the largest benefit in reducing alum days.

As shown in the table, modeling indicates there would be a similar and sizable reduction in the number of days of alum application (alum days) during these episodic turbidity events in the future without and with the Proposed Action as compared to historical conditions presented in Section 1.2.4, "Alum Application and Ashokan Release Channel Use." [12] This is primarily due to the aforementioned DEP infrastructure (turbidity control measures) that are completed and available for use.

Most historical turbidity events that resulted in alum application were the result of large storm events. Given the magnitude of these events, turbid spills would occur in both the future without and with the Proposed Action, transferring a similar amount of turbidity to lower Esopus Creek.

[12] Each day that DEP applies alum to water in the Catskill Aqueduct upstream of Kensico Reservoir is considered an alum day.

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Turbidity in Upper Esopus Creek and Ashokan Reservoir

Geologic conditions in DEP's Catskill System watershed can cause episodic changes to water quality as a consequence of events, such as extreme storms, which can erode the naturally occurring silt and clay deposits present in the watershed's relatively steep slopes, stream banks, and channels. Such events result in elevated turbidity levels in the water of the Catskill System, and occasionally in diversions of water from Ashokan Reservoir to Kensico Reservoir.

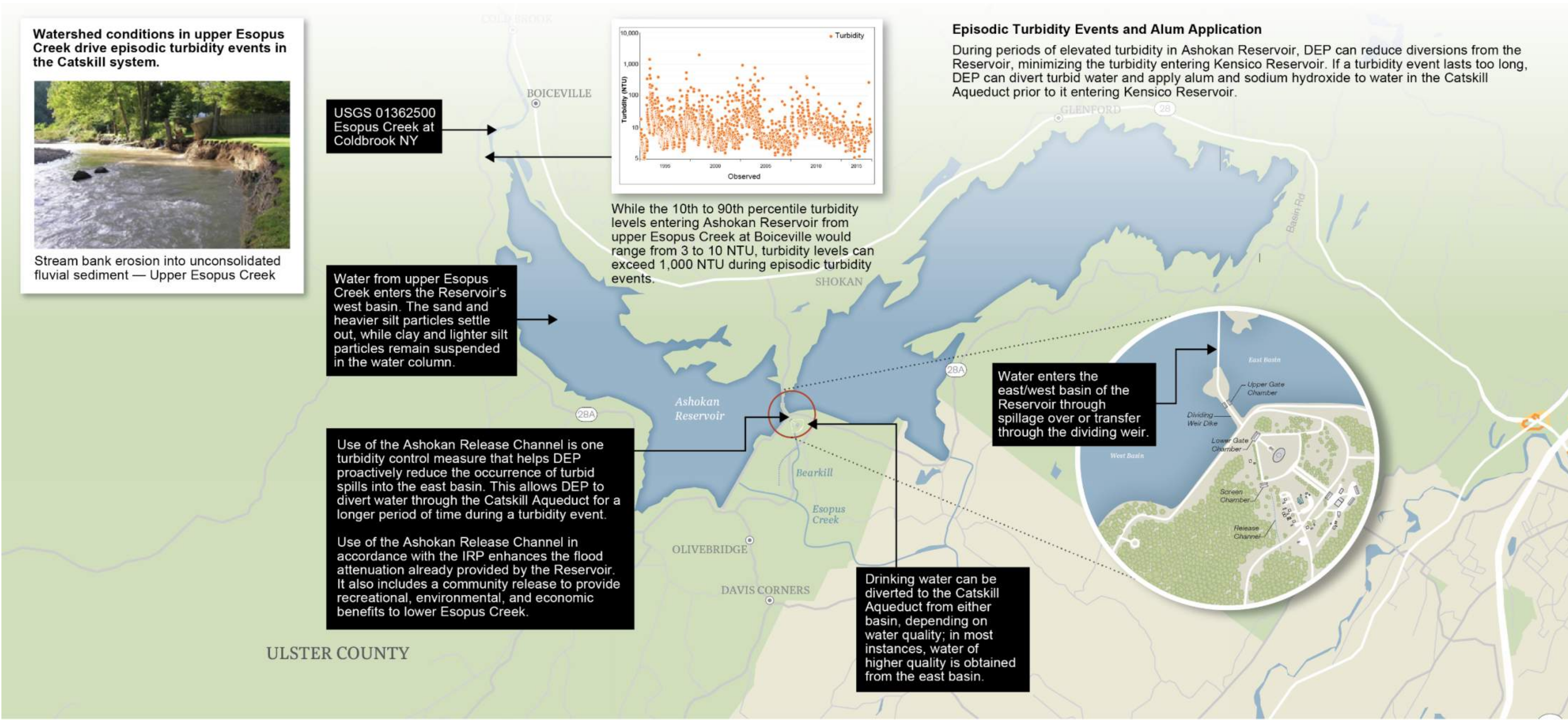

Figure 7.1-28
Turbidity Levels in Ashokan Reservoir

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Table 7.1-7. Modeled Spills, Influent Turbidity Levels, and Ashokan Turbidity Levels for the Future Without and With the Proposed Action for Historical Alum Events[1]

Historical Alum Event		Coldbrook Streamflow (MGD [cfs])		Modeled Inflow Turbidity Levels (NTU)		Future Without the Proposed Action				Future With the Proposed Action				Future Without the Proposed Action		Future With the Proposed Action	
						Modeled Spill (MGD [cfs])		Modeled Confluence Flow (MGD [cfs])		Modeled Spill (MGD [cfs])		Modeled Confluence Flow (MGD cfs])		Modeled Alum Days	Modeled Days >30 NTU[2]	Modeled Alum Days	Modeled Days >30 NTU[2]
Start Date	Days	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg				
2/21/1981	72	3,860 [5,972]	918 [1,420]	144	13	6,220 [9,624]	505 [781]	6,220 [9,624]	505 [781]	2,490 [3,853]	269 [416]	2,490 [3,852]	431 [667]	-	-	-	-
4/9/1984	44	2,280 [3,528]	693 [1,072]	118	25	2,554 [3,952]	897 [1,388]	2,554 [3,952]	897 [1,388]	2,550 [3,945]	752 [1,164]	2,550 [3,945]	940 [1,454]	5	10	6	11
4/6/1987	43	2,390 [3,68]	640 [990]	223	25	5,921 [9,161]	908 [1,405]	5,921 [9,161]	908 [1,405]	5,898 [9,126]	903 [1,397]	5,898 [9,126]	940 [1,454]	8	28	8	28
1/22/1996	151	6,720 [10,397]	581 [899]	568	20	5,869 [9,081]	601 [930]	5,869 [9,081]	601 [930]	5,868 [9,079]	259 [401]	5,868 [9,079]	586 [907]	-	-	-	22
1/14/1997	15	187 [289]	151 [234]	7	4	23 [36]	5 [8]	23 [36]	5 [8]	-	-	67 [104]	17 [26]	-	-	-	-
1/10/2001	23	243 [376]	206 [319]	6	4	-	-	-	-	-	-	600 [928]	202 [313]	-	-	-	-
4/5/2005	76	1,430 [2,213]	435 [673]	53	11	2,431 [3,761]	385 [596]	2,431 [3,761]	385 [596]	2,370 [3,667]	304 [470]	2,370 [3,667]	426 [659]	6	3	6	5
10/13/2005	294	7,370 [11,403]	929 [1,437]	541	21	5,921 [9,161]	434 [671]	5,921 [9,161]	434 [671]	5,925 [9,167]	127 [196]	5,925 [9,167]	378 [585]	-	-	-	14
1/31/2011	11	282 [436]	210 [325]	6	4	255 [395]	154 [238]	255 [395]	154 [238]	-	-	600 [928]	600 [928]	-	-	-	-
3/2/2011	79	9,370 [14,498]	959 [1,484]	455	45	7,577 [11,723]	1,180 [1,826]	7,577 [11,723]	1,180 [1,826]	4,497 [6,958]	778 [1,204]	4,497 [6,958]	924 [1,430]	-	-	-	-
8/29/2011	262	7,110 [11,001]	546 [845]	512	20	10,120 [15,658]	601 [930]	10,120 [15,658]	601 [930]	9,802 [15,166]	337 [521]	9,802 [15,166]	715 [1,106]	11	20	10	17

Notes:

1 Modeling of the future without and with the Proposed Action includes use of turbidity control measures anticipated to be online (stop shutters, the Catskill/Delaware Interconnection at Shaft 4, and the Croton WFP). This infrastructure is not incorporated into the modeling of historical alum events for baseline conditions. Note this does not include the most recent alum application event which was necessary to support shutdown of the Catskill Aqueduct to facilitate repairs.

2 Modeled turbidity levels are at the spillway confluence.

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To explain Catskill System operations during a turbidity event, **Figure 7.1-29** through **Figure 7.1-31** compare flows from Ashokan Reservoir and turbidity levels for three recent alum application events: April 2005, March 2011 and September 2011, respectively. Charts are provided that describe conditions in the water supply system and lower Esopus Creek during these events, labeled on each figure as Charts A through G. For details on the computation of these data, see Section 5.2, "Lower Esopus Creek Modeling Methodology."

In the future with the Proposed Action, DEP would be able to maintain diversions of water to Ashokan Reservoir for a longer period of time and reduce the turbidity load entering the Catskill Aqueduct.

Modeled differences between the future without and with the Proposed Action vary by event but follow the same general pattern. In the future with the Proposed Action, releases are made in advance of an event to maintain the CSSO within Ashokan Reservoir, as shown on "Ashokan Release" Chart G on **Figure 7.1-30** and **Figure 7.1-31**, for the modeled March 2011 and September 2011 alum events, respectively. From a water supply standpoint, this would allow DEP to maintain diversions of water from Ashokan Reservoir to Kensico Reservoir, which would allow DEP to utilize Catskill System water for a longer period of time, corresponding with a delayed need to increase diversions of Delaware System water (Chart C for the September 2011 alum event). In addition, releases would lower the turbidity load entering the Catskill Aqueduct during and following an event (Chart D for the March 2011and September 2011 events). The number of alum days between the future without and with the Proposed Action are comparable (see Chart E on each figure). Releases from the Delaware and Croton systems are also comparable between the future without and with the Proposed Action for the historical alum application events.

During episodic turbidity events, the magnitude, duration, and quality of flows to lower Esopus Creek are comparable between the future without and with the Proposed Action.

Regarding flows to lower Esopus Creek, spill mitigation releases (in the future with the Proposed Action) to maintain the CSSO would delay and attenuate the peak spill during most events as compared to the future without the Proposed Action (see Chart F for the April 2005 and March 2011 events). Since releases would cease once spills from Ashokan Reservoir reach or exceed 1,000 MGD (1,547 cfs), flows to lower Esopus Creek during the peak portion of the event would solely be spills, which would occur in both the future without and with the Proposed Action (see Charts F and G for all three events).

Turbidity levels of flows to lower Esopus Creek would be comparable between the future without and with the Proposed Action as shown on Chart H for each historical alum application event.

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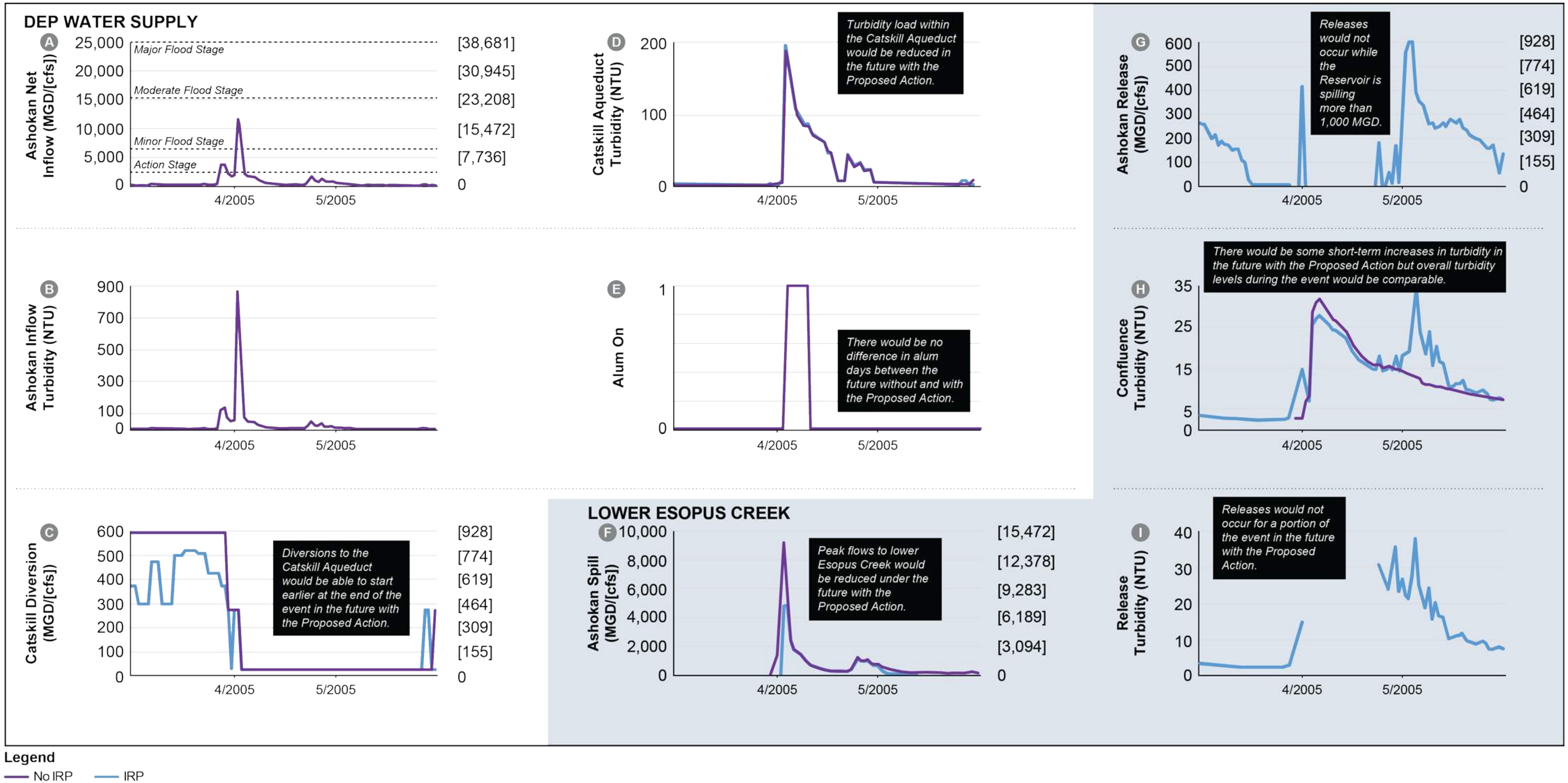

Figure 7.1-29
Modeled Flow Rates and Turbidity Levels Along Lower Esopus Creek for the April 2005 Turbidity Level Event

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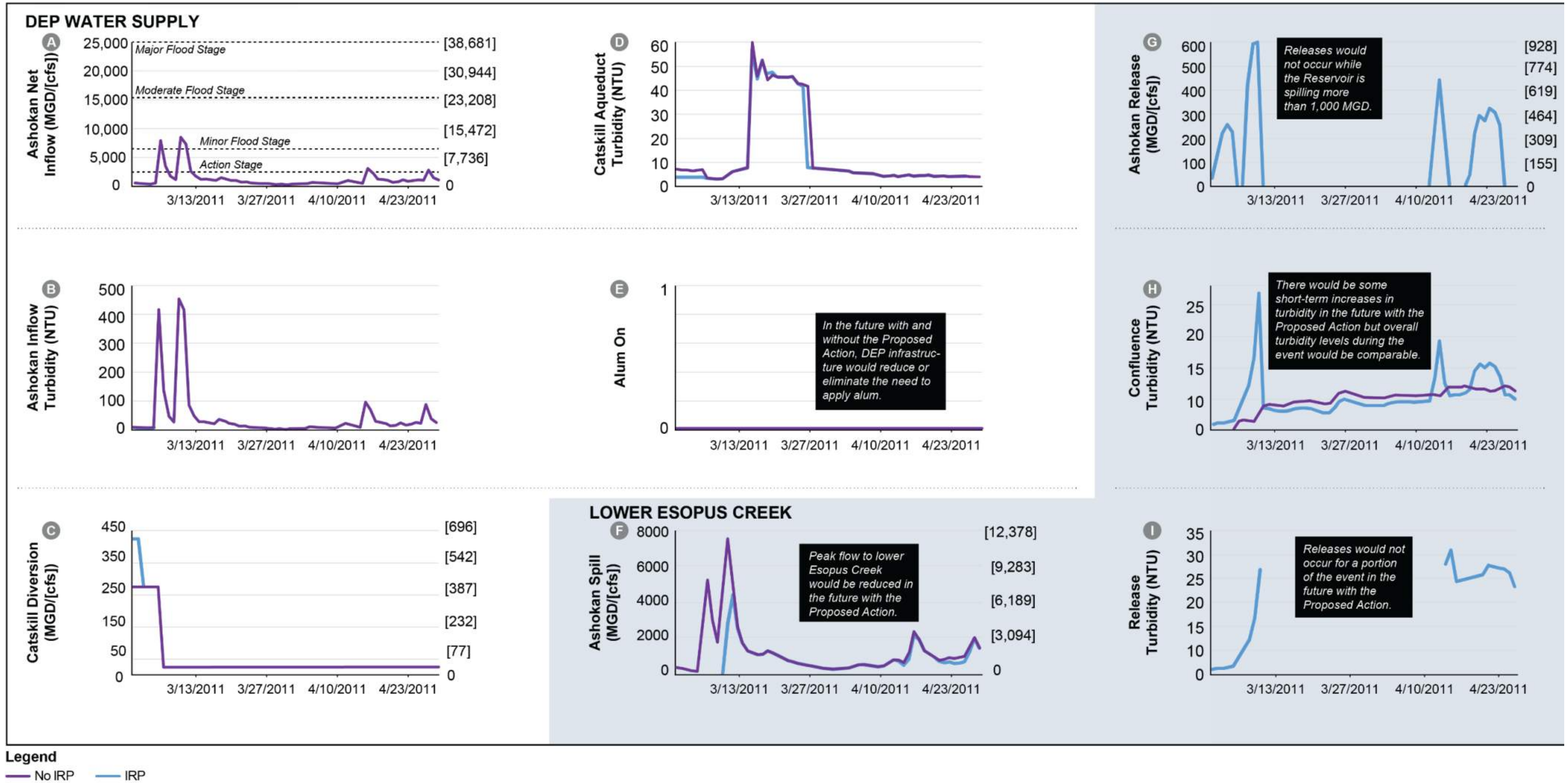

Figure 7.1-30
Modeled Flow Rates and Turbidity Levels of Spills and Releases for the March 2011 Turbidity Level Event

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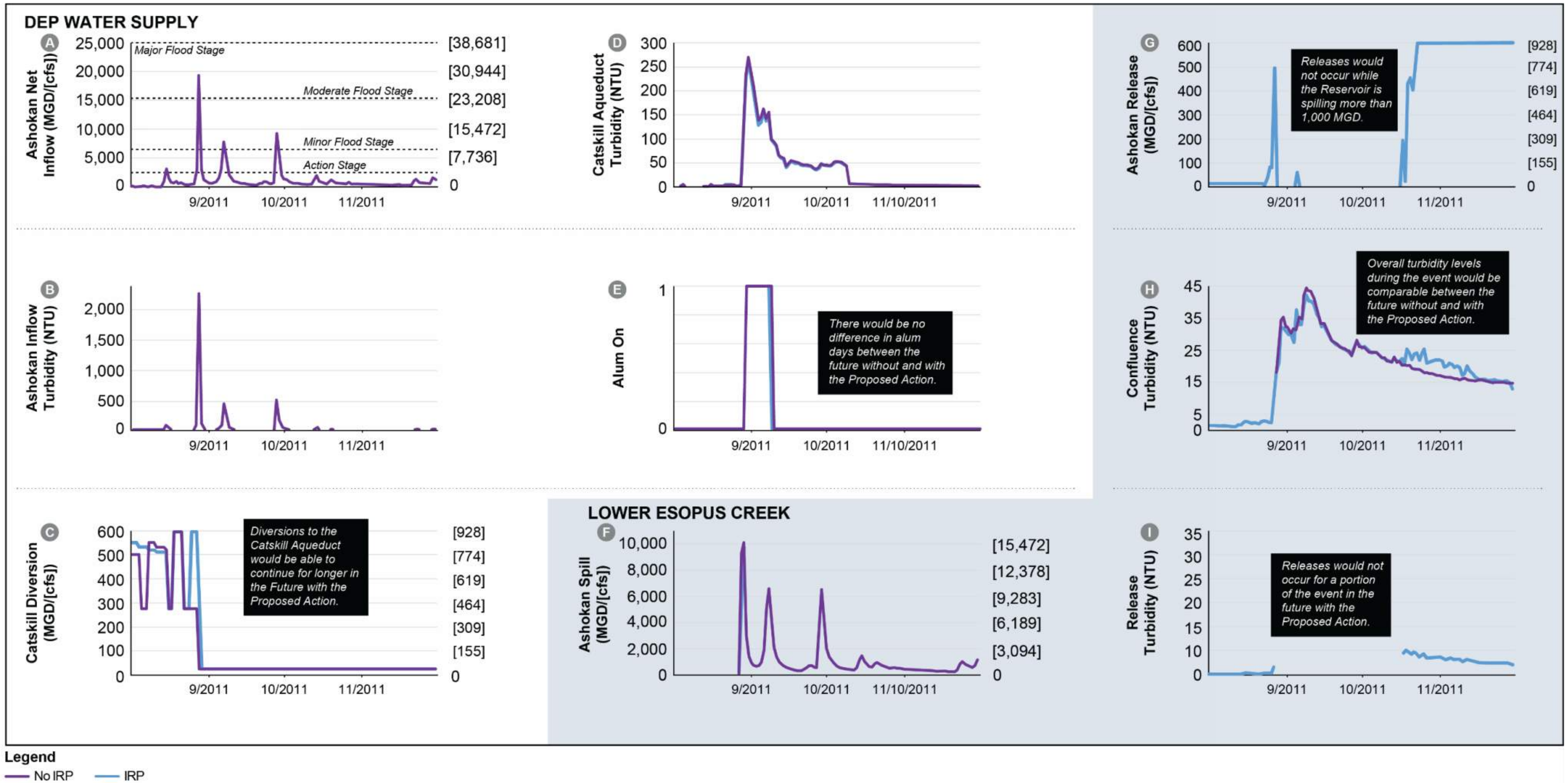

Figure 7.1-31
Modeled Flow Rates and Turbidity Levels of Spills and Releases for the September 2011 Turbidity Level Event

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7.1.2 SUMMARY OF EFFECTS OF THE PROPOSED ACTION ON DEP WATER SUPPLY RELIABILITY

As discussed at the start of Section 7.1, “Water Resources and Water Quality,” in addition to understanding how water supply operations change during episodic turbidity events, identifying potential differences in key DEP water supply metrics between the future without and with the Proposed Action provided context for evaluating changes to lower Esopus Creek flow regime and water quality compared to changes to water supply operations.

Operation of Ashokan Reservoir in accordance with the IRP was previously modeled for inclusion in the Consent Order. The IRP was implemented to enhance flood attenuation by managing Ashokan Reservoir to maintain the CSSO and provide recreational, environmental and economic benefits to lower Esopus Creek while helping DEP address episodic turbidity in the Catskill System. The IRP allows DEP to reliably provide water of sufficient quality to meet customer water demands under various hydrologic conditions, without compromising the flexibility of the water supply system (referred to as DEP water supply reliability). Even though the IRP would preserve DEP’s water supply reliability, there are differences between the future without and with the Proposed Action in the metrics that would be used to evaluate system water supply and water quality. The water supply metrics considered by DEP to assess these differences included:

- system probability of refill, which determines how likely DEP’s reservoirs are to meet a system-wide water supply storage target of 100 percent storage capacity on or around June 1st of each year;
- exceedance of established drought metrics (watch, warning, and emergency) based on reservoir storage conditions;
- balancing water supply from DEP’s three surface water systems (Catskill, Delaware, and Croton) to maintain total system storage; and
- the quality of water diverted from Ashokan Reservoir to Kensico Reservoir as measured by the number of days Catskill Aqueduct turbidity is above 8 NTU[13] and the overall number of days that DEP would need to apply alum in flows in the Catskill Aqueduct.

Table 7.1-8 shows the performance of the system for each of these metrics in the future without and with the Proposed Action. Operation of Ashokan Reservoir in accordance with the IRP in the future with the Proposed Action would result in minor differences in water supply reliability metrics. System probability of refill would be maintained; the Catskill System probability of refill would decrease, from 90 percent to 88 percent in the future without and with the Proposed Action, respectively. In the future with the Proposed Action, the percent of days over the OST simulation period that would exceed “drought warning” and “drought emergency” metrics would increase by 0.2 percent and 0.1 percent, respectively. System balancing is measured by average diversions for each system. Catskill and Croton System diversions would decrease slightly (5 MGD, 8 cfs) between the future without and with the Proposed Action and Delaware System diversions would increase (10 MGD, 15 cfs).

[13] 8 NTU is the Ashokan Diversion Turbidity Level Trigger that initiates use of the Catskill/Delaware Interconnection at Shaft 4 or stop shutters to address episodic turbidity in the Catskill Aqueduct.

Storage and diversion changes within one system can influence the operation of the other two systems. In particular, operation of Ashokan Reservoir can influence storage-based release rules of the Delaware System reservoirs, which are stipulated by the Flexible Flow Management Program (FFMP).[14.] In the future with the Proposed Action, Delaware System releases would decrease in the future with the Proposed Action as a result of increased Delaware System diversions. While the overall change in Delaware System releases would be minimal between the future without and with the Proposed Action, given the importance of meeting the FFMP, Delaware releases were evaluated seasonally to ensure there would be no shifts in seasonal releases. OST modeling indicated the reduction in seasonal releases from the Delaware System would be approximately 0 to 5 MGD (0 to 8 cfs) in June through October with a larger decrease of approximately 0 to 10 MGD (0 to 15 cfs) in November through May. These changes would allow DEP to continue to meet the release requirements of the FFMP in the future with the Proposed Action.

Overall, operation of Ashokan Reservoir in accordance with the IRP in the future with the Proposed Action would reduce the number of days per year that turbidity exceeds 8 NTU, from 48 days under the future without the Proposed Action to 39 days in the future with the Proposed Action. However, because DEP would address periods of elevated turbidity in Ashokan Reservoir through the use of stop shutters and the Catskill/Delaware Interconnection at Shaft 4 in the future with the Proposed Action, the reduction in the number of days above 8 NTU would not result in a reduction in alum application to water in the Catskill Aqueduct upstream of Kensico Reservoir. Therefore, the Proposed Action would provide some operational flexibility to DEP related to reduced reliance on stop shutters and the Catskill/Delaware Interconnection at Shaft 4 but is not anticipated to reduce the need to apply alum for all episodic turbidity events. For more detailed information on episodic turbidity events see Section 7.1.1, “Flow Regime and Water Quality in Lower Esopus Creek.”

Overall, the Proposed Action would result in limited changes to DEP water supply operations and therefore, would not present a significant adverse impact to DEP’s ability to reliably provide water to its customers.

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[14] DEP is required to operate its Delaware System in accordance with a 1954 U.S. Supreme Court Decree (Decree) and subsequent commitments made by the parties to that Decree and adopted by the Delaware River Basin Commission. The current operations protocol was agreed to by the parties of the Decree and is referred to as the Flexible Flow Management Program. The FFMP was originally implemented to better manage flow within the Delaware River. Both the Decree and the FFMP require the City to release water from its Delaware System reservoirs.

Table 7.1-8. DEP Water Supply Reliability Metrics for the Future Without and Future With the Proposed Action Over the OST Simulation Period

Metric	Future without the Proposed Action	Future with the Proposed Action
System Probability of Refill (percent of years that refill on or around June 1)		
System Probability of Refill	90%	90%
Catskill System Probability of Refill	90%	88%
Delaware System Probability of Refill	90%	90%
Croton System Probability of Refill	91%	91%
Drought (percent of days metric is exceeded)		
Drought Watch	2.2%	2.2%
Drought Warning	1.1%	1.3%
Drought Emergency	0.9%	1.0%
System Balancing (Average Diversion in MGD)		
Average Catskill Diversion	360	355
Average Delaware Diversion	585	595
Average Croton Diversion	170	164
Average Delaware System Release	590	580
Catskill System Water Quality		
Average Days Diversion Turbidity is over 8 NTU	48	39
Percent Alum Days	0.3%	0.3%
Shaft 4 On (Average days per year)	48	41
Stop Shutters Installed (Average days/year)	4	4

7.1.3 SUMMARY OF EFFECTS OF THE PROPOSED ACTION ON FLOW REGIME AND WATER QUALITY IN LOWER ESOPUS CREEK

COMMUNITY RELEASES

Unlike the future without the Proposed Action, the future with the Proposed Action would sustain flow to lower Esopus Creek year-round (via the community release). Upstream of the spillway confluence, in Valley Reach 1A, the median contribution of the community release to streamflow in lower Esopus Creek would be 65 percent (Section 6.2, "Operation of Ashokan Reservoir in Accordance with the IRP"). In the future without the Proposed Action, there would be no flows to Valley Reach 1A from Ashokan Reservoir. Therefore, differences between the future without and with the Proposed Action would have the greatest potential to affect this portion of lower Esopus Creek. The community release would continue to comprise a greater percentage of the streamflow through the end of Valley Reach 1B. Downstream of Valley Reach 1B, the community release would provide sustained flow, but at a smaller percentage of overall streamflow in lower Esopus Creek. This less pronounced effect of sustained flows downstream would be due to natural flows from additional sub-watersheds of lower Esopus Creek through Valley Reach 3D. Even further downstream, Valley Reach 3F (i.e., downstream of Cantine Dam), is tidally influenced from the Hudson River. These tidal flows are the key driver of the flow regime in Valley

Reach 3F and any flow effects from the community release are not anticipated to affect Valley Reach 3F. While the community release is of smaller magnitude than maximum spill mitigation and operational releases, it would help to maintain the CSSO and enhance flood attenuation already provided by Ashokan Reservoir.

In the future with the Proposed Action, in the summer, the community release would have the potential to cool water temperature in Valley Reaches 1A and 1B. It is not anticipated that the community release would affect temperature within lower Esopus Creek downstream of Valley Reach 1B since the percent contribution of flow diminishes past this point. Given the percent contribution of flow of the community release in Valley Reach 1A, and small number of tributaries along this reach, turbidity within Valley Reach 1A is anticipated to be equal to that of releases from Ashokan Reservoir. Turbidity of the community release is anticipated to be low, with a median modeled turbidity of 1.8 NTU.

SPILL MITIGATION RELEASES

Spill mitigation releases in the future with the Proposed Action would be conducted to maintain the CSSO in Ashokan Reservoir established by the IRP and would not occur in the future without the Proposed Action. The IRP provides for spill mitigation releases up to 600 MGD (928 cfs) and requires DEP to throttle releases as necessary so that the combined flow from the spillway and Ashokan Release Channel does not exceed 1,000 MGD (1,547 cfs). In addition, the IRP requires all releases from Ashokan Reservoir to cease when the Mount Marion gage is within one foot of the flood Action Stage and forecasted to reach the flood Action Stage. These requirements are designed to reduce the potential for downstream flooding associated with operation of Ashokan Reservoir in accordance with the IRP. Spill mitigation releases would also follow prescribed ramping rates to limit how quickly total streamflow within lower Esopus Creek increases and decreases as a result of releases through the Ashokan Release Channel.

Therefore, compared to the future without the Proposed Action, spill mitigation releases in the future with the Proposed Action would provide a flood attenuation benefit beyond that provided by Ashokan Reservoir and the community release for all portions of lower Esopus Creek downstream of the spillway confluence in two ways: (1) by reducing the number of spill events from proactive management of the Reservoir water level to maintain the CSSO; and (2) by converting shorter duration, higher flow spill events into longer duration, lower flow releases with more gradual ramping rates.[15]

Modeling indicated that spill mitigation releases would occur 22 percent of the time, mostly in the winter and spring (Section 7.1.1, “Flow Regime and Water Quality in Lower Esopus Creek – Flows from Ashokan Reservoir”). In Valley Reach 1A, the median percent contribution of releases up to 600 MGD (928 cfs) would be 90 percent. In the future without the Proposed Action, there would be no flows to Valley Reach 1A from Ashokan Reservoir. Therefore, differences between the future without and with the Proposed Action for releases up to 600 MGD (928 cfs) would have the greatest potential to affect this portion of lower Esopus Creek.

Spill mitigation releases up to 600 MGD (928 cfs) in the future with the Proposed Action are anticipated to have a potential to affect lower Esopus Creek through the downstream end of Valley Reach 2C. At the downstream end of Valley Reach 2C, the median percent contribution of flow from Ashokan Reservoir would reduce to 61 percent due to the increasing size of the sub-watersheds contributing flow to lower Esopus Creek. The Saw Kill joins lower Esopus Creek at the end of Valley Reach 2C, with the Plattekill joining just downstream at the terminus of Valley Reach 3D, where releases up to 600 MGD (928 cfs)

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[15] The flood attenuation benefit would not be realized upstream of the spillway confluence in Valley Reach 1A since spills do not flow through this portion of the lower Esopus Creek.

would comprise approximately 54 percent of streamflow within lower Esopus Creek. The percent contribution of flows from Ashokan Reservoir up to 600 MGD (928 cfs) to streamflow in Valley Reach 3E at its terminus at Cantine Dam would be 51 percent. As stated above, Valley Reach 3F is tidally influenced from the Hudson River and any flow effects from the spill mitigation releases are not anticipated to affect Valley Reach 3F.

OST modeling estimated that the median turbidity level of spill mitigation releases would be 6.6 NTU in the future with the Proposed Action. Turbidity levels would be similar between the future without and with the Proposed Action and would be within the range and variability of turbidity levels in lower Esopus Creek. In the future with the Proposed Action, spill mitigation releases would follow requirements established by the IRP to limit duration of releases based on turbidity levels.

Only 13 percent of the spill mitigation releases that would occur over the OST simulation period are anticipated to occur in the summer. These releases would have the potential to cool water temperature along lower Esopus Creek, with a diminishing effect downstream of Valley Reach 2C.[16] Valley Reach 3F is tidally influenced and any temperature effects from spill mitigation releases are not anticipated to affect this Valley Reach. Given the size of turbidity particles transferred through flows from Ashokan Reservoir, it is not anticipated that turbidity within spill mitigation releases that has not settled in the Reservoir under quiescent conditions would settle in the faster moving water of lower Esopus Creek.

OPERATIONAL RELEASES

Operational releases are the third type of release that would occur in the future with the Proposed Action. Operational releases would be used to prevent spill of turbid water from the west basin to the east basin to protect the quality of water diverted to Kensico Reservoir. As with spill mitigation releases, operational releases conducted in accordance with the IRP would be limited in duration based on the level of turbidity in water released from Ashokan Reservoir. Releases of water with turbidity levels greater than 100 NTU are not permitted except when turbidity of inflow to Ashokan Reservoir from upper Esopus Creek is greater than 100 NTU. Operational releases must also follow prescribed ramping rates to limit how quickly total streamflow within lower Esopus Creek increases or decreases as a result of releases through the Ashokan Release Channel. The percent contribution of flow and associated potential for effects along lower Esopus Creek described for spill mitigation releases up to 600 MGD (928 cfs) would be the same for operational releases up to 600 MGD (928 cfs). However, operational releases are anticipated to occur less than five percent of the time, mostly as a result of episodic turbidity events. When operational releases are anticipated to occur, they would tend to occur in the late winter to early spring (from contributions of rainfall events and spring snowmelt) and late summer (from tropical storms). The median duration of operational releases is anticipated to be 3 days over the OST model simulation period with a median turbidity level of 15 NTU.

7.1.4 PARAMETERS EVALUATED FOR THE TECHNICAL AREA ASSESSMENTS – FLOW REGIME AND WATER QUALITY

Slight differences are anticipated in the flow regime and water quality of lower Esopus Creek between the future without and with the Proposed Action. These differences have the potential to affect various parameters such as water depth, water velocity, erosion, sediment deposition, inundation, turbidity levels, TSS, and temperature. Identifying and evaluating the potential differences of these parameters for the future without and with the Proposed Action is necessary for conducting the technical area assessments (see **Figure 7.1-32**).

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[16] The percent of time the spill mitigation releases occur in the summer was established using a seasonal analysis over the OST simulation period.

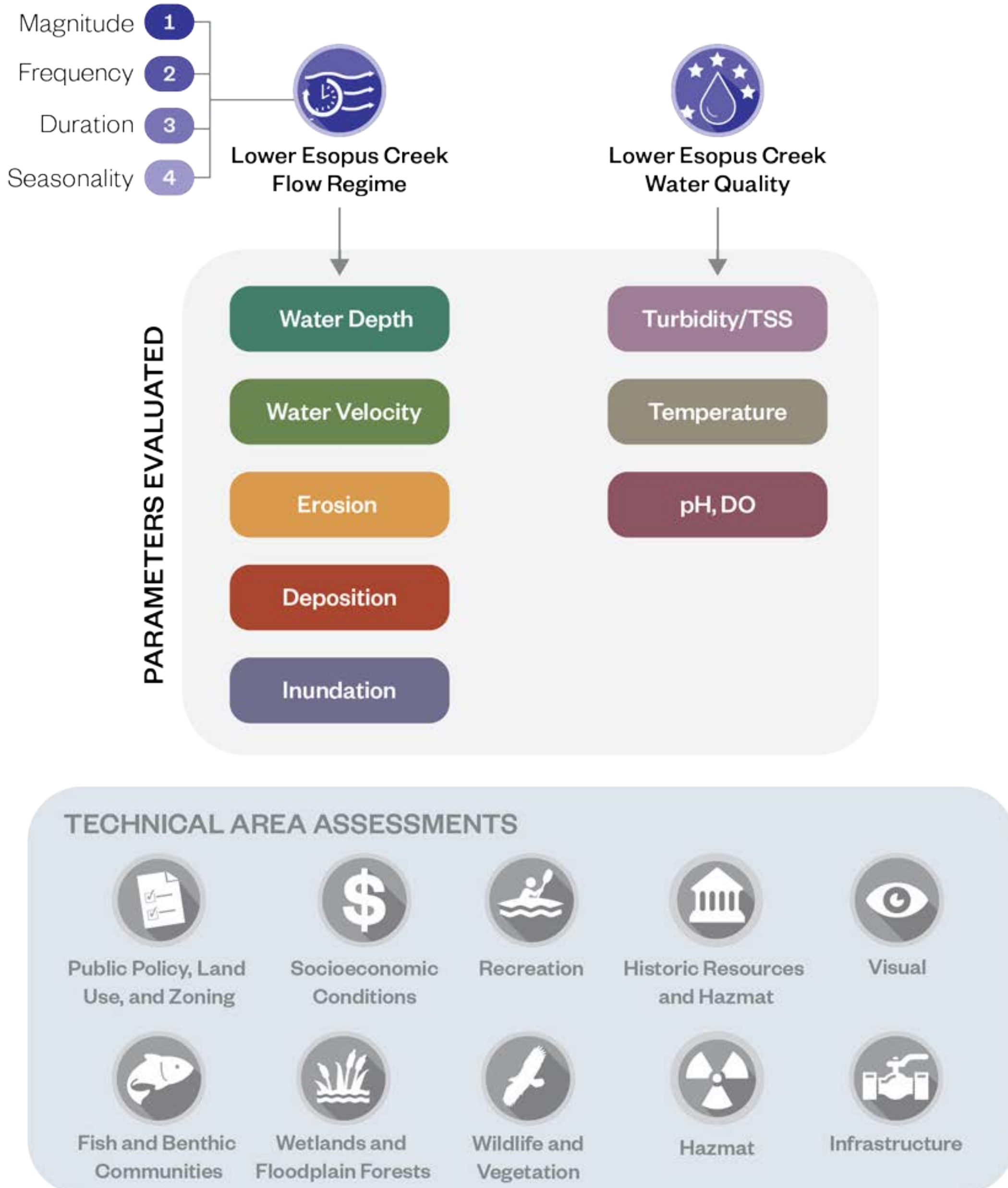

Figure 7.1-32
Flow Regime and Water Quality Parameters Evaluated for the Proposed Action in Lower Esopus Creek

WATER VELOCITY, WATER DEPTH, AND INUNDATION

Water velocity, water depth, and inundation along lower Esopus Creek vary with streamflow and local topography. The HEC-RAS model for lower Esopus Creek was used to estimate the depth and velocity of streamflow within lower Esopus Creek at representative locations in each valley reach and at specific locations important for the technical area assessments. The HEC-RAS model was also used to confirm that releases in the range of 600 MGD (928 cfs) and a combination of releases and spills up to 1,000 MGD (1,547 cfs) would not result in streamflow that causes inundation of roads, buildings, or properties (flooding).

FEMA identifies flood hazards and assesses flood risks in communities across the United States. FEMA oversees the creation of flood hazard maps as part of the National Flood Insurance Program. FEMA is the only party authorized to create, modify, and regulate the flood hazard zone. FEMA has published 100-year and 500-year flood maps for the communities along lower Esopus Creek (see **Figure 7.1-33** through **Figure 7.1-36).**

WATER VELOCITY AND WATER DEPTH

Water velocity and water depth changes with streamflow along lower Esopus Creek depending on the characteristics of the stream channel. Valley Reaches 1A and 1B exhibit typical riffle-pool sequences with alternating sections of faster/shallower and slower/deeper water. As streamflow increases, either due to additional contribution from the surrounding watershed or Ashokan Reservoir, depth and velocity increase proportionally.

Valley Reach 2C, which extends from the Hurley Mountain Road bridge to the Leggs Mill Road bridge, has a shallow channel, and a well-developed floodplain. Background streamflow in this section of lower Esopus Creek can be very shallow and slow-moving. As streamflow increases, velocities in the main channel increase, but the streamflow also spreads out to connect with side channels, oxbow lakes, and wetlands that keep the overall velocities low.

Due to valley confinement in Valley Reaches 3D, 3E, and 3F, as streamflow increases, depths and velocities increase proportionally. However, backwater conditions at Glenerie Falls and Cantine Dam can attenuate streamflow through these reaches of lower Esopus Creek.

Differences in the velocity and depth of flow between the future with and without the Proposed Action are greatest in Valley Reach 1A and diminish moving downstream.

Potential differences in velocity and depth along Valley Reaches 1A, 1B, 2C, and 3D between the future without and with the Proposed Action are shown in **Figure 7.1-37** and **Figure 7.1-38**. Velocity and depth ranges were calculated using the HEC-RAS model of lower Esopus Creek. As with flow regime and water quality, differences in water velocity and depth between the future without and with the Proposed Action would diminish moving downstream and would be largest in Valley Reach 1A, which would not experience flow from Ashokan Reservoir in the future without the Proposed Action. In Valley Reach 1A both the median velocity and depth of streamflow and range of velocities and depth of streamflow would be greater in the future with the Proposed Action. In Valley Reach 1B and 2C, the median velocities would be comparable between the future without and with the Proposed Action while the median depth would be slightly higher in the future with the Proposed Action. Velocities and depths in Valley Reach 3D are shown to be less than those in Valley Reach 2C. Valley Reach 3D is a very short, shallow section primarily composed of the waterfall over Glenerie Falls and velocities and depth would be comparable between the future without and with the Proposed Action for this valley reach. Potential effects from differences in velocity and depth were evaluated within the technical area assessments, as applicable.

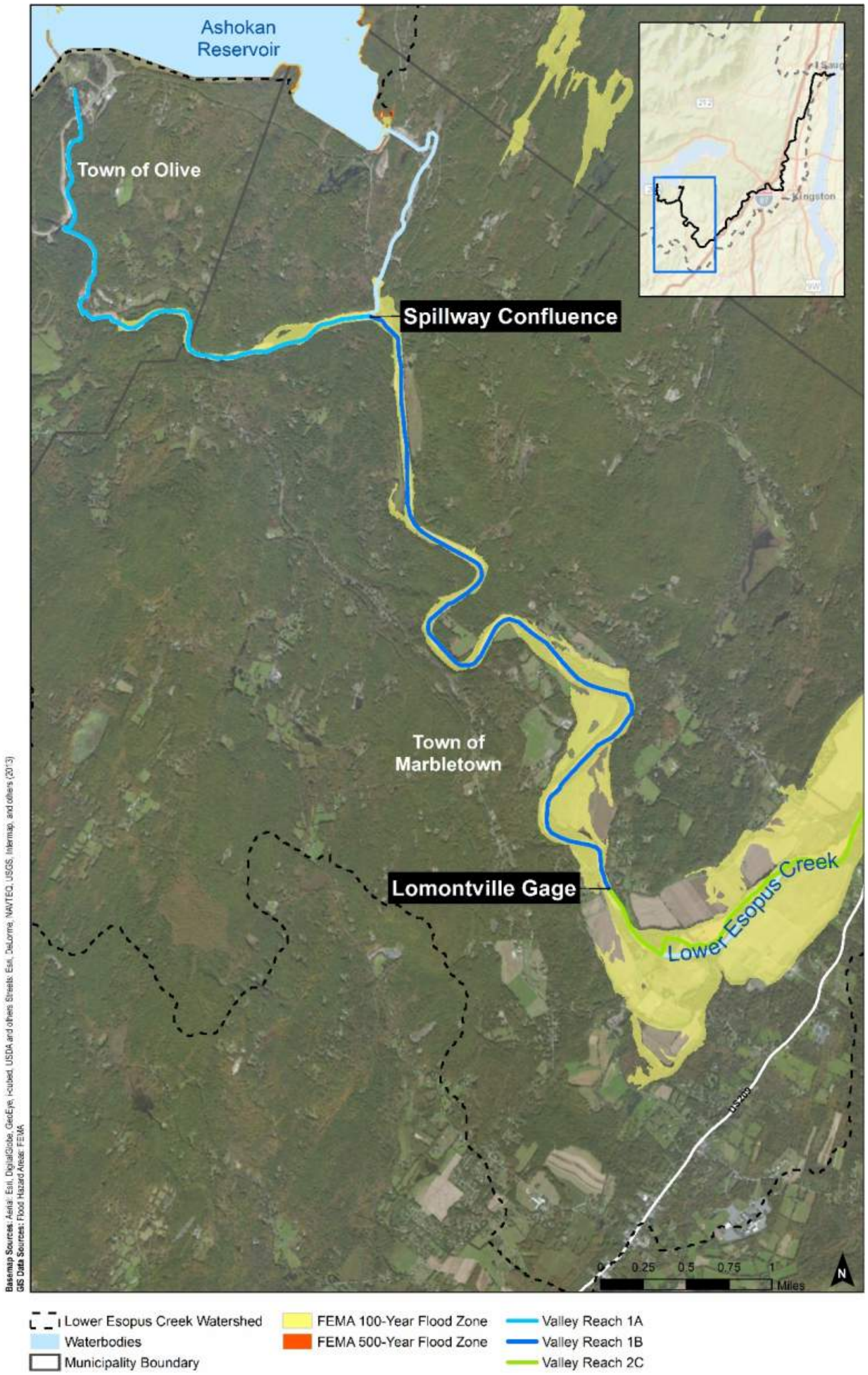

Figure 7.1-33
100- and 500-year FEMA Floodplains in Lower Esopus Creek Watershed

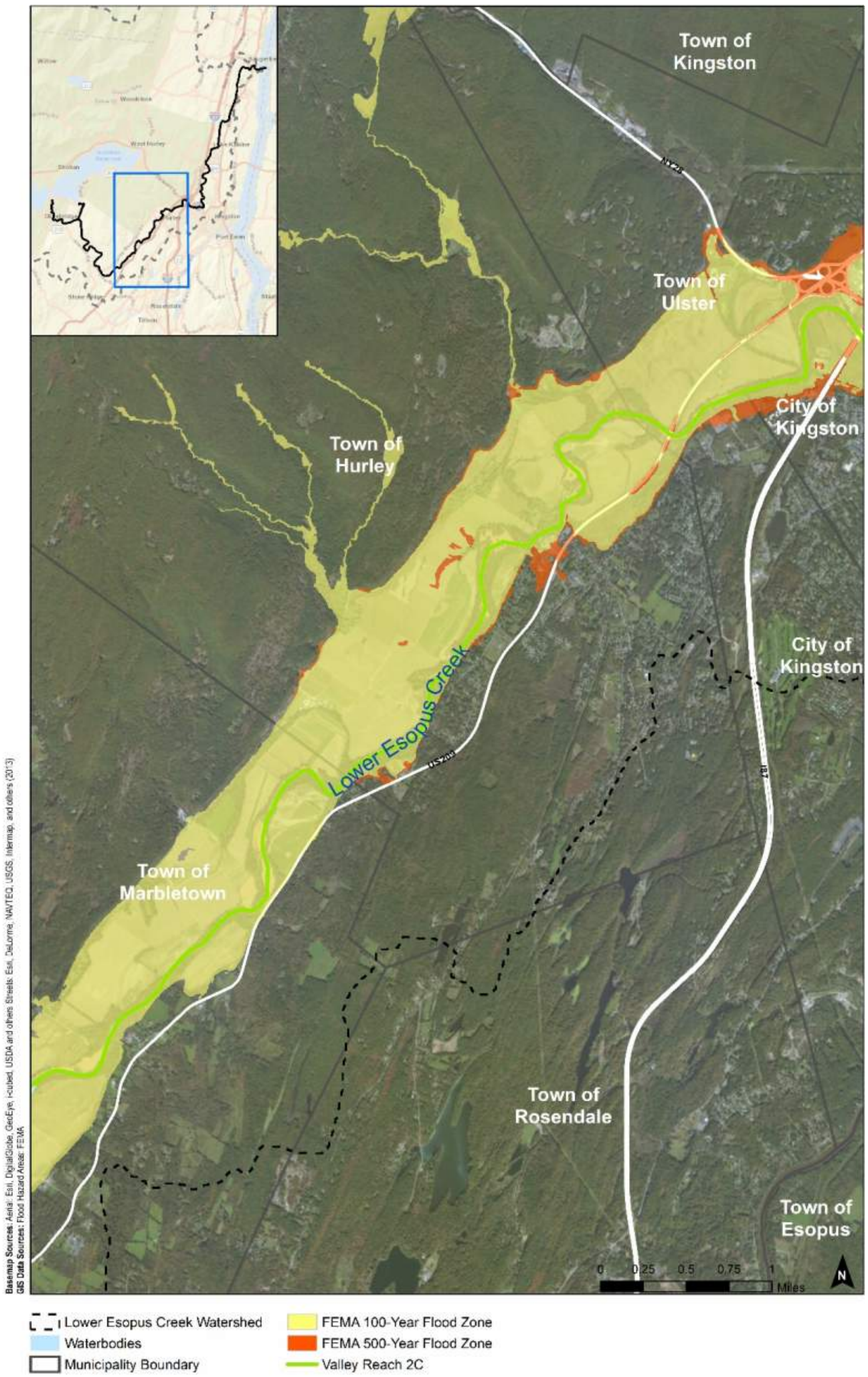

Figure 7.1-34
100- and 500-year FEMA Floodplains in Lower Esopus Creek Watershed

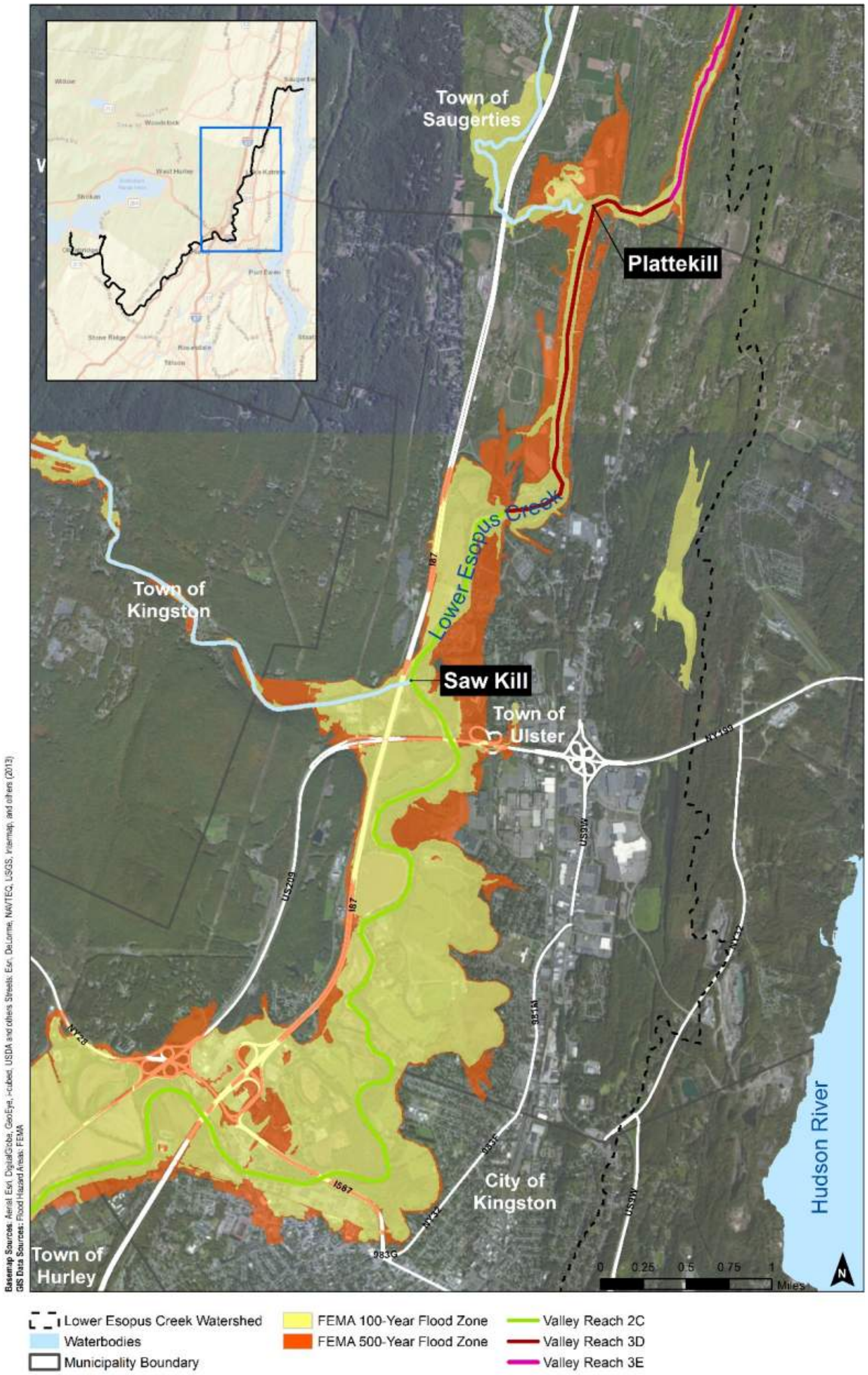

Figure 7.1-35

100- and 500-year FEMA Floodplains in lower Esopus Creek Watershed

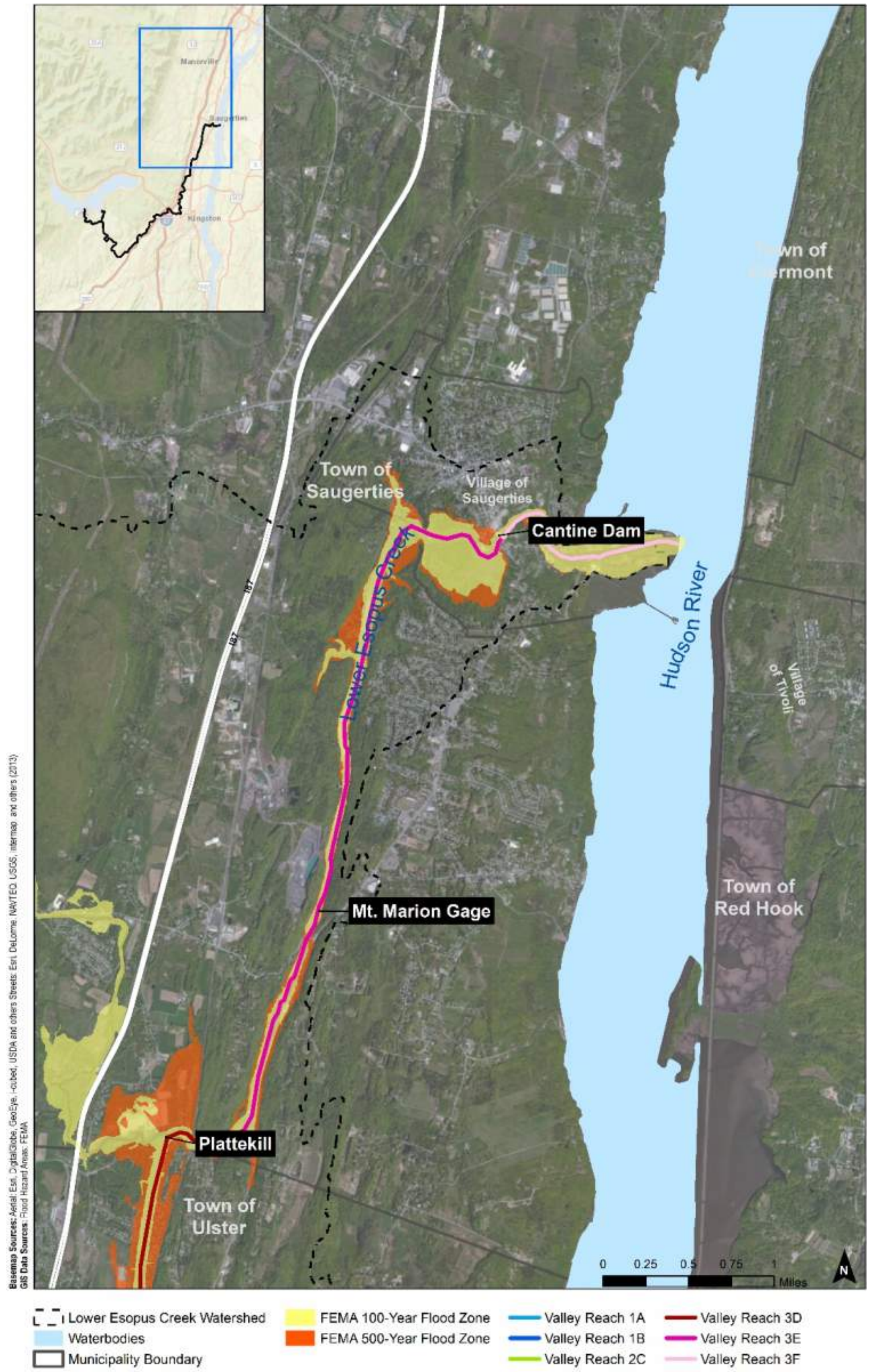

Figure 7.1-36
100- and 500-year FEMA Floodplains in lower Esopus Creek Watershed

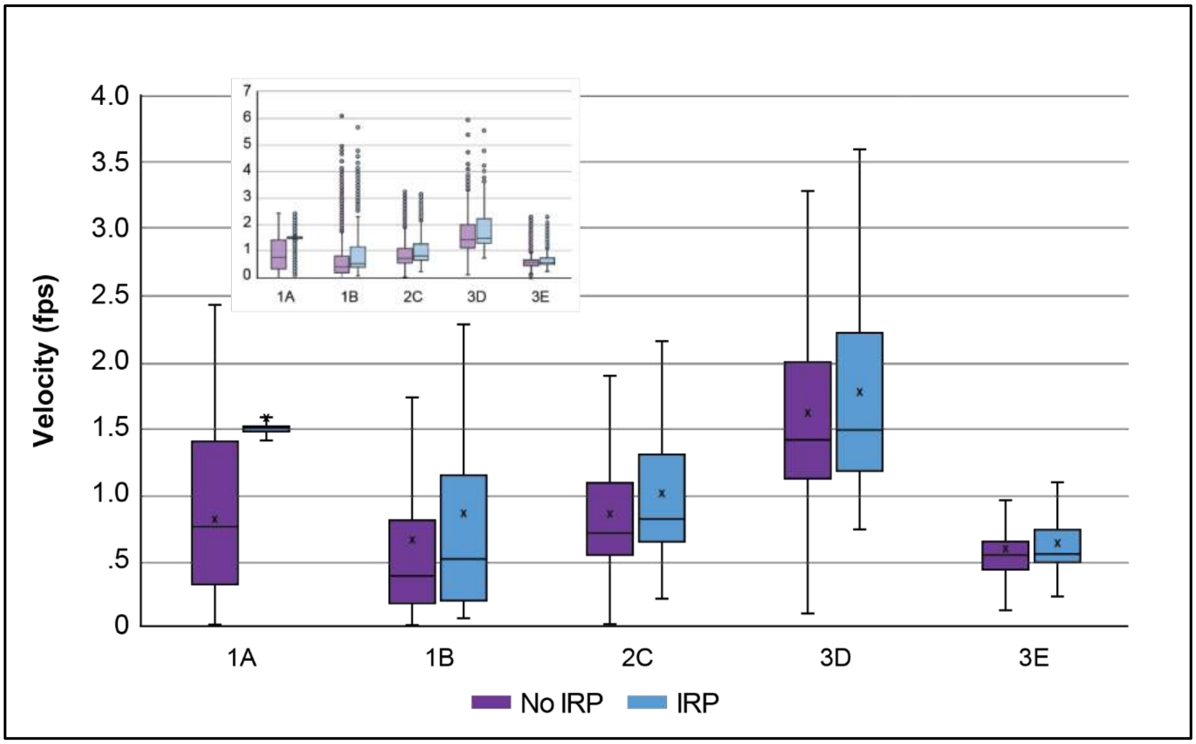

Figure 7.1-37. Modeled Velocity of Streamflow by Valley Reach in the Future Without and With the Proposed Action

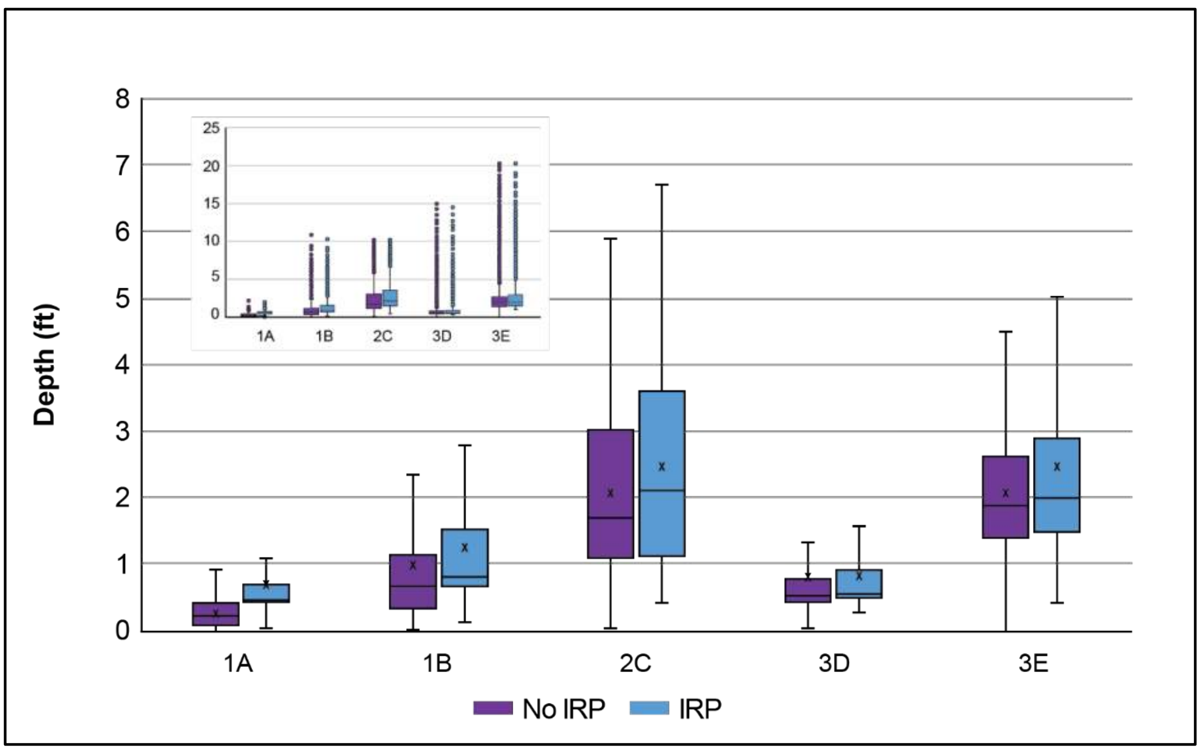

Figure 7.1-38. Modeled Depth of Streamflow by Valley Reach in the Future Without and With the Proposed Action

INUNDATION

HEC-RAS modeling of inundation along lower Esopus Creek indicated that, except for low-lying gravel bars and benches along lower Esopus Creek, streamflow would remain within the channel up to approximately 4,000 to 7,000 MGD (6,189 to 10,831 cfs), depending on the location in lower Esopus Creek. Therefore, flows up to 1,000 MGD (1,547 cfs) in the future with the Proposed Action would result in streamflow that stays within the channel of lower Esopus Creek and not result in any flooding. Further, streamflow above approximately 4,000 MGD (6,189 cfs) that has the potential to cause flooding at certain locations along lower Esopus Creek would occur less frequently in the future with the Proposed Action due to operation of the Ashokan Reservoir in accordance with the IRP. Images showing the inundation at 15 MGD or 23 cfs (seasonally-based community release level) and 600 MGD or 928 cfs (maximum spill mitigation and operational release level) for representative locations along each valley reach are presented in **Figure 7.1-39** through **Figure 7.1-42**. Inundation shown on these figures is based on specific magnitudes of streamflow that would occur in both the future without and with the Proposed Action. Potential differences in inundation between the future without and with the Proposed Action are related to the frequency that streamflow of various magnitudes would occur and this difference would diminish moving downstream.

Releases from Ashokan Reservoir in the future with the Proposed Action would remain within the channel of lower Esopus Creek and would not result in flooding.

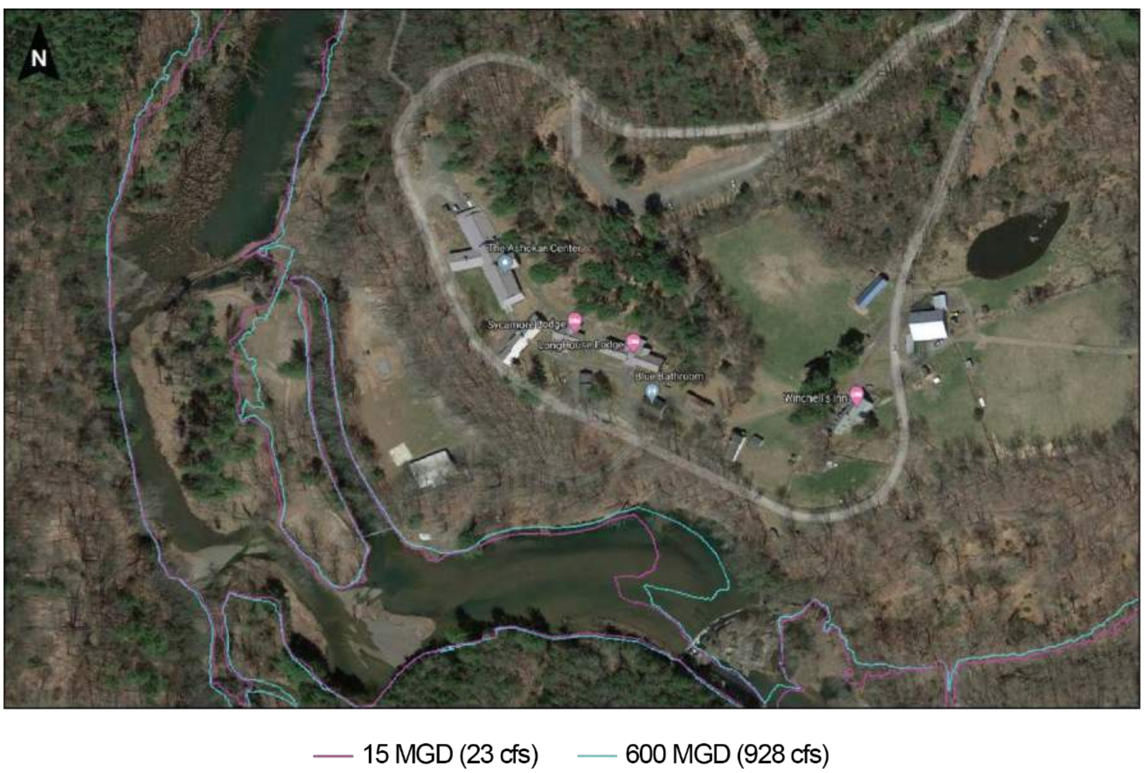

Figure 7.1-39. Modeled Inundation in Valley Reach 1A – Vicinity of the Ashokan Center

Figure 7.1-40. Modeled Inundation in Valley Reach 1B – Vicinity of Hurley Mountain Road Bridge (Lomontville Gage)

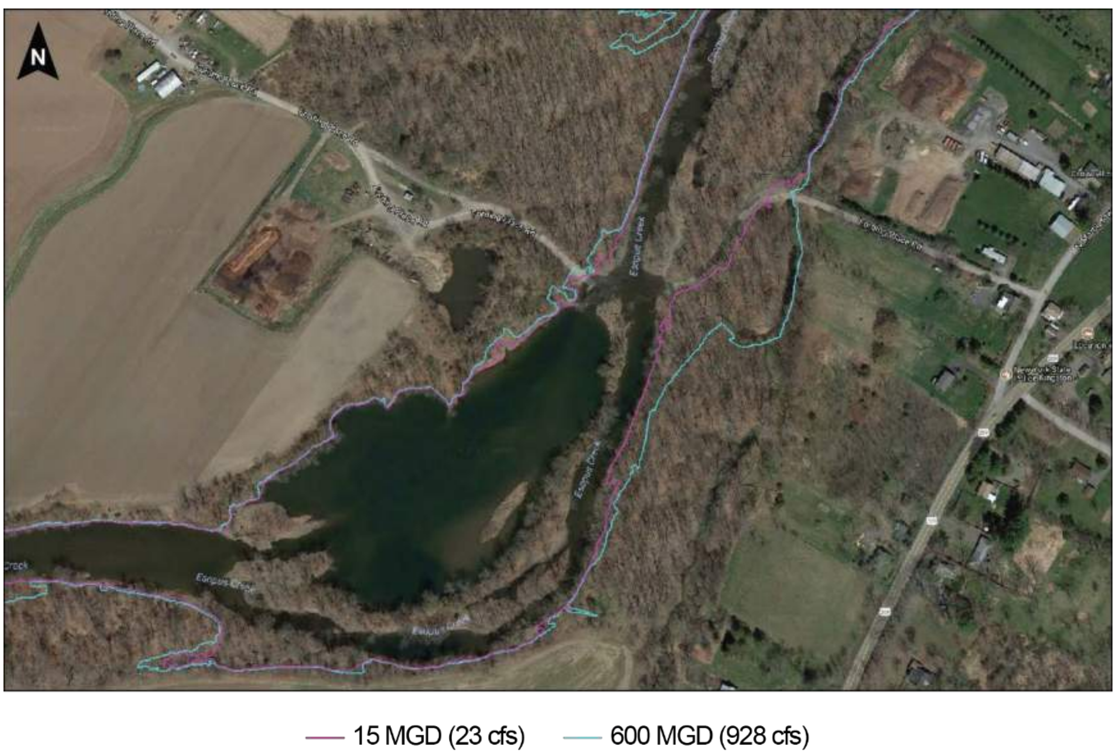

Figure 7.1-41. Modeled Inundation in Valley Reach 2C – Vicinity of Fording Place Road

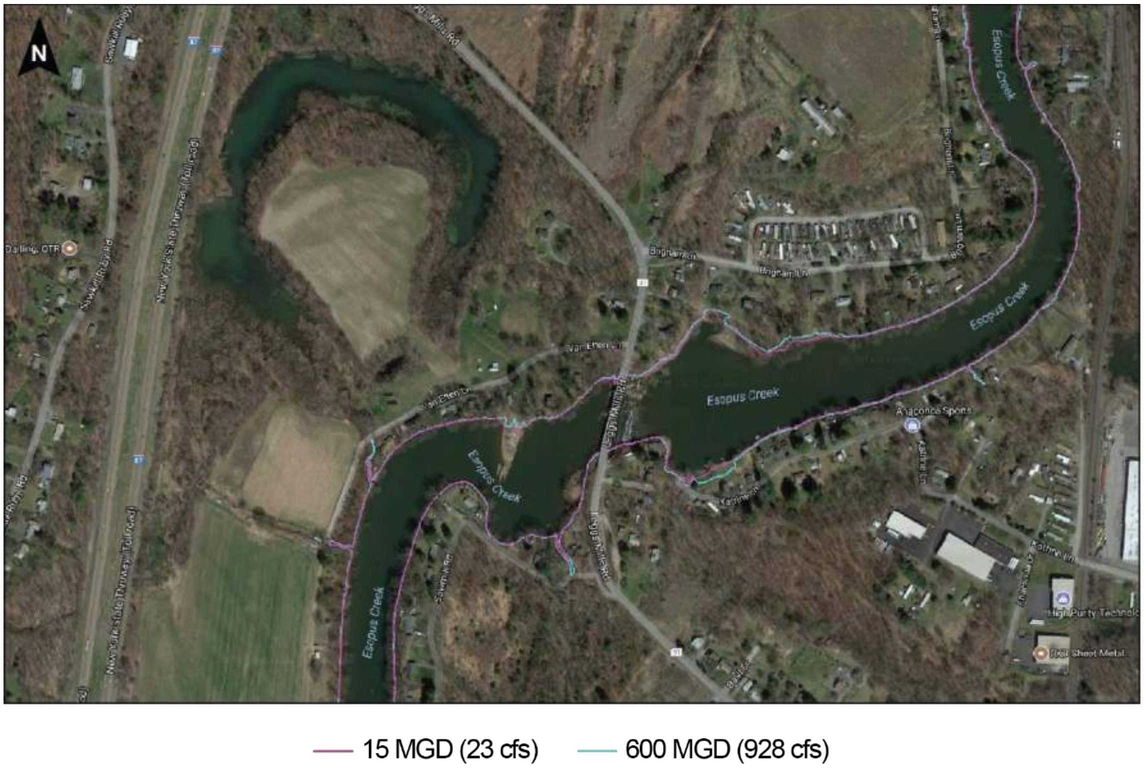

Figure 7.1-42. Modeled Inundation in Valley Reach 3D – Vicinity of Leggs Mill Road (Lake Katrine)

EROSION AND DEPOSITION

Cycles of erosion and deposition are natural and lead to shifts in the pattern, profile, and dimension of a stream channel within its floodplain. In alluvial channels, like much of lower Esopus Creek, stream pattern, profile, and dimension can vary greatly with changes in streamflow, velocity, incoming sediment, bank composition, riparian vegetation, and geologic control. Sediment is carried into and transported within a stream by streamflow, referred to as the sediment load of the stream. Sediment load is a function of both the concentration of sediment in the water and the amount of streamflow carrying such sediment. The full range of streamflow in a flow regime is important to maintain the pattern, profile, and dimension characteristics of a stream. Despite movement, a stable stream is one that, over time, has adjusted its alignment, slope, width, and depth, such that it is able to transport the sediment load with no significant aggradation (deposition) or degradation (erosion) of the streambed. Localized erosion and deposition naturally occur at smaller spatial scales and lead to the formation of microhabitats, such as pools and riffles.[17]

Certain features within a stream are more susceptible to erosion or deposition and the rates at which these processes occur. Meanders are common as the stream erodes outside bends; lower velocities on the opposite side allow sediment to deposit on inner “point bars.” Erosion on outside bends and deposition on point bars occur as the channel migrates, moving it back and forth across the stream valley and floodplain. Major factors that can slow erosion include decreased streamflow, the presence of riparian

[17] Pools are often present in a meandering stream where the outer edge of each meander loop is deep and undercut; riffles typically form in the shallow water of the short, straight, wide reaches between adjacent loops.

vegetation, geologic controls[18], and “hardened” outside stream banks (e.g., placed riprap). Major factors that increase erosion rates include increased stream velocity, banks with little or no vegetation, bank material composition with unconsolidated sediments, and steep streambank angles. The resulting changes to a stream are important to aquatic and riparian wildlife and vegetation, which adapt to conditions within the bounds of certain channel characteristics (e.g., flow regime, velocities, and slopes), including how these characteristics change or cycle over time. For communities adjacent to streams, changes to stream characteristics are important because they can affect existing or planned infrastructure. The following features influence erosional and depositional conditions within lower Esopus Creek.

CHANNEL-FORMING DISCHARGE

Channel-forming (CF) discharge is the streamflow at or above which larger-sized bedload material begins to mobilize and cause degradation of the streambed. CF discharge in the first half of lower Esopus Creek (approximately between Valley Reach 1B and the City of Kingston) was estimated to be between 3,000 and 4,000 MGD (4,642 to 6,189 cfs) based on field measurements of slope-breaks, historical hydrologic data (1970 to 2017), and hydraulic modeling, as described in Section 5.3.1, “Water Resources and Water Quality” methodology.[19] Historical hydrologic data included releases and spills from Ashokan Reservoir and monitored streamflow at the USGS stream gage at Mount Marion. The CF discharge typically reaches the slope-break between the active stream channel and the floodplain, usually the second observable slope-break within the channel as shown on **Figure 5.3-2**. The estimated CF discharge of 3,000 to 4,000 MGD (4,642 to 6,189 cfs) typically has a 30 to 50 percent chance of occurring in a given year (2- to 3-year streamflow event), based on historical streamflow (1970 to 2017) in lower Esopus Creek. CF discharge generally increases moving downstream with increasing local watershed area. Downstream of the City of Kingston, however, lower Esopus Creek has hydraulic controls such as bedrock outcrops and dams that make estimation of CF discharge difficult.

Flows from Ashokan Reservoir in accordance with the IRP are below the channel-forming discharge and would remain in the stream channel.

The associated inner berm (IB) streamflow along lower Esopus Creek is smaller than the CF discharge, typically between 700 and 1,000 MGD (1,083 and 1,547 cfs) in the portion of stream between Ashokan Reservoir and the City of Kingston. IB bars represent a nexus of water flow, flora, and fauna; the constant re-shaping of these bars, carried out through a wide range of flows, is ecologically important. The IB bars may be influenced (defined as changes to boundaries) by streamflow less than the CF discharge but require the CF discharge or larger to be substantially re-shaped (bar location, height, or material change).

Streamflow in the range of the CF discharge would occur in both the future without and with the Proposed Action during spill events and would occur less than one percent of the time. Streamflow in the range of the IB streamflow (500 to 700 MGD, 774 to 1,083 cfs) would occur in the future with the Proposed Action approximately 11 percent of the time as compared to four percent of the time in the future without the Proposed Action. Using modeled streamflow values from HEC-RAS at specific monitoring locations, streamflow in the range of 600 MGD (928 cfs) releases in the future with the Proposed Action is predicted to fill and

Differences between the future without and with the Proposed Action would not result in impacts to overall channel stability of lower Esopus Creek.

[18] Geologic controls include bedrock outcrops or exposures that are highly resistant to erosion.

[19] CF discharge was not estimated for Valley Reach 1A; this valley reach receives minimal local streamflow from tributaries and streamflow is primarily comprised of releases from Ashokan Reservoir, which precludes the estimation of CF discharge from field indicators. This portion of lower Esopus Creek is confined and contains bedrock outcrops and is therefore not anticipated to be responsive to differences in streamflow between the future without and with the Proposed Action.

sometimes overtop the inner berm, but would not leave the active channel of lower Esopus Creek or inundate the floodplain. This was confirmed through several field investigations in 2018 and 2019 during conditions when 600 MGD (928 cfs) releases occurred. **Figure 7.1-43** shows water levels at two representative locations along lower Esopus Creek on a day when releases were at 600 MGD (928 cfs), relative to streamflow conditions on a day when releases were at the magnitude of the community release (10 MGD, 15 cfs, on November 16, 2017 and 15 MGD, 23 cfs, on May 2, 2018).

No changes to long-term channel dimension, pattern, or profile – and overall channel stability – are anticipated from streamflow below the CF discharge, including those associated with releases from Ashokan Reservoir. There would be slight reduction in the frequency of occurrence in streamflow in the range of the CF discharge in the future with the Proposed Action. However, this difference is not anticipated to result in differences in channel stability.

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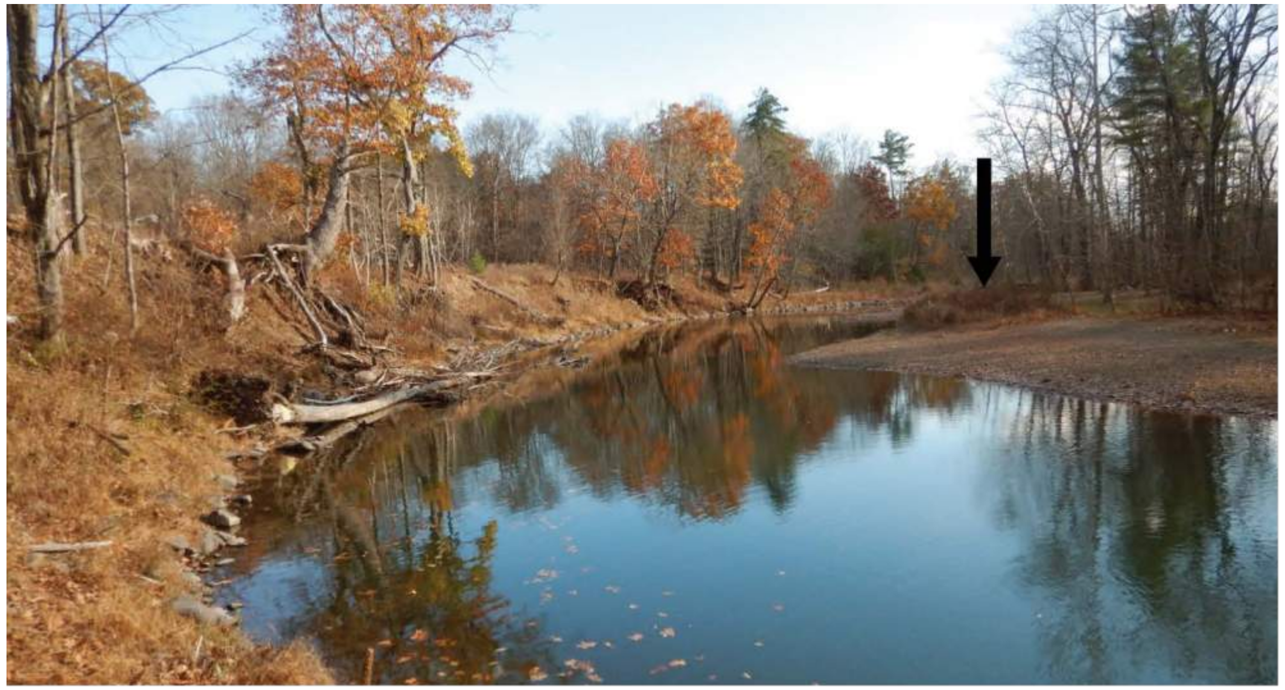

Lower Esopus Creek, XS-3, looking downstream
Baseflow Conditions, November 16, 2017

Lower Esopus Creek, XS-3, looking downstream
Conditions at 600 MGD (928 cfs) Releases, January 7, 2019

Lower Esopus Creek, XS-17, looking across channel (flow left to right)
Baseflow Conditions, May 2, 2018

Lower Esopus Creek, XS-17, looking across channel (flow left to right)
Conditions at 600 MGD (928 cfs) Releases, January 10, 2019

Figure 7.1-43
Lower Esopus Creek Study Area
Photograph Documentation of Conditions: Background Streamflow and 600 MGD (928 cfs) Releases
(arrows used as reference marker for features in each photograph)

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SEDIMENT LOAD AND TRANSPORT

Total suspended solids (TSS) are any particles found in the water column. These particles vary in size. Heavier particles (such as sand) often settle out in areas of low streamflow. Smaller particles such as silt and clay are lighter and take longer to settle. Some can be colloidal, meaning they may never settle out of the water column. Suspended solids in a stream reduce water clarity and make water appear murky or cloudy. Turbidity levels are an optical measure of water clarity. Higher TSS concentrations in a stream cause higher turbidity levels. Very fine clay particles that do not readily settle cause elevated turbidity levels to persist.

Sediment moves through a stream as both bedload and suspended load. Bedload is the material that is moved along the bed of a stream by rolling, sliding, or hopping. Suspended load is the portion of sediments kept in suspension by turbulence. Suspended load typically consists of smaller particles like silt and clay, while bedload typically consists of larger particles like gravel and cobble. Both suspended load and bedload are present in lower Esopus Creek. As stream velocity and streamflow vary, the amount and portion of bedload and suspended load varies. Bedload mobilization has the potential to alter the channel dimension, pattern, and profile of a stream at streamflow at or above the CF discharge. Over time, a stream channel adjusts (through erosion, deposition, and channel migration) to accommodate variations in either sediment supply or streamflow, or both.

The three primary sediment sources to lower Esopus Creek are from: (1) lower Esopus Creek's watershed (including tributaries); (2) Ashokan Reservoir (which collects upper Esopus Creek water); and (3) instream bed and bank erosion. The first two sediment sources are unaffected by the future without and with the Proposed Action, remaining constant. Local tributary sources of sediment supply are dependent on land use and hydrology of the lower Esopus Creek watershed downstream of Ashokan Reservoir and on sediment transport within those tributaries. Sediment inputs from Ashokan Reservoir that originate upstream are not anticipated to be different between the future without and with the Proposed Action (see Section 7.1.1, "Flow Regime and Water Quality in Lower Esopus Creek"). Any potential changes to sediment supply in the future with the Proposed Action would occur from differences in streambed and bank erosion associated with differences in streamflow between the future without and with the Proposed Action (see Section 7.1.1, "Flow Magnitude and Duration" above).

The Proposed Action would convert shorter duration high streamflow events with higher velocities and flow energy to longer duration lower magnitude streamflow with lower velocities and stream energy (see Section 7.1.1, "Flow Regime and Water Quality in Lower Esopus Creek"). Releases in the future with the Proposed Action would reduce the number, magnitude and duration of spill events, which have a greater potential to move sediment within lower Esopus Creek.

To evaluate the potential effects of longer duration of lower magnitude streamflow associated with releases in the future with the Proposed Action, a period of sustained 600 MGD (928 cfs) releases in the latter part of 2018 to support shutdown of the Catskill Aqueduct to conduct repairs was analyzed. As discussed in Section 7.1.1, "Flow Regime and Water Quality in Lower Esopus Creek," both streamflow and turbidity at Mount Marion were observed to be primarily influenced by the localized conditions of lower Esopus Creek during this time period (e.g., suspended sediment flowing into lower Esopus Creek from surrounding watersheds, including the Saw Kill and Plattekill tributaries) rather than releases from Ashokan Reservoir. There were several times when turbidity levels spiked at Mount Marion while turbidity levels of the flow from Ashokan Reservoir remained low (see **Figure 7.1-18).** Magnitude of flow and turbidity from Ashokan Reservoir remained relatively constant while streamflow magnitude and turbidity levels at Mount Marion varied. Increased turbidity levels at Mount Marion followed increases (spikes) in streamflow and ranged from less than 10 NTU to greater than 50 NTU. In addition, it does not appear streamflow in the range of 600 MGD (928 cfs) during this period resulted in erosion of the streambed or banks that mobilized sediment within lower Esopus Creek since there was not a corresponding sustained increase in turbidity levels during the sustained releases.

As discussed at the beginning of this section, higher TSS concentrations in a stream cause higher turbidity levels, and very fine clay particles that do not readily settle cause elevated turbidity levels to persist. Based on the relationships between turbidity and TSS at various points along lower Esopus Creek, it was possible to determine whether the sources of sediment to lower Esopus Creek change. Turbidity and TSS relationships were found to be similar at the various locations that were evaluated (**Figure 7.1-44**). Therefore, with no anticipated differences in TSS load between the future without or with the Proposed Action, no anticipated differences in aggradation or degradation of the streambed are anticipated between the future without and with the Proposed Action.

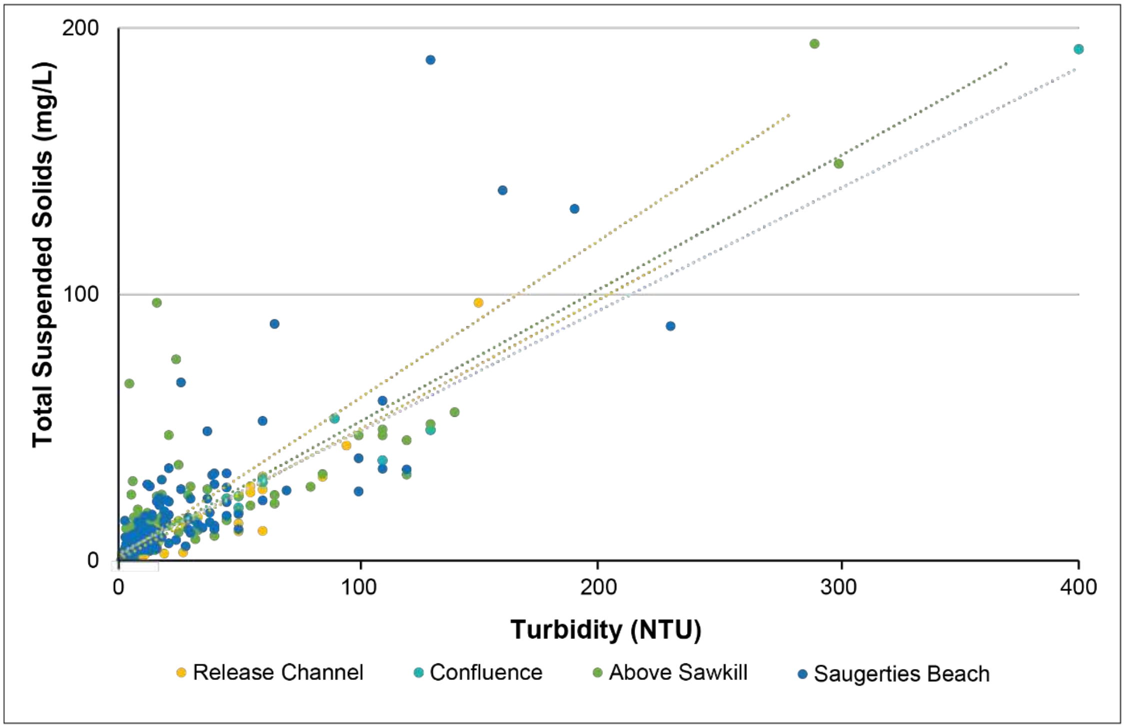

Figure 7.1-44. Observed TSS and Turbidity Levels Along Lower Esopus Creek (2011-2019)

STREAM STABILITY

To better understand the pattern, profile, and dimension of lower Esopus Creek and determine changes to these characteristics over time, DEP has completed several investigations of stream geomorphic stability at specific locations along lower Esopus Creek following the impact assessment methodology described in Section 5.3.1, “Water Resources and Water Quality.” The goal of these investigations was to document observed stream geomorphology and rates of change for the centerline and streambanks of lower Esopus Creek to better describe stream stability.

The first assessment consisted of reviewing historical aerial imagery for lower Esopus Creek. Observed channel centerline migration rates over the period of available imagery (1994 to 2016) ranged from zero to 3.7 feet per year, with rates of 0.4 to 1.0 feet per year being typical. The highest centerline migration rates occurred in Valley Reach 1B, and generally decreased moving downstream. Note that these comparisons, expressed in feet per year, are the average migration rates of the stream centerlines themselves; they are not measurements of bank movement and were used for relative comparisons of migration across meanders only.

The period of available imagery included several notable storm events in the region including an extended period of rainfall in April 2005 (flood of record for the Mount Marion gage), and Tropical Storms Irene and Lee in August and September 2011. These storms are some of the largest in this region in the last 100 years.[20] Observed changes to the stream centerline could not be attributed solely to these large storms due to the length of time between imagery dates (four years); however, the estimated migration rates encompassed any sudden changes due to these storm events, and the resulting adjustments that occur after storms of large magnitude. The 1994 to 2016 period also included releases from Ashokan Reservoir. Again, due to the length of time between imagery dates, observed changes to stream characteristics could not be attributed to any one factor.

Aerial imagery analysis along lower Esopus Creek confirmed the occurrence of historical channel migration in Valley Reach 2C.

Review of aerial imagery revealed that while the lower Esopus Creek channel moves laterally, it did not drastically change its path (i.e., movement of hundreds or even tens of feet within a few years), despite historically large storm events occurring within the observed aerial imagery dates. Aerial imagery also provided evidence of historical lateral migration through the valley prior to 1994. Features typical of historical lateral migration include oxbow lakes and abandoned channels within the floodplain and were observed, primarily in Valley Reach 2C. These features were likely part of the active stream channel before Ashokan Reservoir was in place and were abandoned during historical periods of active lateral migration. Lower Esopus Creek has adjusted over 100+ years to the regulation of flow and sediment from Ashokan Reservoir and is no longer expected to have the streamflow energy to undergo lateral migration to this extreme. Lateral migration ranges observed in aerial imagery of lower Esopus Creek were several feet per year or less. These rates were deemed to be indicative of a stable channel.

In addition to review of aerial imagery, the stream geomorphology assessment included field data collection and analysis. The geomorphic investigation conducted in 2006 for the portion of lower Esopus Creek upstream of the spillway confluence confirmed that Valley Reach 1A has largely adjusted to changes due to the presence of Ashokan Reservoir. Reduced streamflow due to the presence of Ashokan Reservoir, coupled with the presence of two small ponds and wetlands adjacent to lower Esopus Creek, further reduces the potential for stream channel adjustment from future differences in streamflow within this valley reach. Local aggradation has occurred within the portions of Valley Reach 1A that contain the two small ponds. Streamflow within Valley Reach 1A rarely accesses the adjacent former floodplain terraces and this valley reach is stable with no significant bank erosion. In addition, wetlands monitoring conducted in Valley Reach 1A since 2006 (prior to operation of Ashokan Reservoir in accordance with the IRP) has not shown evidence of changing wetland extents. Therefore, lateral migration of lower Esopus Creek in this valley reach is not anticipated as a result of differences in flow between the future without and with the Proposed Action (see Section 7.8, “Wetlands and Floodplain Forests”).

Stream channel degradation (streambed erosion) was not observed along lower Esopus Creek during field investigations conducted downstream of the spillway confluence. Aerial imagery and field investigations revealed the presence of mid-channel sediment features and multiple channels split around mid-channel features in some areas, which can be indications of aggradation (deposition). These features primarily

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[20] Wall, G.R., Murray, P.M., Lumia, Richard, and Suro, T.P., 2014. *Maximum known stages and discharges of New York streams and their annual exceedance probabilities through September 2011*. U.S. Geological Survey Scientific Investigations Report 2014–5084, 16 p., https://pubs.usgs.gov/sir/2014/5084/, accessed 2020.

occur in Valley Reach 2C. However, mature trees exist on these features, indicating that they are permanent islands that have been established for decades or longer, rather than temporary mid-channel bars that form in an actively aggrading channel. Moreover, aerial imagery from 1994 to 2016 did not show significant movement or growth of these features, which also indicates aggradation is not occurring.

Stream power in lower Esopus Creek downstream of the spillway confluence is not anticipated to be different between the future without and with the Proposed Action. Stream power is a function of channel slope and streamflow, of which only streamflow would be affected by the Proposed Action. The frequency of streamflow in the range of 600 MGD (928 cfs) up to channel-forming discharge in the range of 3,000 to 4,000 MGD (4,642 to 6,189 cfs) would be similar in the future without and with the Proposed Action downstream of the spillway confluence, as shown in **Figure 7.1-12**.

As stated, overall observations of desktop and field data indicated that lower Esopus Creek is a stable channel. Hydrologic conditions during these observations have included a range of streamflow conditions similar to those anticipated to occur in the future with the Proposed Action based on OST modeling. Some instances of localized erosion or deposition are occurring and the detailed investigations of these areas that were conducted are described below.

BANK STABILITY

As discussed in Section 5.3.1, "Water Resources and Water Quality" methodology, BEHI ratings provided context for field observations of bank retreat. The BEHI ratings indicated that the majority of monitored stream geomorphology cross-sections with above-average BEHI ratings were located in Valley Reaches 1B and 2C (see **Figure 7.1-45**).

Bank retreat over seven years of monitoring (2012 to 2018) to support the stream geomorphic assessment also identified the largest magnitudes of retreat in Valley Reaches 1B and 2C (see **Figure 7.1-46)**. Valley Reach 2C showed the greatest amount of bank retreat due to its meandering stream reaches within a wide alluvial valley which are often areas of lateral movement. Next, moderate retreat was observed within Valley Reach 1B given the presence of steeper slopes (increased stream power and shear stress potential) and composite banks.[21] Finally, though Valley Reaches 3D and 3E are located within a confined valley, these reaches are largely backwater-affected with slower moving water, so a low retreat rate was observed. Bank retreat was not monitored in Valley Reach 3F because it is tidal. These findings are in agreement with descriptions of lower Esopus Creek and the comparative potential for erosion between different valley reaches presented in the *River Reconnaissance Report* by Milone and MacBroom (2009). **Figure 7.1-46** provides information on total measured bank retreat over seven years of monitoring. Average retreat rates per year varied between cross-sections and the highest retreat rate was approximately 1.5 feet per year (located in Valley Reach 2C). The wetted width of streamflow (top width) associated with the channel-forming discharge was determined at each cross-section and ranged from approximately 200 to 800 feet. Most of the cross-sections had top widths at CF discharge between 200 to 400 ft. The larger top widths were observed in Valley Reach 2C where the floodplain is wide. Total bank retreat over the seven years of monitoring ranged from 0.1 to 2.5 percent of the top width across the 17 monitored cross-sections.

While streamflow magnitude and associated hydraulics (e.g. shear stress) are recognized drivers of channel erosional response, there were no consistent patterns between the measured bank retreat rates and the volume, intensity, and duration of streamflow observed over the seven years of monitoring. Results of shear stress analyses were also not found to be sufficiently predictive of bank retreat. This further

[21] Composite banks contain varying sediment sizes in stratified layers that increase susceptibility to erosion, such as gravel at the toe of the bank overlaid by silts and clays.

indicates bank retreat in lower Esopus Creek is influenced by factors beyond exposure to a specific streamflow magnitude for a certain duration. Results suggest there are local site conditions unrelated to duration of and exposure to a specific streamflow for each cross-section that influence retreat rates. Information on these localized conditions is presented below in the "Stream Management Plan Considerations" section.

Additional factors that can accelerate or resist bank erosion (see Section 5.3,1, "Water Resources and Water Quality" methodology) were documented at each cross-section where bank pin monitoring occurred. The bed and bank material transitions from coarse, unconsolidated sediments in Valley Reaches 1A, 1B, and 2C to finer material with cohesive silt and clay in the downstream portion of Valley Reach 2C and in Valley Reaches 3D and 3E. These cohesive soils have inter-particle forces that can resist erosion. Valley Reach 1B, 3D, and 3E had frequent bedrock outcrops that are highly resistant to erosion and that serve as a barrier against channel migration or erosion. Valley Reaches 1B and 2C typically had adequate vegetation in the streambank and "riparian" zone adjacent to the stream that can help hold bank material in place and resist erosion; however, Valley Reach 2C also included numerous examples of local hydraulic conditions that can affect erosion, including embedded logs, large wood accumulations, debris jams, scour pools, tributaries from adjacent developed watersheds that provide flow and sediment contributions from stormwater, mid-channel islands, multiple channels split around mid-channel features, or placement of riprap for stream channel stabilization. Such features are highly variable and were unique to certain locations in lower Esopus Creek. Examples of such features are shown in **Figure 7.1-47**.

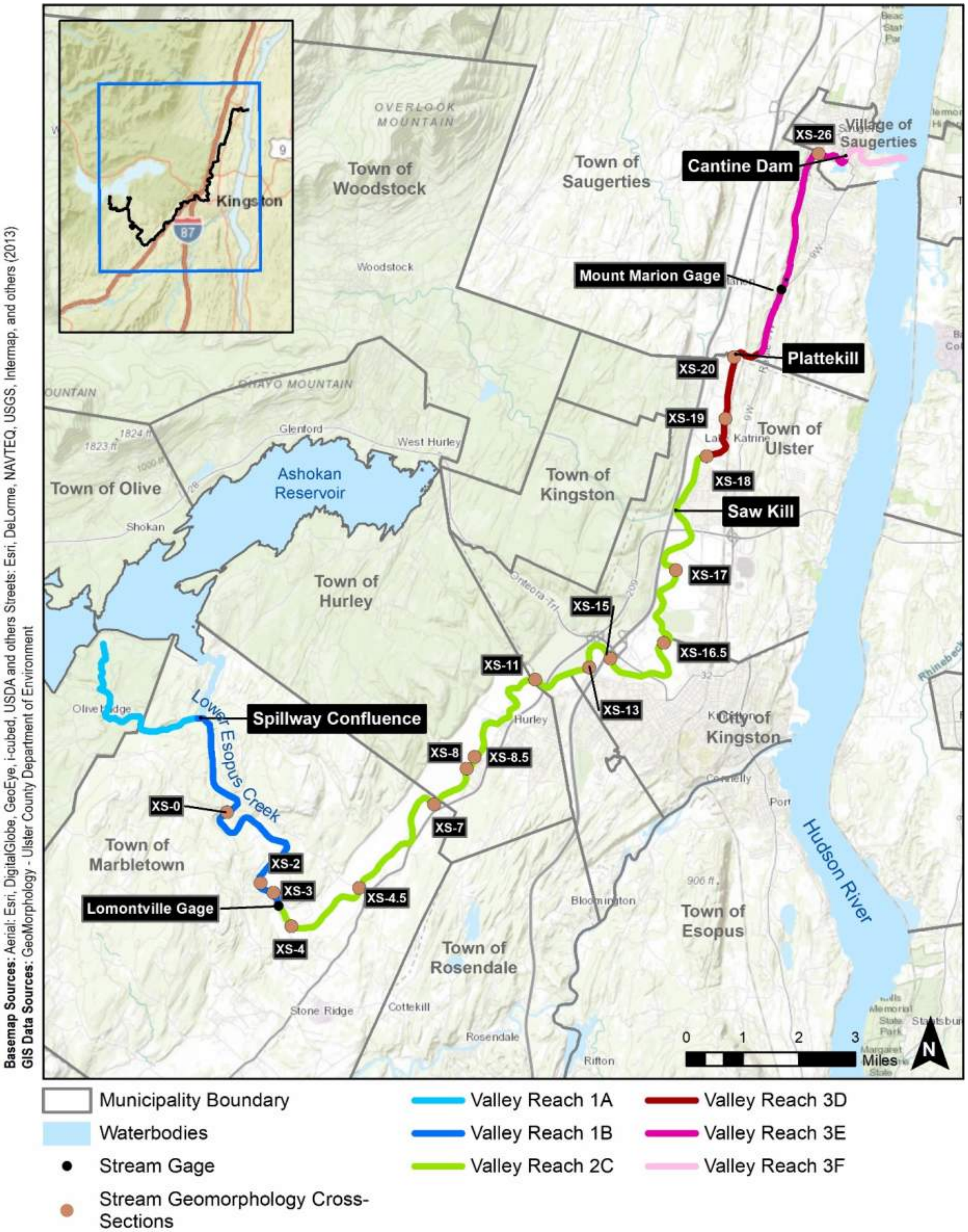

Figure 7.1-45
Lower Esopus Creek Study Area
Stream Geomorphology Cross-Sections

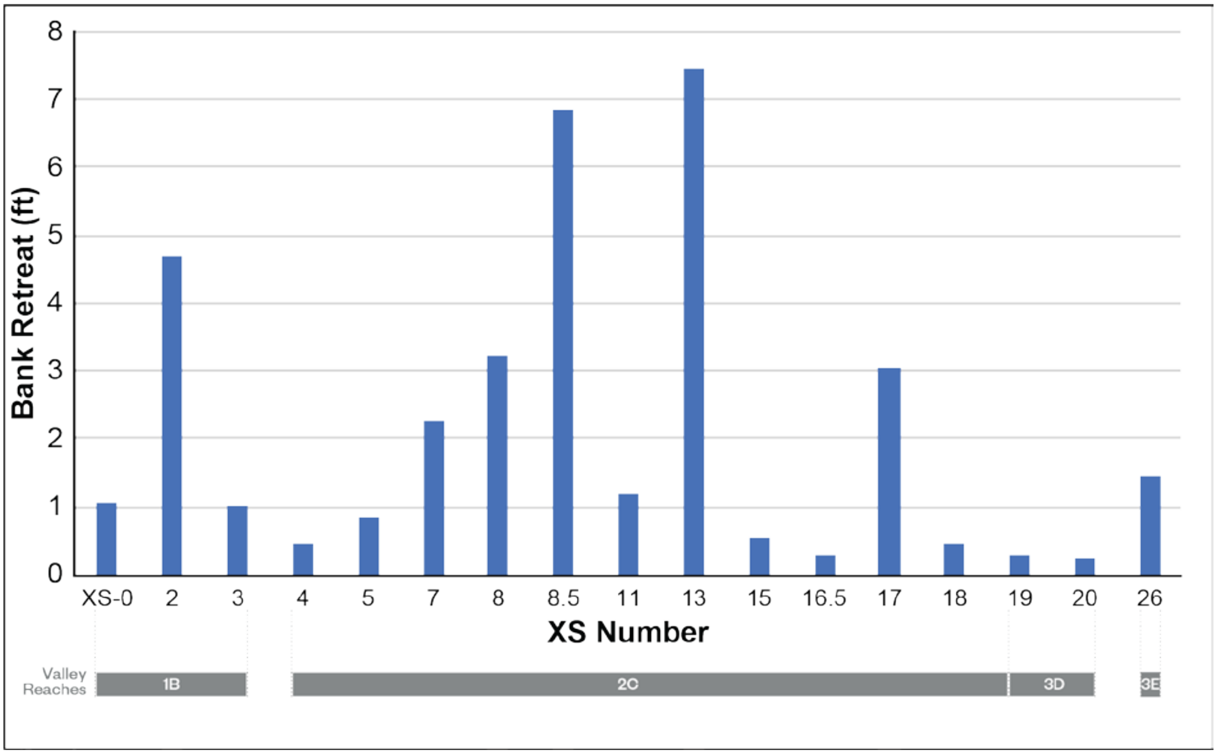

Figure 7.1-46. Observed Total Bank Retreat by Cross-Section over Seven Years of Monitoring, 2012 to 2018

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CONDITIONS SUPPORTING BANK STABILITY

Stable bank angles and healthy vegetation (9/30/2014)

Bedrock controls (10/7/2014)

CONDITIONS CAUSING BANK INSTABILITY

Mid-channel island (3/30/2016)

Embedded logs and debris jams (11/14/2017)

Bank material stratification and composite bank (10/3/2014)

Stormwater gully entering Lower Esopus Creek (11/15/2017)

Figure 7.1-47
Lower Esopus Creek Study Area
Local Near-bank Conditions Affecting Erosion

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The geomorphic characteristics in lower Esopus Creek provide context for areas susceptible to erosion. As discussed in Section 6.1.4, "Summary of Valley Reach Characteristics," Valley Reach 2C is in an unconfined valley underlain by soft erodible bedrock with surficial geologic deposits of erodible material, including alluvium and lacustrine silt and clay. This geologic setting has resulted in a sinuous channel with typical riffle-pool sequences, a wide accessible floodplain, and evidence of historic lateral migration. Development and agricultural practices in this area are located within the floodplain in close proximity to the stream channel, creating disturbances to streambanks and adding to the flow and sediment that enter lower Esopus Creek from contributing sub-watersheds. Human activities such as sand and gravel mining have widened several sections in this valley reach. These characteristics are generally typical areas of active erosion and were also observed in the stream reconnaissance study conducted in 2009 (Milone and MacBroom 2009).[22] Bank retreat monitoring shown in **Figure 7.1-46** demonstrated that Valley Reach 2C had more observed bank retreat than other reaches in lower Esopus Creek.

Individual areas in Valley Reach 2C have numerous factors that cause streambanks to be more susceptible to erosion. Field observations in Valley Reach 2C demonstrated that the streambanks in this area contain fine, erodible soils, often with composite banks. Composite banks contain varying sediment sizes in stratified layers that increase susceptibility to erosion, such as gravel at the toe of the bank overlaid by silts and clays. Embedded logs and trees and mid-channel islands were also common in this area. As discussed, these in-channel features create complex hydraulics that typically increase shear stress against banks and the potential for bank retreat. These areas of existing instability would be susceptible to erosion in both the future without and with the Proposed Action. would be susceptible to erosion in both the future without and with the Proposed Action.

The same areas of existing instability in Valley Reach 2C are generally co-located with adequate undeveloped riparian zones in the floodplain adjacent to lower Esopus Creek. The presence of these riparian buffer zones provides lower Esopus Creek with an area to move laterally without affecting adjacent land uses. Bank retreat only becomes a concern if there are sensitive land uses immediately adjacent to lower Esopus Creek. For example, if structures are located within the floodplain near areas experiencing bank retreat, then these structures could be damaged if additional bank retreat occurs. Similarly, if agricultural fields are located immediately adjacent to the stream channel, then additional retreat could cause loss of arable land. Field observations at monitored locations in Valley Reach 2C typically had riparian buffers and space for lower Esopus Creek to slightly move back and forth.

The other valley reaches in lower Esopus Creek demonstrated fewer existing areas of instability. Valley Reach 1B showed moderate retreat given the higher velocities present within the valley reach and some areas with composite banks that can be more susceptible to erosion; however, Valley Reaches 1A and 1B have coarse bed material and bedrock outcrops that are resistant to bank erosion, as well as wetlands in the floodplain that dissipate streamflow energy. In Valley Reach 2C downstream of the City of Kingston and into Valley Reaches 3D and 3E, the velocities and shear stresses are low enough and the banks have enough cohesive soils that bank retreat rates are low. These reaches are largely backwater-affected with slower moving water and located further downstream where the effects of flows from Ashokan Reservoir diminish and would be anticipated to show the least amount of bank retreat. One exception is a monitored location at the end of Valley Reach 2C where a large log and debris jam was creating local erosion at the bank immediately upstream. The debris jam persisted through the entire seven years of monitoring. A deeply-incised gully also delivers stormwater runoff from the adjacent watershed immediately upstream of the debris jam, compounding the local erosion.

[22] Milone & MacBroom. 2009. River Reconnaissance Report for Sustainable River Management: Lower Esopus Creek, Ulster County, NY.

The frequency of streamflow in the range of 600 MGD (928 cfs) would be similar in the future without and with the Proposed Action downstream of the spillway confluence, as shown in **Figure 7.1-12**. The annualized analysis of streamflow (see Section 7.1.1, "Flow Regime and Water Quality in Lower Esopus Creek") shows streamflow of this magnitude would occur more frequently in the winter and spring (times of the year when natural hydrology throughout the region leads to wetter conditions) in both the future without and with the Proposed Action. Considering observed bank retreat data and characteristics of the banks, particularly along Valley Reach 2C, there are areas anticipated to be susceptible to erosion at streamflow in the range of 600 MGD (928 cfs). However, because bank pin measurements and assessments focused on areas of known or suspected erosion, instability may not be representative of the entire valley reach. It is also anticipated that the less frequent occurrence of spills in the future with the Proposed Action could reduce erosion at some banks along Valley Reach 2C.

Valley Reach 2C is most susceptible to erosion but there is generally an adequate riparian buffer that is protective of resources along lower Esopus Creek and erosion would be comparable between the future without and with the Proposed Action.

In addition to differences in frequency of streamflow, differences in the duration and fluctuations of streamflow could affect bank retreat in either the future without or with the Proposed Action. Longer durations of streamflow at release magnitudes in the future with the Proposed Action could contribute to increased bank retreat from geotechnical instability following desaturation of stream bank material; however, monitoring data from periods with longer durations of releases did not suggest an increase in bank retreat. Additionally, the Proposed Action would reduce the variability of streamflow magnitudes compared to the future without the Proposed Action, which may provide a stabilizing effect for streambanks (Simon et al., 2000).[23] Gradual ramping and reduced magnitude of streamflow in the future with the Proposed Action would also help control fluctuations in water content of streambank material, which may protect against falling or slumping banks.

Future stream management activities along lower Esopus Creek could focus on identifying areas in Valley Reach 2C without adequate riparian buffer to resist erosion or where structures or resources are located immediately adjacent to the channel.

Bank retreat (erosion) is a natural process that has occurred at all monitored locations in lower Esopus Creek, even during periods when flows from Ashokan Reservoir were at or below the community release. The range, variability, and pattern of bank retreat rates observed over seven years of monitoring from 2012 to 2018 are not indicative of a stream undergoing significant lateral movement.[24] In addition, releases in the range of 600 MGD (928 cfs) fall well below the geomorphologically significant channel-forming discharge that maintains channel stability over time, 3,000 to 4,000 MGD (4,642 to 6,189 cfs). As discussed previously, the frequency of occurrence of streamflow in the range of the channel-forming discharge would also be similar in the future without and with the Proposed Action downstream of the spillway confluence.

Areas of higher retreat have been observed to occur primarily in Valley Reach 2C and, based on the composition of the streambanks in this reach, are anticipated to occur in both the future without and with the Proposed Action. Along this reach, there is space for lower Esopus Creek to move within the riparian buffer, and it is not anticipated that adjacent structures or land uses would be affected.

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[23] Simon, A., A. Curini, S.E. Darby and E.J. Langendoen. Bank and Near-bank Processes in an Incised Channel. Geomorphology. 335:193-217.

[24] The seven years of monitoring covered dry to normal hydrologic conditions; monitoring in wet years is expected to demonstrate slightly larger retreat rates than what was observed in 2012 to 2018 because wet hydrologic conditions would include large storms that could increase bank erosion in both the future without and with the Proposed Action.

STREAM MANAGEMENT PLAN CONSIDERATIONS

Pursuant to the Consent Order, DEP funded Environmental Benefit Projects in lower Esopus Creek. A portion of the funds were used to support development and implementation of a Lower Esopus Creek Stream Management Plan. Erosion and deposition along lower Esopus Creek are anticipated to be comparable between the future without and with the Proposed Action. However, the erosion and deposition assessments presented above provide information that could be used to support Stream Management Plan development.

The erosion and deposition assessments found that locations and total observed bank retreat along lower Esopus Creek are representative of geomorphic conditions present in each valley reach. Valley Reach 1B showed moderate retreat given the higher velocities present within the reach and composite banks which can be more susceptible to erosion. However, the stream channel in this valley reach is confined by bedrock outcrops and is not anticipated to experience lateral movement that would affect channel stability in either the future without or with the Proposed Action. Valley Segment 2 had the most retreat due to the wide alluvial valley and meandering stream reaches, which are often areas of lateral movement (in the direction of the outside meander bend which typically erodes first). Valley Segment 3 showed the lowest retreat; it is largely backwater-affected with slower moving water so it was anticipated to show the least amount of retreat. Based on field observations, it is anticipated that Valley Segment 2 would be the most responsive to streamflow and Valley Segment 3 would be least responsive in both the future without and with the Proposed Action.

Additional localized conditions were identified in the field that may further contribute to erosion in the future without and with the Proposed Action within Valley Reach 2C. Future stream management activities along lower Esopus Creek could focus on identifying and addressing these areas in Valley Reach 2C that are more susceptible to erosion based on localized geomorphic conditions, or where structures located in the floodplain may be adversely affected by bank retreat in the future without and with the Proposed Action. These locations may include areas where an adequate riparian buffer is not present, where composite banks are present, or where structures are located immediately adjacent to the channel. Additional considerations for future stream management activities could include addressing in-channel obstructions such as removal of extensive erosion-inducing debris jams, modification of past efforts to stabilize the channel, and modification of augmentations to streamflow (e.g., concentrated areas where stormwater runoff enters lower Esopus Creek). Specific locations where some of these conditions were observed in this geomorphic assessment are provided in **Table 7.1-9** and **Figure 7.1-48**.

WATER QUALITY

As described under Section 7.1.1, “Flow Regime and Water Quality in Lower Esopus Creek,” OST modeling shows turbidity levels of flows from Ashokan Reservoir in the future with the Proposed Action would be within the range and variability of turbidity levels that occur within lower Esopus Creek streamflow. Turbidity levels and potential summer temperature changes in the future without and with the Proposed Action were evaluated for applicable technical area assessments.

Table 7.1-9. Localized Factors Influencing Bank Retreat

Valley Reach	Cross-Section	Description
1B	2	Narrow channel with coarse bed and bank material, steep slope, and little vegetation on banks or in riparian zone. Aerial imagery suggests that a side channel existed and was cut off.
2C	7	Bank pins are located in a scour pool in a reach with evidence of instability. There are a series of conditions that create complex hydraulics: multiple channels, mid-channel islands, a bedrock outcrop immediately downstream, and a hardened channel (man-made) upstream. Based on the existing channel planform alignment, the stream will likely move laterally where erodible material is present upstream and downstream of the existing hardened features (man-made features, bedrock, and mid-channel islands). The mid-channel island also diverts streamflow toward the outside banks.
	8	Bed and bank material include both small cobble and gravel, as well as fine sand in stratified layers, resulting in highly erodible material. A side channel on the opposite bank diverts streamflow at higher flows but limited at low or intermediate flows.
	8.5	Bank pins are located at a highly unstable bank toward the downstream end of a large meander. Shape is concave, and bank is a composite bank of layers of fine sand and gravel. Embedded logs in streambed create complex streamflow patterns.
	11	At this location, streamflow is split into two channels around a large permanent mid-channel island. The mid-channel island diverts streamflow toward the outside banks.
	13	Banks are 15-20 ft high and composed of sand, silt, and clay. Watershed is more urban in this section and erosion may be influenced by stormwater runoff. Evidence of freeze-thaw effects on clay soils observed during one monitoring period. Discharge from leaking pipe(s) also observed at bank pin location during one monitoring period. A side channel here diverts streamflow at high flows, but not at low or intermediate flows.
	17	This bank is vertical, approximately 20 ft high, and primarily silt and clay. The bank experiences undercutting. There is an incised stormwater runoff tributary that enters immediately downstream of the bank pins. At the confluence of lower Esopus Creek and this tributary, a large persistent debris jam exists (this debris jam has been present for the entire 7-year bank pin monitoring period).
3E	26	This portion of stream is backwater-affected from the Cantine Dam in Saugerties. Backwater effects can include erosion by wave action. Across the channel from these bank pins is a bedrock outcrop that may be diverting streamflow toward the bank where pins are located.

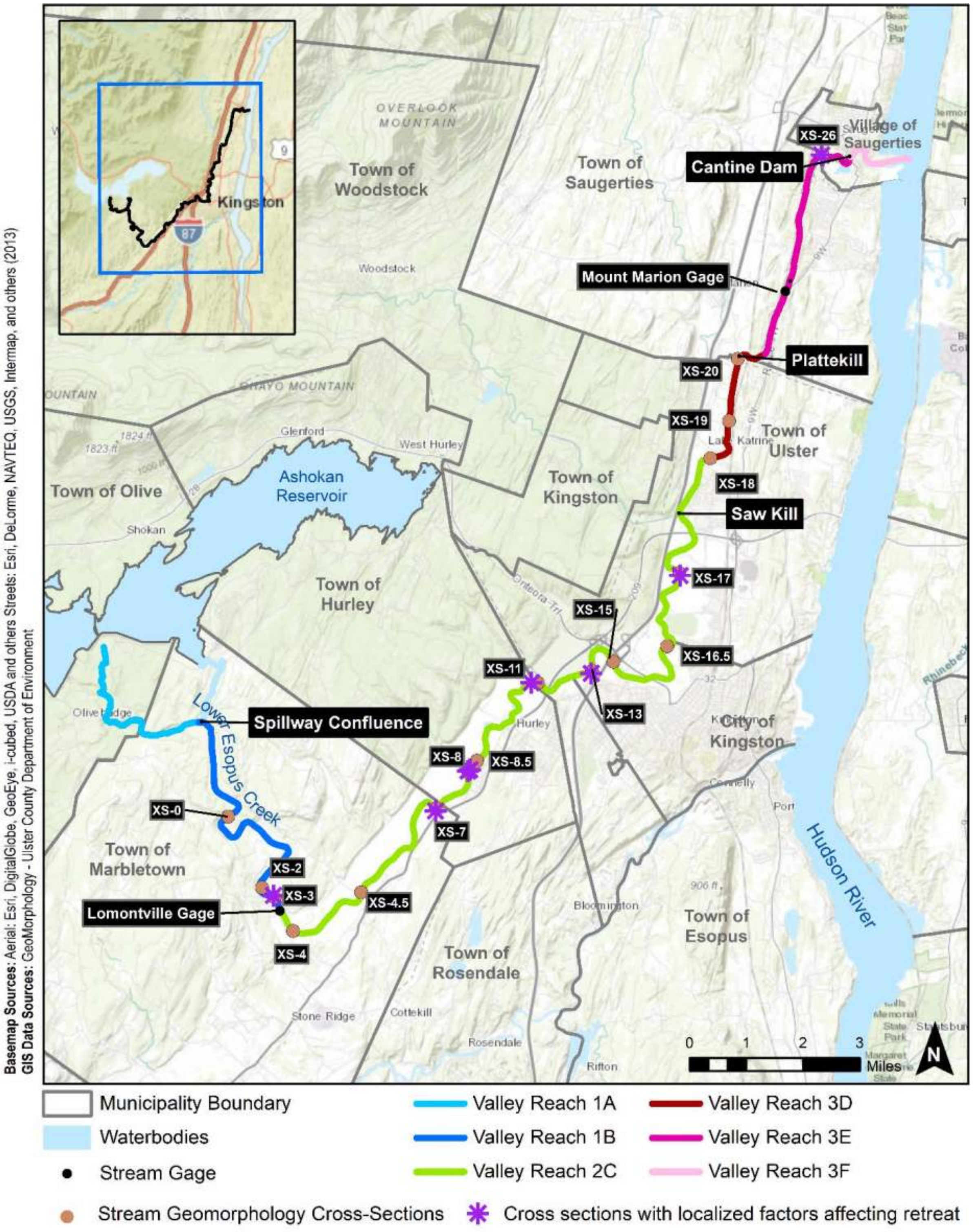

Figure 7.1-48
Lower Esopus Creek
Localized Factors Affecting Retreat