The Nature Conservancy
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July 31, 2023

Via electronic mail

Danielle Spendiff, Regulatory and Customer Service Division Chief
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Attn: Conowingo Dam WQC

Re: Application #17-WQC-02, Constellation Power Generation, LLC, Conowingo Hydroelectric Project

Dear Ms. Spendiff,

The Nature Conservancy (TNC) submits these comments in response to the Maryland Department of the Environment's (MDE or Department) "Public Notice Announcement Soliciting Limited Public Comments related to the Section 401 Water Quality Certification, 17-WQC-02, Issued on April 27, 2018, to Constellation Power Generation, LLC (formerly Exelon) for the Conowingo Hydroelectric Project," which was issued on June 30, 2023. In accordance with MDE's solicitation, we have focused on providing "newly available data, science or information related to water quality standards or impacts since April 27, 2018 when the WQC was issued, as applicable to Maryland's WQC decision."

These comments are organized as follows: Section I summarizes the procedural background for reconsideration; Section II describes TNC's interests in the certification proceeding and affirms the analysis and recommendations in our prior comments on Exelon's certification request; Section III provides new information for MDE to consider on reconsideration of the 2018 WQC; and Section IV concludes our comments.

I. BACKGROUND

MDE granted a Water Quality Certification (WQC) with conditions to Exelon[1] in 2018. Timely requests for reconsideration in accordance with COMAR 26.08.02.10F(4) were filed by Exelon and the Stewards of the Lower Susquehanna, d/b/a Lower Susquehanna Riverkeeper Association, and Waterkeepers Chesapeake (Waterkeepers et al.). The next year, MDE withdrew its WQC and waived its authority as part of a settlement agreement with Exelon.[2]

In 2021, the Federal Energy Regulatory Commission (FERC) issued a license to Exelon incorporating certain water quality terms and conditions from the Conowingo Dam Water Quality Settlement Agreement by and between State of Maryland, Department of the Environment and Exelon Generation Company, LLC (2019 Settlement Agreement).[3]

In 2022, the United States Court of Appeals for the D.C. Circuit found that FERC had exceeded its authority under Section 401(a) of the Clean Water Act (CWA), 33 U.S.C. § 401(a).[4] The court vacated the license and remanded to FERC to

> allow completion of the administrative and judicial review that was interrupted by the settlement agreement.... That review could result in either (1) the invalidation of Maryland's 2018 certification, which would require Constellation to request a new certification, or (2) the validation of the 2018 certification, which would require FERC to issue a license incorporating the conditions contained therein.[5]

In accordance with the D.C. Circuit's direction, MDE is now continuing its administrative review of the 2018 WQC.

Pending reissuance of a new license, Constellation is operating the Project under an annual license issued on terms consistent with the license issued in 1980.[6] To our knowledge, Constellation has not sought permission from FERC to continue implementing any of the protection, mitigation, and enhancement (PM&E) measures included in the vacated license, even those not contested by the relicensing parties, pending FERC's issuance of a new license. FERC

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[1] Constellation Power Generation, LLC is the successor licensee to Exelon Generation Company, LLC.

[2] "Joint Offer of Settlement and Explanatory Statement of Exelon Generation Company, LLC and the Maryland Department of the Environment," eLibrary no. 20191029-5119 (Oct. 29, 2019).

[3] *Exelon Generation Co., LLC*, 174 FERC ¶ 61,217, 61,970 (2021).

[4] *Waterkeepers Chesapeake v. FERC*, 56 F.4th 45, 50 (D.C. Cir. 2022).

[5] *Id.*

[6] *Susquehanna Power Co. Philadelphia Elec. Power Co.*, 19 FERC ¶ 61,348, 61,681 (1980).

cannot reissue a new license until MDE issues a final decision on water quality certification following completion of the reconsideration process and any contested case hearing.

II. THE NATURE CONSERVANCY'S INTERESTS IN CERTIFICATION

TNC has significant interests in the restoration and long-term protection of the lower Susquehanna River and Chesapeake Bay. It participated actively in the federal relicensing proceeding to develop the scientific record regarding the Project's impacts on water quality and aquatic resources in the lower Susquehanna River and Chesapeake Bay and measures to avoid, minimize, or mitigate those impacts.

TNC also participated actively in MDE's proceeding on Exelon's request for water quality certification under CWA section 401 and submitted comments on August 23, 2017 (2017 Comments) and January 16, 2018 (2018 Comments).[7]

The 2017 and 2018 Comments continue to accurately reflect TNC's goals for the certification (and relicensing) proceeding, as stated below:

> Our goals for the certification proceeding include the support of low-carbon electricity while: (1) restoring self-sustaining migratory fish populations by improving access to historic habitats above the Conowingo dam; (2) restoring habitat below the dam to restore populations of fish, mussels, turtles, submerged aquatic vegetation (SAV), and other aquatic life; and (3) improving water quality and sediment transport patterns in the Lower River and Upper Chesapeake Bay.[8]

Achieving those goals over the next license term requires that the certification address the Conowingo Project's unmitigated impacts, namely:

> The unmitigated impact of reservoir design, storage, and releases on designated beneficial uses including: Growth and propagation of fish, other aquatic life and wildlife (year round); Seasonal migratory fish spawning and nursery use (2/1-5/31); Seasonal Shallow-Water Submerged Aquatic Vegetation (4/1-10/30); and Open-water fish and shellfish (year-round); and

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[7] Both comments are entitled "Letter to Elder Ghigiarelli, re: Application#17-WQC-02, Lower Susquehanna River and Upper Chesapeake Bay, Use I and II Waters." We understand that MDE has maintained copies of those comments and they remain part of the administrative record for the certification proceeding. Accordingly, we incorporate and refer to, but do not restate or resubmit, those comments here and will provide additional copies only upon request.

[8] 2017 Comments, p. 2.

> The unmitigated impact of reservoir design, storage and releases on the timing and quality of sediment and nutrient loads stored in, and released from, the dam to the lower Susquehanna River and Upper Chesapeake Bay, which impede the achievement of designated uses … and the Chesapeake Bay TMDL.[9]

As described below, TNC previously disputed that the measures included in the 2019 Settlement Agreement would be adequate to address the Project's unmitigated impacts on designated uses. Instead, TNC advocated MDE's adoption of certification conditions consistent with the Proposed Conditions and Recommendations stated in our 2018 Comments (pp. 4-19) and overviewed in Table 1 below:

Table 1. Overview of Proposed Conditions

Unmitigated Impact	Affected WQS	Proposed Condition or Recommendation	Page*
1. Dam releases on downstream habitat	All Designated Uses referenced above & Chesapeake Bay TMDL	1.a. Proposed flow schedule	3
		1.b. Implementation and adaptive management	5
2. Migratory fish passage	Seasonal migratory fish spawning and nursery use	2. Adoption of settlement agreement	14
3. Sediment & Water Quality	All Designated Uses referenced above & Chesapeake Bay TMDL	3.a. Mitigation for excess nutrients 3.b. Mitigation for lack of coarse sediments 3.c. Completing the record and adaptive management	14
4. Uncertainty & Transparency	All Water Quality Standards	4. Certificate term and data accessibility	15

* Page references are to 2018 Comments.

The existing administrative record and the additional information provided in Section III, *infra*, continue to show these Proposed Conditions and Recommendations should be incorporated into MDE's certification decision on reconsideration to effectively address the Project's unmitigated impacts on designated uses and water quality in the Lower Susquehanna River and Chesapeake Bay over the term of the new FERC license.

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[9] 2018 Comments, p. 4.

III. ADDITIONAL INFORMATION

TNC provides new information gathered since MDE issued the 2018 WQC. We request that MDE reconsider its analysis and findings in the 2018 WQC based on the new information provided in the attached documents. Such reconsideration is necessary because the Project's potential impacts on water quality, particularly the designated uses related to aquatic life and wildlife, are material to MDE's decision that the Project as licensed will comply with MDE's water quality standards over the license term.

The eight (8) documents TNC submits are:

1. Maryland's Final 2018 Integrated Report, Part F.6;[10]

2. EPA's April 9, 2019 approval letter for the Final 2018 Integrated Report;[11]

3. Maryland's Final Combined 2020-2022 Integrated Report, Part F.6;[12]

4. U.S. Environmental Protection Agency's (EPA) February 25, 2022 approval letter for the Final Combined 2020-2022 Integrated Report;[13]

5. Letter from Mark Bryer to Kimberly D. Bose (Oct. 29, 2019);[14]

6. The Nature Conservancy's Answer to Joint Motion for a Ruling on Joint Offer of Settlement and Issuance of License (Mar. 10, 2021);[15]

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[10] *Available at* https://mde.maryland.gov/programs/water/TMDL/Integrated303dReports/Documents/Integrated_Report_Section_PDFs/IR_2018/2018IR_Part_F.6_Final.pdf (Attachment 1).

[11] *Available at* https://mde.maryland.gov/programs/water/TMDL/Integrated303dReports/Documents/Integrated_Report_Section_PDFs/IR_2018/2018_EPA_Approval_Letter.pdf (Attachment 2).

[12] *Available at* https://mde.maryland.gov/programs/water/TMDL/Integrated303dReports/Documents/Integrated_Report_Section_PDFs/IR_2020_2022/MD_Final_Approved_Combined2020_2022IR_Part_F.6.pdf (Attachment 3).

[13] *Available at* https://mde.maryland.gov/programs/water/TMDL/Integrated303dReports/Documents/Integrated_Report_Section_PDFs/IR_2020_2022/MD_2020_2022_IR_Approval_Letter_Final.pdf (Attachment 4).

[14] FERC eLibrary no. 20191029-5163 (Attachment 5).

[15] FERC eLibrary no. 20210310-5217 (Attachment 6).

7. Yoga Anindito et al., "A new solution to mitigate hydropeaking? Batteries versus re-regulation reservoirs," Journal of Cleaner Production Volume 210, 2019, pp. 477-489, ISSN 0959-6526;[16] and

8. B. Bellgraph et al., "Deployment of Energy Storage to Improve Environmental Outcomes of Hydropower," PNNL-SA-157672 (May 2021).[17]

A. MDE's 303(d) listing for lower Susquehanna River

Maryland's 2018 Final Integrated Report, Section "F.6 Category 4c Waters," was the first time the Lower Susquehanna River mainstem below Conowingo dam was listed as an impaired waterbody under the CWA. Attachment 1, p. 1. MDE listed the Lower Susquehanna as impaired for non-attainment of the designated use of supporting *aquatic life and wildlife*, and identified the cause of impairment as "flow alteration – changes in depth and flow velocity," and the source of pollution as dam or impoundment. *Id.* The report noted that both assessment of the flow regime and measured biological impacts were used to demonstrate that "Conowingo Dam operations cause impairment of the aquatic life and wildlife designated use." *Id.* EPA approved Maryland's 2018 Final Integrated Report, including the initial listing of the Lower Susquehanna River as impaired due to flow alteration, on April 9, 2019. Attachment 2.

Maryland's 2020-2022 Combined Final Integrated Report reaffirmed the listing of the Lower Susquehanna River as impaired due to flow alteration caused by the Project. Attachment 3, p. 2. EPA approved Maryland's 2020-2022 Combined Final Integrated Report on February 25, 2022. Attachment 4.

TNC entered the listing into the administrative record for relicensing, explaining that the listing was supported by the best available data, models and literature in the record, which show that existing project operations, particularly the Project's combined minimum flows (0 to 10,000 cfs), maximum generation flows (86,000 cfs), and ramping rates (86,000 cfs/hour), have resulted in:

- Between a 75% and 95% loss in migration and spawning habitat for diadromous fish …;
- Alteration of the resident fish community toward habitat generalists and estimated loss of 50 to 80% of persistent spawning habitat …;
- Loss of freshwater mussel recruitment below the dam …;

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[16] *Available at* https://www.sciencedirect.com/science/article/abs/pii/S0959652618334401?via%3Dihub (Attachment 7).

[17] *Available at* https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-SA-157672.pdf (Attachment 8).

- 'Hydrologically impaired' macroinvertebrate community …;
- Fish stranding and mortality due to ramping and resulting dewatering, thermal stress and predation…;
- Loss of state and federally endangered species habitat for reproductive growth and hibernation …;
- Sediment-starved lower river and flats…; and
- Absence or reduction of Submerged Aquatic Vegetation (SAV) communities below the dam ….[18]

We further commented that the scientific evidence in the record showed TNC's proposed instream flow regime to be the superior alternative for addressing the impairment.[19] By contrast, the record evidence showed that the instream flow schedules in the 2018 WQC and the 2019 Settlement Agreement would not be adequate to address the impairment below Conowingo dam.[20]

We request that MDE consider this additional evidence, developed since MDE's issuance of the 2018 WQC, which continues to support TNC's proposed flow regime to address the Project's impairment of the designated use of aquatic life and wildlife below Conowingo dam.

B. There are improved energy storage technologies that could be integrated at the Project to help meet peak energy demands under TNC's proposed flows.

In issuing its prior decisions on the 2018 WQC and 2019 Settlement Agreement, MDE did not make specific findings regarding the potential impacts of the proposed PM&E measures prescribed or recommended for inclusion in the new FERC license on power generation at the Project. Nevertheless, we provide additional information on this issue for MDE's consideration because it was relevant to FERC staff's environmental analysis for relicensing, specifically its consideration of alternative flow regimes.

FERC staff rejected TNC's proposed flow regime, even though it would provide greater protection to the aquatic life and wildlife designated use, because "[o]peration under the TNC Flow Regime would be restrained and would eliminate many of the [Project's] peaking and

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[18] 2017 Comments, pp. 6-9; Attachment 5, pp. 3-4 (internal citations omitted). We submitted evidence that climate change could worsen the impairment caused by Project Operations. Attachment 6, pp. 11-13.

[19] Attachment 5, pp. 4-5.

[20] *Id.* at 5; Attachment 6, pp. 9-10.

ancillary services benefits …..”[21] TNC objected to this finding as vague.[22] We also urged FERC staff to consider alternatives incorporating battery storage technologies into Project operations to reduce ecological impacts while maintaining the Project’s power benefits:

> There is new information since the FEIS was published that integration of battery storage at the Project could reduce the impacts of peaking generation at the Project for the benefit of aquatic species without restraining operations in a manner that would harm the energy market. Research by the U.S. Energy Information Administration shows “[l]arge-scale battery storage systems are increasingly being used across the power grid in the United States,” as technology costs decrease and regulatory hurdles are addressed.[23]

Since the FERC license issued, the feasibility and potential benefits of integrating battery storage technologies into Project operations has increased, as described below.

C. A new solution to mitigate hydropeaking? Batteries versus re-regulation reservoirs

This 2018 study evaluated the potential use of battery energy storage systems (BESS) to reduce the negative downstream ecosystem impacts from flow fluctuation.

> [BESS are] rapidly increasing their installation rates and are projected to soon be viable for energy peaking purposes in power systems. Lower-cost BESS could conceivably substitute for the peaking ability usually provided by conventional hydropower plants, by storing hydropower produced during off-peak hours and discharging this power during peak hours. The market for grid-scale BESS is growing quickly, reaching volumes in 2015 that were four times larger than any prior year. Future projections for the year 2030 indicate (Li-ion BESS) cost reductions of the order of 60%-80%.[24]

The study highlights the role BESS could play for relicensing proceedings, particularly peaking plants like the Conowingo Project:

> BESS should begin to enter into discussions related to hydropeaking mitigation, especially given the typically long duration (e.g. 30 years) of operating license agreements at many dams. For example, in the US, 10 GW of hydropower capacity is scheduled to go through the re-licensing process before 2025, and another 16 GW before

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[21] Attachment 6, p. 13 (quoting FEIS, p. 429).

[22] Attachment 5, p. 7.

[23] Attachment 6, pp. 13-15; *see also* Attachment 5, p. 7.

[24] Attachment 7, pp. 478 (internal citations omitted).

> 2030. During this process, the legally binding operational balance between dam operations and environmental impacts (including any potential restrictions on hydropower peaking) will be fixed for another period of 30 years. *If power systems soon have a wider range of cost-effective options (i.e., BESS) for offsetting the economic penalties associated with ramping restrictions, this information could be directly useful in informing re-licensing discussions*.[25]

This additional information shows that FERC staff's prior cost-benefit analysis for the flow regime alternatives is outdated and warrants further review and update based on information developed since 2018, including the sources cited below.

D. <u>Deployment of Energy Storage to Improve Environmental Outcomes of Hydropower</u>

The Department of Energy released a white paper in 2021, finding that integrating energy storage systems with hydropower plants can result in "improvements in both river health[26] and the financial future of hydropower plants" (Attachment 8, p. 22). The study examined hydropeaking's potential adverse effects on ecosystems (*see id.* at 7-8), and explained:

> Co-sited energy storage may enable a hydropower facility to meet system peaking needs, provided that state-of-charge control is aligned with the peaks, without releasing such significant water volumes downriver. Thus, energy storage systems would decrease peak generation flow releases, thereby reducing flow fluctuations downstream of the hydroelectric project—and ultimately, lowering the potential impacts on threatened fish and other organisms using the river habitat. Response times are also much faster when using batteries and power factors of 0.0 are supported, so more than just maintained but improved power system benefits (i.e., energy and ancillary services) may be achievable along with environmental improvements. (*Id.* at 8).

While the potential use of co-located batteries was limited in the past due to high costs (*see id.* at 4-5), the overall capital costs for batteries have continued to decline in recent years while scalability has increased.

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[25] *Id.* at 487 (italics added; internal citations omitted).

[26] River health benefits are summarized earlier as including:

> Integrated operations support increased flexibility in the management of the underlying water system and the associated ecosystem. The connections are particularly clear in modifying power generation relative to water storage, release, and flow regimes. Such integrated operations support regulatory requirements, including maintaining upstream reservoir levels, ensuring adequate downstream flows to meet an ecological target, or for human uses of a river such as fishing or boating (Attachment 8, p. iii).

E. Energy Storage in Maryland

The Maryland Department of Natural Resources (MDNR) has reported that advanced energy storage technologies, including BESS, are increasingly cost effective and feasible for deployment in Maryland.

> Over the past decade, a variety of newer energy storage technologies (including water- or salt based thermal storage, compressed air energy storage, batteries and flywheels) have emerged. These are collectively known as "advanced" energy storage technologies, and they hold the potential to increase the grid's storage capacity and flexibility, especially if technological advances and recent price declines continue. Storage systems now range in size from small, on-site units to utility-scale systems that interconnect to the bulk power grid …. Depending on the technology used and project size, advanced energy storage systems can discharge at their full capacity for 15 minutes to days. Some storage projects can be developed in months rather than years, and can be sized precisely to meet demand.[27]

IV. CONCLUSION

The Nature Conservancy thanks the Department for the opportunity to provide comments on reconsideration. We request that the Department consider the recommendations and new information provided herein. We further request that the Department publish a schedule for further proceedings.

Respectfully submitted,

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[27] *See* Maryland Department of Natural Resources, "Energy Storage in Maryland" (2018), *available at* https://dnr.maryland.gov/pprp/Documents/Energy-Storage-In-Maryland.pdf; *see also* Department of Energy, "Energy Storage Grand Challenge Roadmap" (Dec. 2020, *available at* https://www.energy.gov/sites/default/files/2020/12/f81/Energy%20Storage%20Grand%20Challenge%20Roadmap.pdf), identifying several advanced alternative energy storage technologies, including battery storage.

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Attachment 1

F.6 Category 4c Waters

Maryland's 2018 Final Integrated Report - Category 4c Waters

Assessment Unit	*Basin Name*	*County*	*Cycle Listed*	*Designated Use*	*Water Type Detail*	*Cause*	*Indicator*	*Pollution Sources*	*Notes*
MD-02120201-Lower_Susquehanna_Mainstem	Lower Susquehanna River	CE, HA	2018	Aquatic Life and Wildlife	River Mainstem	Flow Alteration-Changes in Depth and Flow Velocity	Habitat Evaluation	Dam or Impoundment	Assessment of flow regime and biological impacts demonstrate that Conowingo Dam operations cause impairment of the aquatic life and wildlife designated use.
MD-02130203	Upper Pocomoke River	WI, WO	2012	Aquatic Life and Wildlife	1st thru 4th order streams	Riparian Buffer, Lack of	Direct Measurement	Agriculture	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130203	Upper Pocomoke River	WI, WO	2012	Aquatic Life and Wildlife	1st thru 4th order streams	Habitat Alterations	Direct Measurement	Channelization	The Biostressor analysis indicates that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130305	Nanticoke River	CA, DO, WI	2016	Aquatic Life and Wildlife	1st thru 4th order streams	Habitat Alterations	Direct Measurement	Channelization	The Biostressor analysis indicated that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130306	Marshyhope Creek	CA, DO	2012	Aquatic Life and Wildlife	1st thru 4th order streams	Habitat Alterations	Direct Measurement	Channelization	The Biostressor analysis indicated that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130404	Upper Choptank River	TA, QA, CA	2012	Aquatic Life and Wildlife	1st thru 4th order streams	Habitat Alterations	Direct Measurement	Channelization	The Biostressor analysis indicates that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130510	Upper Chester River	KE, QA	2012	Aquatic Life and Wildlife	1st thru 4th order streams	Habitat Alterations	Direct Measurement	Channelization	The Biostressor analysis indicates that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.

Assessment Unit	*County*	*Designated Use*	*Cause*	*Indicator*	*Notes*
Basin Name	*Cycle Listed*	*Water Type Detail*		*Pollution Sources*	
MD-02130701	HA	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Direct Measurement	The Biostressor analysis indicated that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Bush River	2014	1st thru 4th order streams		Urban Development in Riparian Buffer	
MD-02130701	HA	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicated that channelization is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Bush River	2014	1st thru 4th order streams		Channelization	
MD-02130704	HA	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Bynum Run	2012	1st thru 4th order streams		Channelization	
MD-02130705	HA	Aquatic Life and Wildlife	Habitat Alterations	Fish and Benthic IBIs	The Biostressor analysis indicated that channelization is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Aberdeen Proving Ground	2014	1st thru 4th order streams		Channelization	
MD-02130802	BA	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Lower Gunpowder Falls	2012	1st thru 4th order streams		Channelization	
MD-02130805	BA, CR	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Direct Measurement	The Biostressor analysis indicates that lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Loch Raven Reservoir	2014	1st thru 4th order streams		Urban Development in Riparian Buffer	
MD-02130901	BA, BC	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Direct Measurement	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Back River	2012	1st thru 4th order streams		Loss of Riparian Habitat	
MD-02130901	BA, BC	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Back River	2012	1st thru 4th order streams		Channelization	

Assessment Unit	County	Designated Use	Cause	Indicator	Notes
Basin Name	*Cycle Listed*	*Water Type Detail*		*Pollution Sources*	
MD-02130903	AA, BA, BC	Aquatic Life and Wildlife	Habitat Alterations	Habitat Evaluation	The Biostressor analysis indicates that stream channelization is a major stressor affecting biological integrity in this watershed. This listing, along with others, replace the biological listing.
Baltimore Harbor	2014	1st thru 4th order streams		Channelization	
MD-02130903	AA, BA, BC	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Habitat Evaluation	The Biostressor analysis indicates that the lack of an adequate riparian buffer is a major stressor affecting biological integrity in this watershed. This listing, along with others, replaces the biological listing.
Baltimore Harbor	2014	1st thru 4th order streams		Urban Development in Riparian Buffer	
MD-02130904	BA, BC	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Jones Falls	2012	Non-tidal 8-digit watershed		Channelization	
MD-02130905	BA, BC	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Gwynns Falls	2012	Non-tidal 8-digit watershed		Channelization	
MD-02130906	AA, BA, BC, HO, CR	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Patapsco River Lower North Branch	2012	1st thru 4th order streams		Channelization	
MD-02131003	AA	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Direct Measurement	The Biostressor analysis indicates that the lack of an adequate riparian buffer is a major stressor affecting biological integrity in this watershed. This listing, along with others, replaces the biological listing.
South River	2014	1st thru 4th order streams		Urban Development in Riparian Buffer	
MD-02140201	PG, CH	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicated that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Potomac River Upper tidal	2018	1st thru 4th order streams		Channelization	
MD-02140205	MO, PG	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Direct Measurement	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Anacostia River	2012	1st thru 4th order streams		Loss of Riparian Habitat	

Assessment Unit	*County*	*Designated Use*	*Cause*	*Indicator*	*Notes*
Basin Name	***Cycle Listed***	***Water Type Detail***		***Pollution Sources***	
MD-02140205	MO, PG	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Anacostia River	2012	1st thru 4th order streams		Channelization	
MD-02140207	MO	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Cabin John Creek	2012	Non-tidal 8-digit watershed		Channelization	
MD-02140301-Wadeable_Streams	FR, WA	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Direct Measurement	The Biostressor analysis indicates that the lack of an adequate riparian buffer is a major stressor affecting biological integrity in this watershed. This listing, along with others, replaces the biological listing.
Potomac River Frederick County	2018	1st thru 4th order streams		Urban Development in Riparian Buffer	
MD-02140302	CR, FR, MO	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Direct Measurement	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Lower Monocacy River	2012	Non-tidal 8-digit watershed		Agriculture	
MD-02140502	WA	Aquatic Life and Wildlife	Habitat Alterations	Habitat Evaluation	The Biostressor analysis indicates that channelization is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Antietam Creek	2014	1st thru 4th order streams		Channelization	
MD-02140502	WA	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Habitat Evaluation	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Antietam Creek	2014	1st thru 4th order streams		Agriculture	
MD-02141002	AL	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Direct Measurement	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Evitts Creek	2012	Non-tidal 8-digit watershed		Loss of Riparian Habitat	
MD-02141003	AL, GA	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicated that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Wills Creek	2012	Non-tidal 8-digit watershed		Channelization	

Assessment Unit Basin Name	County Cycle Listed	Designated Use Water Type Detail	Cause	Indicator Pollution Sources	Notes
MD-05020201-Wadeable_Streams Youghiogheny River	GA 2014	Aquatic Life and Wildlife 1st thru 4th order streams	Riparian Buffer, Lack of	Habitat Evaluation Urban Development in Riparian Buffer	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing addresses a portion of the biological listing and therefore replaces it on the list.

Attachment 2

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

APR 0 9 2019

Mr. Lee Currey, Director
Water and Science Administration
Maryland Department of the Environment
1800 Washington Blvd., Suite 540
Baltimore, Maryland 21230-1718

Dear Mr. Currey:

The U.S. Environmental Protection Agency (EPA), Region III, has conducted a complete review of Maryland's 2018 Section 303(d) List, and supporting documentation and information. Based on this review, EPA has determined that Maryland's list of water quality limited segments still requiring Total Maximum Daily Loads, meets the requirements of Section 303(d) of the Clean Water Act and EPA's implementing regulations. Therefore, with this letter, EPA hereby approves Maryland's 2018 Section 303(d) List. The statutory and regulatory requirements, and EPA's review of Maryland's compliance with each requirement, are described in the enclosure.

We commend you and your staff for the thorough work and exemplary effort in establishing the list and in responding to the comments received.

If you have any questions regarding this decision, please feel free to contact Ms. Evelyn S. MacKnight, Associate Director, at 215-814-5717, or Macknight.Evelyn@Epa.gov.

Sincerely,

Catherine A Libertz

Catherine A. Libertz, Director
Water Protection Division

Enclosure

cc : Matthew Stover, MDE-WSA

EPA Region III Approval Rationale for Maryland's 2018 Section 303 (d) List

EPA has conducted a complete review of Maryland's 2018 Section 303(d) list and supporting documentation and information, which was submitted to EPA on March 11, 2019. Based on this review, EPA has determined that Maryland's list of water quality limited segments (WQLSs) still requiring Total Maximum Daily Loads (TMDLs) meets the requirements of Section 303(d) of the Clean Water Act ("CWA" or "the Act") and EPA's implementing regulations. Therefore, EPA hereby approves Maryland's Section 303(d) list. The statutory and regulatory requirements, and EPA's review of Maryland's compliance with each requirement, are described in detail below.

Statutory and Regulatory Background

Identification of WQLSs for Inclusion on Section 303(d) List

Section 303(d)(1) of the Act directs States to identify those waters within its jurisdiction for which effluent limitations required by Section 301(b)(1)(A) and (B) are not stringent enough to implement any applicable water quality standard, and to establish a priority ranking for such waters, taking into account the severity of the pollution and the uses to be made of such waters. The Section 303(d) listing requirement applies to waters impaired by point and/or non-point sources, pursuant to EPA's long-standing interpretation of Section 303(d).

EPA regulations provide that States do not need to list waters where the following controls are adequate to implement applicable standards: (1) technology-based effluent limitations required by the Act; (2) more stringent effluent limitations required by State, local, or federal authority. See 40 CFR 130.7(b)(1). EPA's review and action on Maryland's 2018 list is generally consistent with EPA guidance, including *Guidance for 2006 Assessment, Listing, and Reporting Requirements Pursuant to Sections 303(d), 305(b), and 314 of the Clean Water Act* (July 29, 2005), and the memorandum titled "*Information Concerning 2018 Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions*".

Consideration of Existing and Readily Available Water Quality-Related Data and Information

In developing Section 303(d) lists, States are required to assemble and evaluate all existing and readily available water quality-related data and information, including, at a minimum, consideration of existing and readily available data and information about the following categories of waters: (1) waters identified as partially meeting or not meeting designated uses, or as threatened, in the State's most recent Section 305(b) report; (2) waters for which dilution calculations or predictive modeling indicate non-attainment of applicable standards; (3) waters for which water quality problems have been reported by governmental agencies, members of the public, or academic institutions; and (4) waters identified as impaired or threatened in any Section 319 nonpoint assessment submitted to EPA. See 40 CFR 130.7(b)(5). In addition to these minimum categories, States are required to consider any other data and information that is existing and readily available.

While States are required to evaluate all existing and readily available water quality-related data and information, States may decide to rely or not rely on particular data or information in determining whether to list particular waters.

In addition to requiring States to assemble and evaluate all existing and readily available water quality-related data and information, EPA regulations at 40 CFR 130.7(b)(6) require States to include as part of their submissions to EPA, documentation to support decisions to rely or not rely on particular data, information, and decisions to list or not list waters. Such documentation needs to include, at a minimum, the following information: (1) a description of the methodology used to develop the list; (2) a description of the data and information used to identify waters; and (3) any other reasonable information requested by the Region.

Priority Ranking

EPA regulations also codify and interpret the requirement in Section 303(d)(1)(A) of the Act that States establish a priority ranking for listed waters. The regulations at 40 CFR 130.7(b)(4) require States to prioritize waters on their Section 303(d) lists for TMDL development, and also to identify those WQLSs targeted for TMDL development activities in the next two years. In prioritizing and targeting waters, States must, at a minimum, take into account the severity of the pollution and the uses to be made of such waters. See Section 303(d)(1)(A). As long as these factors are taken into account, the Act provides that States establish priorities. States may consider other factors relevant to prioritizing waters for TMDL development, including immediate programmatic needs, vulnerability of particular waters as aquatic habitats, recreational, economic, and aesthetic importance of particular waters, degree of public interest and support, and State or national policies and priorities. See 57 FR 33040, 33045 (July 24, 1992).

Analysis of Maryland's Submission

Identification of Waters and Consideration of Existing and Readily Available Water Quality-Related Data and Information

EPA has approved Section 303(d) lists submitted by Maryland including, but not limited to, Section 303(d) lists, for the years 1996, 1998, 2002, 2004, 2006, 2008, 2010, 2012, 2014 and 2016. To the extent that these prior lists have been incorporated into the 2018 Section 303(d) list, EPA's rationale for approving those lists remains operative. EPA's review of the 2018 Section 303(d) list focused on changes from the prior lists.

Maryland Department of the Environment (MDE) public noticed the draft 2018 Section 303(d) list for a comment period of 32 days, from February 16, 2018 through March 19, 2018. The draft list was posted on several outlets including among others, MDE's internet world-wide-web, Maryland Register, and several of MDE's social media outlets (e.g. Facebook). MDE held an informational public meeting on February 27, 2018, at MDE Headquarters in Baltimore, Maryland. Comments were received in writing and all were responded to appropriately.

EPA received MDE's final 2018 Section 303(d) list package on March 11, 2019 through the Assessment, Total Maximum Daily Load (TMDL) Tracking and Implementation System (ATTAINS), which is EPA's new electronic system to accept and track 303(d) submissions and actions. Specifically, Maryland's 2018 Category 5 data in ATTAINS represents Maryland's 2018 303(d) list of impaired waters. Maryland also submitted a narrative report in ATTAINS. The 2018 Section 303(d) package included: (1) an overview of the process for development of the 2018 Section 303(d) list; (2) surface water monitoring strategy, assessment units, links to the listing methodologies used by MDE (all listing methodologies have undergone public review, but further public comment was welcomed during the 303(d) list public comment period); (3) assessment results associated with biological impairments, toxics, bacteria, temperature, and solids from rivers/streams, lakes/ponds, estuarine and ocean waters; (4) the public process related to the 303(d) list; and (5) the integrated Section 305(b) report and Section 303(d) list, consisting of parts 2, 3, 4, and 5. MDE also provided a list of TMDLs approved (Table 29) and anticipated for completion for Fiscal Year 2018 and 2019 (Table 69 and 70, respectively). The package also included a responsiveness summary to comments received during the public review. In taking this action, EPA considered the information in its record, including but not limited to, Maryland's 2018 Category 5 data in ATTAINS and Maryland's narrative submissions.

EPA concludes that the State properly assembled and evaluated all existing and readily available data and information, including data and information relating to the categories of waters specified in 40 CFR 130.7(b)(5). In addition, the State provided its rationale for not relying on particular existing and readily available water quality-related data and information as a basis for listing waters.

In total, MDE received 36 written comments from five parties during the public comment period and responded to all appropriately. EPA appreciates MDE's identification on Category 5 certain waters that do not meet Maryland's numeric criterion for temperature based on EPA's draft Integrated Report comments. EPA encourages MDE to continue working with stakeholders to consider whether any temperature standard should be revised. EPA supports MDE's efforts to work with stakeholders to determine whether temperature standards should be revised based upon sound scientific rationale and scientifically defensible methods. EPA agrees with the subsequent changes made to the final 2018 303(d) list.

In regards to the comments submitted by Waterkeepers Chesapeake, EPA notes that Waterkeepers Chesapeake incorporated by reference its members' comments on MDE's 2012, 2014, and 2016 Integrated Reports regarding moving the entries for total nitrogen, total phosphorus, and total suspended solids on 53 Chesapeake Bay tidal segments from Part 5 (waters that may require a TMDL) to Part 4a (waters that are still impaired but have an approved TMDL) of Maryland's Integrated Report, where applicable. Each of these 53 segments is a tidal portion of one of the Chesapeake Bay tributaries, and each segment was classified as a Chesapeake Bay segment in 2008. As part of the 2010 Chesapeake Bay TMDLs, [1] TMDLs were established for each of these 53 Chesapeake Bay tidal segments at a level necessary to meet the applicable water quality standards for that segment for total nitrogen, total phosphorus, and total suspended solids

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[1] EPA agrees with MDE's observation that the December, 2010 action is more properly characterized as the "Chesapeake Bay TMDLs." While for ease of reference, the action is often referenced in the singular (i.e., "Chesapeake Bay TMDL"), the action consists of 276 separate TMDLs for 92 separate tidal waterbody segments adjoining the Chesapeake Bay.

(totaling to 139 segment-pollutant combinations). Because the TMDLs were established, those Chesapeake Bay segment-pollutant combinations that were previously in Part 5 were moved to Part 4a. MDE incorporated its previous responses to Waterkeepers Chesapeake's comments by reference. EPA agrees with MDE's previous responses and with MDE's response to comments on the 2018 Integrated Report. EPA incorporates by reference its Decision Rationale approving MDE's 2014 and 2016 Section 303(d) list, which also addressed Waterkeepers' previous comments on this topic. MDE's categorization of waters that have TMDLs on Part 4a of the Integrated Report rather than Part 5 is consistent with EPA guidance [Memorandum titled "*Information Concerning 2018 Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions*"].

A. Description of the methodology used to develop this list, Section 130.7(b)(6)(i)

For the 2018 reporting cycle, no changes were made to any of MDE's assessment methodologies, but further public comment on the methodologies was welcomed during the 303(d) list public comment period and no related comments were received. All assessment methodologies are available on MDE's Web site at http://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Pages/ir_listing_methodologies.aspx.

B. Description of the data and information used to identify waters, including a description of the data and information used by Maryland as required by Section 130.7(b)(5).

1. Section 130.7(b)(5)(i), Waters identified by Maryland in its most recent Section 305(b) report as "partially meeting" or not meeting designated uses or as "threatened."

Maryland's Section 303(d) list is mostly defined by the data collection and assessment contained in the 305(b) report of the State's water quality. In Maryland, responsibility for collection and compilation of this information is shared between the Maryland Department of Natural Resources (MDNR) and MDE. MDE compiles Maryland's Inventory of the Water Quality, the Section 305(b) Report, every two years pursuant to Section 305(b) of the CWA. MDNR collects many of the data that goes into the assessments. Also, MDE sets water quality standards (WQS), regulates discharges to Maryland waters through environmental permitting, enforcement and compliance activities, identifies waters for inclusion on the Section 303(d) list, and develops TMDLs. Since 2002 and consistent with EPA guidance, Maryland has submitted an integrated report combining the Section 303(d) list and the Section 305(b) report (Integrated Report). Beginning this cycle in 2018, MDE submitted these data through EPA's electronic ATTAINS system. The following categories are used to describe water quality in Maryland's Integrated Report. Category 1 of the Integrated Report identifies waters that meet all water quality standards and no use is threatened. Category 2 identifies waters meeting water quality standards for at least one designated use, but with insufficient information to determine if WQS are being met for other designated uses. Category 3 identifies waters where there is insufficient information to determine if any water quality standard is being attained, and includes subcategories for insufficient data quantity and insufficient data quality. Category 4 identifies waters where one or more WQS are impaired or threatened, but for which a TMDL is not required because a TMDL has already been approved or established by EPA (Subcategory 4a), other pollution control requirements are expected to attain WQS (Subcategory 4b), or the impairment is not caused by a pollutant (Subcategory 4c). Categories 1-4 comprise the Section 305(b) portion of the integrated report. Category 5 is the Section 303(d) list and identifies waters that are not attaining WQS and for which a TMDL may be necessary.

Maryland considers a waterbody as "impaired" (and therefore subject to listing pursuant to Section 303(d)) when it does not attain a designated use pursuant to Maryland's WQS. Maryland has developed numerous methodologies for assessing whether waters are achieving their designated uses. MDE has provided the public with notice and an opportunity to comment on its assessment methodologies as they are developed and/or amended and during public comment on the Integrated Report.

In September 2004, Maryland updated its Comprehensive Water Quality Monitoring Strategy for all State waters consistent with current EPA guidance (see "Elements of a Water Monitoring and Assessment Program," EPA document 841-B-03-003). This Strategy describes Maryland's water quality monitoring framework and covers all State waters, including rivers and streams, lakes, tidal waters, ground water and wetlands. These water quality monitoring programs support the assessment of Maryland's designated uses as well as integrated reporting activities under Sections 303(d) and 305(b) of the CWA.

In the fall of 2007, MDE initiated monitoring strategy discussion with MDNR in anticipation of a revised strategy for 2009-2010. This 2009 Strategy has been completed and submitted to EPA and represents Maryland's last update of its comprehensive water monitoring strategy. Maryland's water quality monitoring programs are designed to support State Water Quality Standards (Code of Maryland Regulations Title 26, Subtitle 08) for the protection of both human health and aquatic life. This strategy identifies the programs, processes and procedures that have been institutionalized to ensure state monitoring activities continue to meet defined programmatic goals and objectives. The strategy also discusses data management and quality assurance/quality control procedures implemented across the State to preserve data integrity and assure that data are of sufficient quality and quantity to meet the intended use. Finally, this document serves as a road map for assigning monitoring priorities and addressing gaps in current monitoring programs.
(http://www.mde.state.md.us/programs/ResearchCenter/EnvironmentalData/Documents/www.mde.state.md.us/assets/document/Maryland_Monitoring_Strategy2009.pdf).

EPA concludes that the Section 303(d) list identifies waters identified by Maryland on its Section 305(b) report as "partially meeting" or not meeting designated uses.

2. Section 130.7(b)(5)(ii), Waters for which dilution calculations or predictive models indicate non-attainment of applicable water quality standards.

Maryland supports the use of computer models and other innovative approaches to water quality monitoring and assessment. Maryland and the Bay partners also relied heavily on the Chesapeake Bay model to develop loading allocations, assess the effectiveness of best management practices, and guide implementation efforts. Several different modeling approaches have also been used in TMDL development. With the growing number of biological impairments in Category 5 of the list, Maryland will be relying more heavily on land use analyses, Geographic Information System (GIS) modeling, data mining, and other innovative approaches to identify stressors, define ecological processes, and develop appropriate TMDLs.

3. Section 130.7(b)(5)(iii), Waters for which water quality problems have been reported by local, state, or federal agencies; members of the public; or academic institutions

A MDE data request letter was widely advertised for the solicitation of data for the 2018 list. With the integration of Sections 305(b) and 303(d) of the CWA and the adoption of a multi-category reporting structure, Maryland has developed a two-tiered approach to data quality. Tier 1 data are those used to determine impaired waters (e.g., Category 5 waters or the traditional 303(d) list) and are subject to the highest data quality standards. Maryland waters identified as impaired using Tier 1 data may require a TMDL or other regulatory actions. These data should be accompanied by a Quality Assurance Project Plan (QAPP) consistent with EPA data guidance specified in Guidance for Quality Assurance Project Plans. Dec 2002. EPA /240/R-02/009 available at https://www.epa.gov/quality/guidance-quality-assurance-project-plans-epa-qag-5. Tier 1 data analysis must also be consistent with Maryland's Assessment Methodologies.

Tier 2 data are used to assess the general condition of surface waters in Maryland and may include land use data, visual observations of water quality condition, or data not consistent with Maryland's Assessment Methodologies. Such data may not have a QAPP or may have one that is not consistent with EPA guidance. Waters with Tier 2 data may be placed in Categories 2 or 3 of the Integrated Report, denoting that water quality is generally good or that there are insufficient data to make an assessment, respectively. However, Tier 2 data alone are not used to make impairment decisions (i.e., Category 5 listings requiring a TMDL) because the data are of insufficient quantity and/or quality for regulatory decision-making. MDE notes that it will be reevaluating the current data quality tier system to determine if changes are necessary to establish consistency with the Chesapeake Bay Monitoring Cooperative and further refine the data evaluation process. As a result of the data solicitation, 24 organizations/programs submitted water quality data for consideration in the 2018 Integrated Report. Of those 24 organizations/programs, 13 submitted Tier 1 data. MDE coordinates with the remaining organizations providing Tier 2 data to improve data quality and further promote the use of Tier 1 data for assessment purposes.

Maryland has made significant efforts to incorporate non-state government data in ways that increase the resolution of the state's water quality assessments. Datasets used included those collected by federal agencies, county governments, water utility agencies, and non-profit watershed organizations. The 2018 Integrated Report includes a GIS submittal that provides coverages for streams, impoundments, and estuarine waters which depict assessment information at appropriate scales. MDE also makes Integrated Reporting data available to the public in several user-friendly formats. Accessible via the web, users can query MDE's searchable Integrated Report database to find individual assessments or groups of assessments that are of interest. The searchable Integrated Report database and companion clickable map application are available online at
http://www.mde.maryland.gov/programs/water/tmdl/integrated303dreports/pages/303d.aspx .

New this year is a revamped online map which displays water quality assessment information overlaid on top of TMDL watersheds. This newly reformatted map is meant to highlight the spatial relationship between the specific water body impaired for a given pollutant and the TMDL that accounts for all sources of that pollutant in that water body's watershed. Users can select as few or as many pollutants to display as they like with this fully interactive map. This map therefore replaces the previously provided single-pollutant maps and provides users with a one-stop map for visualizing water quality assessment information. The newly created map can be found at http://mdewin64.mde.state.md.us/WSA/IR-TMDL/index.html.

In addition to MDE's new online resources, EPA has transitioned 305(b) and 303(d) reporting to the new ATTAINS, which is an electronic system that holds all water quality assessment decisions for states and territories. ATTAINS transformed and modernized paper reporting into an electronic system, which allows EPA, states, and the public to access, search, and track all water quality assessment decisions.

4. Section 130.7(b)(5)(iv), Waters identified by Maryland as impaired or threatened in a non-point assessment submitted to EPA under section 319 of the CWA or in any updates of the assessment.

MDE considered waters identified in a Section 319 assessment during the development of the 1996 Section 303(d) list, and all such water segments were included on the 1996 list, which was incorporated into all subsequent lists, including the 2018 Section 303(d) list. The Clean Water Action Plan of 1998 required a statewide Unified Watershed Assessment which set priorities for Section 319 activities. Maryland's Unified Watershed Assessment, Category I assignments were based on the 1998 Section 303(d) list.

5. Other data and information used to identify waters (besides items 1-4 discussed above).

In addition to waters identified as impaired on the 2016 Section 303(d) List that have not been delisted, the 2018 Section 303(d) lists 42 additional impaired waters. Six of the new listings resulted from MDE's Biological Stressor Identification Analyses. Of these six new 'biostressor' listings, three are for total suspended solids, two are for sulfates, and one is for chlorides. In addition, there are four new fecal coliform listings in shellfish harvesting waters, one new listing for PCBs in fish tissue, one new listing for phosphorus, and, as discussed above, 30 new listings for temperature, which were moved from category 3 in the draft list to Category 5 in the final list in response to EPA's comments.

C. A rationale for any decision to not use any existing and readily available data and information for any one of the categories of waters as described in Sections 130.7(b)(5) and 130.7(b)(6)(iii).

Starting in 2002, Maryland developed and published for public review the Listing Methodologies to describe the State's interpretation of its WQS and establish scientifically defensible approaches for determining water body impairment. Listing Methodologies are not considered rules, but rather provide a means to provide consistency and transparency in Integrated Reporting so that the public and other interested stakeholders understand why listing decisions are made and can independently verify listing decisions. The methodologies are living documents that are revised as new statistical approaches, technologies, or other improved methods are adopted by the State. When changes are proposed to the Listing Methodologies, Maryland advertises the revised methodologies for public review via the biennial Integrated Report.

In Maryland's Section 305(b) Report, certain water bodies are conditionally approved shellfish areas. A sub-set of these water bodies are restricted because they are closed for administrative reasons under guidance of the National Shellfish Sanitation Program. Typically, these waters are restricted due to their vicinity to wastewater treatment plants and the restriction is precautionary against the potential treatment system failure, rather than an expression of failure to meet WQS. In accordance with MDE's listing methodology, both administratively restricted and conditionally approved shellfish waters are not listed on the Section 303(d) list.

D. Rationale for delisting of waterbodies from the previous 303(d) list[2].

Maryland has indicated, in the Integrated Report (Table 2), that 11 delistings have occurred during this cycle. Four biological listings without a specified impairing substance have been replaced by specific pollutant listings enumerated by the Biological Stressor Identification analyses (BSID). Another three (of the 11) listings, originally listed as impaired for exceedances above the pH criteria (i.e. > 8.5 pH units), were removed from Category 5 because new data showed that water quality standards were being met. The last four listings removed from Category 5 included two for fecal coliform in shellfish harvesting areas, one for mercury in fish tissue, and one for PCBs in fish tissue. All of these four listings were moved to Category 2 on the basis of new data that demonstrated water quality that met the applicable criterion.

In addition, there were seven other water quality listings removed from Category 4a (impaired, TMDL approved) and placed in Category 2 (meeting some standards). Four of these assessment records were tidal tributaries to the Chesapeake Bay that now meet the submerged aquatic vegetation (SAV)/water clarity criteria. The other three assessment records all relate to streams in the Casselman River watershed (Garrett County) where MDE recently (2013) implemented acid mine remediation projects. In all three cases, at Alexander, Spiker, and Tarkiln Run, MDE measured stream pH after the remediation project for a minimum of 3 years and found these streams to be consistently meeting Maryland's pH criteria range of 6.5 – 8.5. Management of these streams will still be ongoing to ensure that they continue to meet pH criteria moving forward.

There were also three partial removals of Category 4a (impaired, TMDL approved) listings on the 2018 Integrated Report. A partial Category 4a removal can occur in cases where an assessment unit that was previously entirely listed as impaired (with a TMDL established) had new data collected that demonstrated use support in some smaller geographic portion. In order to reflect this new information and the fact that a portion of the original water segment now meets standards, MDE may split the original assessment unit into two assessment units, one which is still impaired and another that is not. All of the three partial removals occurred in shellfish

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[2] Public comments received during the 2018 Integrated Reporting cycle concerning delistings that occurred on MDE's 2012 Integrated Report have been addressed above.

harvesting areas due to new data demonstrating that a portion of the water body now meets water quality criteria.

Maryland has demonstrated, to EPA's satisfaction, its rationale for these delistings.

E. Rationale for Maryland's decision not to list waters pursuant to 40 CFR 130.7(b)(1) because they are expected to meet water quality standards.

Maryland's decision not to include waters on its 2018 Section 303(d) list due to other required pollution controls is consistent with EPA regulations at 40 CFR 130.7(b)(1). These waters were identified in Category 4b of the Integrated Report. Under 40 CFR 130.7(b)(1), states are not required to list WQLSs still requiring TMDLs where effluent limitations required by the CWA, more stringent effluent limitations required by state or local authority, or other pollution control requirements required by state, local, or federal authority, are stringent enough to implement applicable WQS. The regulation does not specify the timeframe in which these various requirements must implement applicable WQS to support a state's decision not to list particular waters. EPA expects that required controls will result in attainment in a reasonable time, based on the nature of the pollutant and actions that need to be taken to achieve attainment.

Monitoring should be scheduled for these waters to verify that the water quality standard is attained as expected in a reasonable time frame. Where standards will not be attained through implementation of the requirements listed in 40 CFR 130.7(b)(1) in a reasonable time, it is appropriate for the water to be placed on the Section 303(d) list to ensure that implementation of the required controls, and progress towards compliance with applicable standards, is tracked. If it is determined that the water is, in fact, meeting applicable standards when the next Section 303(d) list is developed, it would be appropriate for the state to remove the water from the list at that time.

As indicated above, Maryland has several listings in Category 4b. All of these listing records still require more data collection and analysis to either confirm impairment or to demonstrate water quality standards attainment.

Consistent with a program of continuous assessment, EPA encourages MDE to continue efforts, including monitoring as appropriate, to provide updates on the status of the segments and to confirm that previous delistings remain supportable. As part of the Integrated Report, MDE would review the remainder of waters identified in Category 4b to determine whether the water quality standards are expected to be attained in a reasonable time or whether the waters need to be moved to Category 5. EPA recommends that MDE collect and analyze ambient water quality data as part of its analysis.

F. TMDL Priority Ranking and Targeting

MDE used the same priority ranking methodology used in previous lists. Documentation describing this prioritization was incorporated as part of Maryland's 2016 Integrated Report and can be accessed at
http://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Pages/2016IR.aspx.

Within the Section 303(d) list, Maryland has provided both a priority ranking of high, medium, or low, and a separate indication for waters targeted for TMDL development in the next two years. In general, criteria that affect human health or have an extreme effect on natural resources are ranked high, criteria that indicate a continuing downward trend in the loss of a significant resource, create a serious nuisance, or constitute a significant loss of a natural resources are ranked as medium, and the remaining cases rank low.

EPA concludes that MDE's TMDL prioritization plans are acceptable as the State properly took into account the severity of pollution and the uses to be made of such waters. Scheduling, however, takes into account additional considerations other than priority designations, such as programmatic consideration (e.g., efficient allocation of resources, basin planning cycles, coordination with other programs or states) and technical considerations (e.g., data availability, problem complexity, availability of technical tools). This is consistent with EPA guidance. In addition, EPA reviewed the State's identification of WQLSs targeted for TMDL development in the next two years (i.e., those targeted as a high priority), and agrees that the targeted waters are appropriate for TMDL development in this timeframe.

G. Consultation with Other Agencies

EPA sought review and comments from the U.S. Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) (collectively the Services) through a letter sent on March 5, 2018. This letter included website links to the draft 2018 Integrated Report. In reaching its conclusions on approving Maryland's 2018 303(d) list, EPA collected and appropriately considered information on the endangered and threatened species and their critical habitat in Maryland's waters identified by NMFS and FWS.

Attachment 3

F.6 Category 4c Waters

Maryland's Combined 2020-2022 Final Integrated Report- Category 4c Waters

Assessment Unit ID	Assessment Unit Name	Location Description	Water Type	Designated Use	Designated Use Attainment	Parameter Name	Cycle First Listed	Parameter Attainment	Parameter Status	EPA Category	MDE Category	Comment
MD-02120201-Lower_Susquehanna_Mainstem	Lower Susq. downstream from Dam to head of tide	River Mainstem	RIVER	Aquatic Life and Wildlife	Not Supporting	FLOW ALTERATION-CHANGES IN DEPTH AND FLOW VELOCITY	2018	Not meeting criteria	Cause	4C	4c	Assessment of flow regime and biological impacts demonstrate that Conowingo Dam operations cause impairment of the aquatic life and wildlife designated use.
MD-02130202	Lower Pocomoke River	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2022	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that sulfates are a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130202	Lower Pocomoke River	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2022	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that sulfates are a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130203	Upper Pocomoke River	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.

Assessment Unit ID	Assessment Unit Name	Location Description	Water Type	Designated Use	Designated Use Attainment	Parameter Name	Cycle First Listed	Parameter Attainment	Parameter Status	EPA Category	MDE Category	Comment
MD-02130203	Upper Pocomoke River	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130305	Nanticoke River	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2016	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicated that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130306	Marshyhope Creek	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicated that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130404	Upper Choptank River	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.

Assessment Unit ID	Assessment Unit Name	Location Description	Water Type	Designated Use	Designated Use Attainment	Parameter Name	Cycle First Listed	Parameter Attainment	Parameter Status	EPA Category	MDE Category	Comment
MD-02130510	Upper Chester River	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130701	Bush River	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2014	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicated that channelization is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130701	Bush River	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2014	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicated that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130704	Bynum Run	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.

Assessment Unit ID	Assessment Unit Name	Location Description	Water Type	Designated Use	Designated Use Attainment	Parameter Name	Cycle First Listed	Parameter Attainment	Parameter Status	EPA Category	MDE Category	Comment
MD-02130705	Aberdeen Proving Ground	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2014	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicated that channelization is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130802	Lower Gunpowder Falls	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130805	Loch Raven Reservoir	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2014	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130901	Back River	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.

Assessment Unit ID	Assessment Unit Name	Location Description	Water Type	Designated Use	Designated Use Attainment	Parameter Name	Cycle First Listed	Parameter Attainment	Parameter Status	EPA Category	MDE Category	Comment
MD-02130901	Back River	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130903	Baltimore Harbor	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2014	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization is a major stressor affecting biological integrity in this watershed. This listing, along with others, replace the biological listing.
MD-02130903	Baltimore Harbor	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2014	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that the lack of an adequate riparian buffer is a major stressor affecting biological integrity in this watershed. This listing, along with others, replaces the biological listing.
MD-02130904	Jones Falls	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.

Assessment Unit ID	Assessment Unit Name	Location Description	Water Type	Designated Use	Designated Use Attainment	Parameter Name	Cycle First Listed	Parameter Attainment	Parameter Status	EPA Category	MDE Category	Comment
MD-02130905	Gwynns Falls	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130906	Patapsco River Lower North Branch	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02131003	South River	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2014	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that the lack of an adequate riparian buffer is a major stressor affecting biological integrity in this watershed. This listing, along with others, replaces the biological listing.
MD-02140201	Potomac River Upper tidal	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2018	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicated that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.

Assessment Unit ID	Assessment Unit Name	Location Description	Water Type	Designated Use	Designated Use Attainment	Parameter Name	Cycle First Listed	Parameter Attainment	Parameter Status	EPA Category	MDE Category	Comment
MD-02140205	Anacostia River	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02140205	Anacostia River	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02140207	Cabin John Creek	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02140301-Wadeable_Streams	Potomac River Frederick County	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2018	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that the lack of an adequate riparian buffer is a major stressor affecting biological integrity in this watershed. This listing, along with others, replaces the biological listing.

Assessment Unit ID	Assessment Unit Name	Location Description	Water Type	Designated Use	Designated Use Attainment	Parameter Name	Cycle First Listed	Parameter Attainment	Parameter Status	EPA Category	MDE Category	Comment
MD-02140302	Lower Monocacy River	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02140502	Antietam Creek	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2014	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02140502	Antietam Creek	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2014	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that channelization is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02141002	Evitts Creek	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02141003	Wills Creek	Non-tidal 8-digit watershed	RIVER	Aquatic Life and Wildlife	Not Supporting	HABITAT ALTERATIONS	2012	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicated that stream channelization due to urban development is a major stressor affecting

Assessment Unit ID	Assessment Unit Name	Location Description	Water Type	Designated Use	Designated Use Attainment	Parameter Name	Cycle First Listed	Parameter Attainment	Parameter Status	EPA Category	MDE Category	Comment
												biological integrity in this watershed. This listing replaces the biological listing.
MD-05020201-Wadeable_Streams	1st through 4th order wadeable streams	1st thru 4th order streams	RIVER	Aquatic Life and Wildlife	Not Supporting	RIPARIAN BUFFER, LACK OF	2014	Not meeting criteria	Cause	4C	4c	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing addresses a portion of the biological listing and therefore replaces it on the list.

Attachment 4

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

Mr. D. Lee Currey, Director
Water and Science Administration
Maryland Department of the Environment
1800 Washington Blvd., Suite 4502
Baltimore, Maryland 21230-1718

Dear Mr. Currey,

The U.S. Environmental Protection Agency, Region III (EPA) reviewed the Maryland Department of Environment's (MDE) Final Draft Combined 2020-2022 Integrated Report and supporting documentation and information submitted as final on January 27, 2022. MDE published the draft Combined 2020-2022 Integrated Report for public notice and comment from December 6, 2021, until January 17, 2022. EPA reviewed and determined that the portion of the Integrated Report (Category 5) constituting Maryland's list of water quality-limited segments still requiring Total Maximum Daily Loads meets the requirements of Section 303(d) of the Clean Water Act (CWA) and EPA's implementing regulations. With this letter and the enclosed rationale, EPA approves MDE's Combined 2020-2022 Section 303(d) list as submitted electronically to EPA through the Assessment, TMDL Tracking and Implementation System (ATTAINS). The enclosed approval rationale describes the applicable statutory and regulatory requirements and EPA's review of Maryland's compliance with those requirements.

EPA commends you and your staff for the thorough work and exemplary effort in developing the list. EPA looks forward to working with MDE staff in preparation for the next Section 303(d) list submission due April 1, 2024, along with implementation of EPA's Vision for the Clean Water Act 303(d) Program.

If you have any questions, don't hesitate to contact me at 215-814-2737, or have staff contact Mr. Gregory Voigt, Chief of Standards and TMDLs Section, at 215-814-5737.

Sincerely,

CATHERINE
LIBERTZ
Digitally signed by
CATHERINE LIBERTZ
Date: 2022.02.25
09:22:48 -05'00'

Catherine A. Libertz, Director
Water Division

Enclosure

cc : Matthew Stover, MDE-WSA

Rationale for EPA Approval of
Maryland's Combined 2020-2022 Clean Water Act Section 303(d) List

I. Purpose

This document sets forth the U.S. Environmental Protection Agency, Region III's (EPA's) rationale for approving Maryland's Combined 2020-2022 Clean Water Act (CWA) Section 303(d) list. On January 27, 2022, EPA received the Maryland Department of the Environment (MDE) final Combined 2020-2022 Integrated Report (IR) and supporting documentation and information through the Assessment, Total Maximum Daily Load (TMDL) Tracking and Implementation System (ATTAINS). EPA has conducted a review of MDE's Combined 2020-2022 IR and supporting documentation and information. Based on this review, EPA has determined that the portion of the IR constituting Maryland's list of water quality-limited segments (WQLSs) still requiring TMDLs (i.e., Category 5 of the IR) satisfies the requirements of Section 303(d) of the CWA and EPA's implementing regulations. Therefore, EPA hereby approves Maryland's Combined 2020-2022 Section 303(d) list. The statutory and regulatory requirements, and EPA's review of Maryland's compliance with each requirement, are described in detail below.

II. Statutory and Regulatory Background

1) Identification of WQLSs for Inclusion on Section 303(d) List

Section 303(d)(1) of the CWA and EPA's implementing regulations at 40 C.F.R. Part 130 direct states to identify those waters within their jurisdiction for which effluent limitations required by Section 301(b)(1)(A) and (B) are not stringent enough to implement the applicable water quality standards, and to establish a priority ranking for such waters taking into account the severity of the pollution and the uses to be made of such waters. EPA's regulations require states to biennially submit to EPA the list identifying WQLSs still requiring a TMDL. This list of WQLSs is commonly referred to as the Section 303(d) list. The Section 303(d) listing requirement applies to waters impaired by point and/or nonpoint sources, pursuant to EPA's long-standing interpretation of Section 303(d). EPA regulations provide that states do not need to identify waters on the Section 303(d) list where the following controls are adequate to implement applicable water quality standards: (1) technology based effluent limitations required by the CWA; (2) more stringent effluent limitations required by state or local authority; and (3) other pollution control requirements required by state, local, or federal authority. See 40 CFR §130.7(b)(1) and (2).

EPA's recommended multi-part IR format is intended to satisfy the listing requirements of Section 303(d) and the requirements of Sections 305(b) and 314 of the CWA[1]. This IR format is intended to provide the public and other interested stakeholders with a comprehensive summary of a state's water quality. Consistent with that format, MDE's IR places all surface waters in Maryland into one of the five assessment categories. Category 5 of the IR represents the Section 303(d) list of WQLSs still requiring a TMDL. The assessment categories used in MDE's IR are as follows[2]:

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[1] With the exception of Category 5, EPA neither approves nor disapproves the Integrated Report. Category 5 constitutes the list of impaired waters pursuant to CWA Section 303(d) that EPA approves or disapproves pursuant to 40 C.F.R. 130.7

[2] Integrated Report categories are described in further detail in EPA's Guidance for 2006 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act:

- Category 1 – water bodies that meet all WQS and no use is threatened.
- Category 2 – water bodies meeting some WQS but with insufficient data and information to determine if other WQS are being met.
- Category 3 – Insufficient data and information are available to determine if a water quality standard is being attained. This can be related to having an insufficient quantity of data and/or an insufficient quality of data to properly evaluate a water body's attainment status.
- Category 4 – one or more WQS are impaired or threatened but a TMDL is not required or has already been established. The following subcategories are included in Category 4:
    - Category 4a – TMDL already approved or established by EPA.
    - Category 4b – Other pollution control requirements (i.e., permits, consent decrees, etc.) are expected to attain WQS.
    - Category 4c – Water body impairment is not caused by a pollutant (e.g. habitat is limiting, dam prevents attainment of use, etc.).
- Category 5 – Water body is impaired, does not attain the water quality standard, and a TMDL or other acceptable pollution abatement initiative is required. This is the part of the IR historically known as the 303(d) List.
    - Subcategory 5s: Waterbody impairment is caused by chloride from road salt.

2) Consideration of Existing and Readily Available Water Quality Related Data and Information

In developing the Section 303(d) list, states are required to assemble and evaluate all existing and readily available water quality related data and information including, at a minimum, consideration of existing and readily available data and information about the following categories of waters: (1) waters identified as partially meeting or not meeting designated uses, or as threatened, in the state's most recent Section 305(b) report; (2) waters for which dilution calculations or predictive modeling indicate non-attainment of applicable water quality standards; (3) waters for which water quality problems have been reported by governmental agencies, members of the public, or academic institutions; and (4) waters identified as impaired or threatened in any Section 319 nonpoint assessment submitted to EPA. In addition to these minimum categories, states are required to evaluate and should actively solicit any other data and information that is existing and readily available. See 40 CFR §130.7(b)(5). While states are required to evaluate all existing and readily available water quality related data and information, states may make reasonable decisions to rely or not rely on particular data or information in determining whether to list particular waters.

In addition to requiring states to assemble and evaluate all existing and readily available water quality related data and information, EPA regulations at 40 CFR §130.7(b)(6) require states to include, as part of their submissions to EPA, documentation to support decisions to rely or not rely on particular data and information, and decisions to list or not list waters on the Section 303(d) list. Such documentation needs to include, at a minimum, the following information: (1) a description of the methodology used to develop the list; (2) a description of the data and information used to identify waters; (3) a rationale for any decision to not use existing and readily available data discussed in 130.7(b)(5); and (4) any other reasonable information requested by the Region.

3) Priority Ranking

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https://www.epa.gov/sites/production/files/2015-10/documents/2006irg-report.pdf

EPA regulations also codify and interpret the requirement in Section 303(d)(1)(A) of the CWA that states establish a priority ranking for Section 303(d) listed waters. The regulations at 40 CFR §130.7(b)(4) require states to prioritize waters on their Section 303(d) lists for TMDL development, and also to identify those WQLSs targeted for TMDL development in the next two years. In prioritizing and targeting waters, states must, at a minimum, take into account the severity of the pollution and the uses to be made of such waters. See Section 303(d)(1)(A). As long as these factors are taken into account, states retain considerable discretion and may consider other factors when prioritizing and scheduling TMDLs. See 57 FR 33040, 33045 (July 24, 1992).

III. Analysis of Maryland's Submission

1) Identification of Waters and Consideration of Existing and Readily Available Water Quality Related Data and Information (CFR §130.7(b)(1), (2), (5))

EPA has reviewed MDE's Combined 2020-2022 IR and has concluded that MDE developed its Combined 2020-2022 Section 303(d) list in compliance with Section 303(d) of the CWA and 40 CFR §130.7. EPA's review is based on its analysis of whether MDE reasonably considered existing and readily available water quality related data and information, and reasonably identified waters required to be listed on the Section 303(d) list.

EPA received MDE's final Combined 2020-2022 Section 303(d) list on January 27, 2022, through ATTAINS, which is EPA's electronic system to accept and track 303(d) submissions and actions. ATTAINS transformed and modernized paper integrated reporting into an electronic system, which allows EPA, states, and the public to access, search, and track water quality assessment decisions[3]. Specifically, MDE's Category 5 data in ATTAINS represents MDE's Section 303(d) list of impaired waters requiring TMDLs. In addition to the Section 303(d) list, MDE submitted through ATTAINS water quality assessment results for its other surface waters pertaining to IR assessment categories 1 – 4, along with a narrative IR and supporting documentation and information. In addition to ATTAINS, MDE shares their IR and supporting documentation and information, including the Section 303(d) list, on their webpage[4].

In summary, EPA considered the following as MDE's Combined 2020-2022 IR submission for its review: (1) the Integrated Report narrative and appendices; (2) the Section 303(d) list, or waters listed in Category 5, present within ATTAINS; (3) the remaining waters listed in Categories 1 – 4, present within ATTAINS; (4) the state's assessment methodologies; (5) descriptions of the data solicitation and public notice processes; (6) documentation to support decisions to list or not list waters, including decisions to remove waters from Category 5; (7) descriptions of data that the state considered; (8) comments received on the draft list; and (9) the state's response to those comments.

To the extent that prior approved Section 303(d) lists have been incorporated into the Combined 2020-2022 Section 303(d) list, EPA's rationale for approving those lists remains operative unless otherwise noted. EPA's review of the Combined 2020-2022 Section 303(d) list focused on changes from the prior lists.

A) Description of the methodology used to develop the list (CFR §130.7(b)(6)(i))

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[3] ATTAINS data is publicly accessible via EPA's How's My Waterway online tool and ATTAINS web and geospatial services. For more information, see: https://www.epa.gov/waterdata/get-data-access-public-attains-data

[4] https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Pages/index.aspx

MDE has developed methodologies for assessing whether waters are achieving their water quality standards, including their designated uses and associated water quality criteria. These assessment methodologies are intended to describe the state's interpretation of its water quality standards and establish scientifically defensible approaches for assessing water quality. Assessment methodologies are not considered rules, but rather provide a means to provide consistency and transparency in integrated reporting. Furthermore, assessment methodologies are living documents that are revised as new statistical approaches, technologies, or other improved methods are adopted by the state.

On December 6, 2021, MDE provided the public with notice and an opportunity to comment on all of their assessment methodologies, and particularly those where changes were made. MDE's final assessment methodologies are published on their webpage[5], which EPA reviewed and considered as supporting documentation associated with the IR. These assessment methodologies include:

- Bacteria Assessment Methodology
- Biological Assessment Methodology for Non-tidal Wadeable Streams
- Delisting Methodology for Biological Assessments
- Biological Data Quality Guidelines
- Chesapeake Bay Benthic Biological Assessment Methodology
- Chesapeake Bay Assessment Methodologies
- Assessment Methodology for Dissolved Oxygen and Chlorophyll a Criteria in Maryland's Seasonally Stratified Water-Supply Reservoirs
- pH Assessment Methodology
- Sediment Assessment Methodology
- Temperature Assessment Methodology for Use Class III(-P) Waters
- Toxics Assessment Methodology

For the Combined 2020-2022 reporting cycle, MDE made changes to three assessment methodologies and another new assessment methodology was created. The Listing Methodology for Identifying Waters Impaired by Bacteria in Maryland's Integrated Report was updated to reflect the updated recreational water quality criteria, including the addition of targeting a weekly sampling frequency and considerations for bacteria sampling at non-beach areas. The Fish Tissue Assessment Methodology section, which is part of the Methodology for Determining Impaired Waters By Chemical Contaminants for Maryland's Integrated Report of Surface Water Quality, was updated to include a target data requirement of five fish, a data assessment period of ten years, and information concerning the use of best professional judgement. The Temperature Assessment Methodology for Use III (-P) Streams in Maryland was updated to include a decision diagram and assessment process that supports the policy of independent applicability. The Delisting Methodology for Biological Assessments is a new assessment methodology intended to refine the spatial scale of biological impairment listings in order to demonstrate progress and identify areas that are attaining. The delisting methodology utilizes a targeted standardized approach that is complementary to the large-scale probabilistic design of the current biological assessment methodology.

B) Description of the data and information used to identify waters (CFR §130.7(b)(6)(ii))

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[5] https://mde.maryland.gov/programs/water/TMDL/Integrated303dReports/Pages/ir_listing_methodologies.aspx

In preparation for the 303(d) listing process, MDE is responsible for the collection and compilation of water quality-related data and information. MDE based the Combined 2020-2022 Section 303(d) list on a variety of data and information sources and considered all data and information regarding CFR §130.7(b)(5) categories.

In December 2009, MDE completed the last update of its comprehensive water monitoring strategy.[6] Maryland's water quality monitoring programs are designed to support state WQS (Code of Maryland Regulations Title 26, Subtitle 08) for the protection of both human health and aquatic life. This strategy identifies the programs, processes and procedures that have been institutionalized to ensure state monitoring activities continue to meet defined programmatic goals and objectives.

Maryland assesses state waters using data generated by both long-term ongoing monitoring programs as well as short-term targeted monitoring efforts. These monitoring programs predominantly sample four water body types (flowing waters, impoundments, estuarine waters, and beaches) found throughout Maryland and collect water quality samples for both conventional and toxic pollutants. Although many assessments are still based on data collected by state agencies, MDE continues to make greater use of data collected by county government and non-governmental organizations.

For the Combined 2020-2022 Section 303(d) list, MDE considered and evaluated water quality monitoring datasets from the Chesapeake Bay and Coastal Bay assessment programs, EPA's National Estuary Program Coastal Condition Report, EPA's National Coastal Condition Assessment, MDE's and Maryland Department of Natural Resources (DNR) Lake Monitoring program, EPA's National Lake Survey, DNR's Maryland Biological Stream Survey and CORE/TREND non-tidal rivers and streams program, EPA's National Rivers and Streams Assessment, MDE's State Beaches program, MDE's TMDL program, MDE's Wetland Monitoring program, EPA's National Wetland Condition Assessment, United States Geological Survey's (USGS) non-tidal network trends program, DNR's tidal water quality trends program, Chesapeake Bay Program trends analysis program, EPA's waterborne disease program, MDE's Drinking Water program, MDE's Shellfish Harvesting program, MDE's fish tissue, shellfish, and crab toxic contaminant monitoring programs, MDE's, DNR's, and the Maryland Department of Health's Harmful Algal Bloom program, MDE's fish kill program, MDE's Combined and Sanitary Sewer Overflow program, DNR's invasive aquatic species program, and MDE's and DNR's groundwater monitoring and assessment programs. See Part C of MDE's IR for more information.

Although MDE considered data from all of these programs, data from some of these programs were not used for IR assessment decisions. For example, since national monitoring programs such as EPA's National Coastal Condition Assessment and EPA's National River and Streams Assessment were intended to inform national and regional water quality comparisons, the number of samples collected in these efforts is different than that needed to make site-specific attainment decisions and biological sampling methods are not comparable to Maryland Biological Stream Survey biological indices used for attainment decisions. So, data from EPA's national survey were not used for assessment decisions.

Maryland supports the use of computer models and other innovative approaches to water quality monitoring and assessment. Maryland and the Bay partners also relied heavily on the Chesapeake Bay model to develop loading allocations, assess the effectiveness of best management practices, and guide implementation efforts. Several different modeling approaches have also been used in TMDL development. With the growing number of biological impairments in Category 5 of the list, Maryland will be relying more heavily on land use analyses, Geographic Information System (GIS) modeling, data

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[6] https://mde.maryland.gov/programs/Water/TMDL/MD-AWQMS/Documents/Maryland_Monitoring_Strategy2009.pdf

mining, and other innovative approaches to identify stressors, define ecological processes, and develop appropriate TMDLs.

MDE also solicited relevant water quality data and information from the public via their webpage, and considered data collected from 2014 through 2019 for this IR cycle. As a result of the data solicitation, 31 organizations/programs submitted water quality data for consideration in MDE's Combined 2020-2022 IR.

MDE properly listed waters with nonpoint sources causing or expected to cause impairment, consistent with Section 303(d) and EPA guidance[7]. EPA's long-standing interpretation is that Section 303(d) applies to waters impacted by point and/or nonpoint sources.

In addition, MDE assembled and evaluated other data in addition to the categories of existing and readily available data and information listed in the EPA regulations and set out above.

EPA has reviewed MDE's description of the data and information considered in the listing process and its methodology for identifying waters. EPA concludes that MDE properly assembled and evaluated all existing and readily available water quality-related data and information, including data and information relating to the categories of waters specified in 40 CFR §130.7(b)(5).

C) A rationale for any decision to not use any existing and readily available data and information (CFR §130.7(b)(6)(iii))

While states are required to evaluate all existing and readily available water quality-related data and information, states may make reasonable decisions whether and how particular data or information is used in determining whether to list particular waters. MDE provided its rationale for not relying on particular existing and readily available water quality related data and information as a basis for identifying waters as part of the Section 303(d) list.

To aid in their evaluation of water quality data, MDE developed and published its assessment methodologies for public review. See section III(1)(A) of this document. These assessment methodologies describe target data sizes and data collection procedures that MDE utilizes when assessing water quality data. MDE's rationale to not use certain data and information may include incompatibilities with how criteria or assessment methodologies were derived compared to how data were collected.

In addition to requirements outlined in assessment methodologies, MDE explains that water quality datasets used for IR assessments should have a Quality Assurance Project Plan (QAPP) or other reports that define monitoring objectives and quality control. In general, when evaluating data, MDE reviews the data for sufficient sample size, data distribution (type and outliers/errors) and spatial and temporal distribution in the field. Censored data and field comments are examined for unusual events that may affect data quality (e.g., storm event). Data are examined for seasonality and known correlations (e.g., conductivity and salinity) are reviewed to verify that data are accurate. In addition, some assessments are conducted by other state programs using peer-reviewed or defined methods and are not re-evaluated using other approaches. Some assessments are conducted externally by other agencies and programs. In these circumstances, the assessment methods are peer reviewed and results

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[7] https://www.epa.gov/sites/default/files/2015-10/documents/lisgid.pdf

are provided to MDE.

To evaluate the external data submitted to MDE for the Combined 2020-2022 IR during the data solicitation period, MDE reevaluated their data quality system to promote greater consistency with Virginia Department of Environmental Quality and the Chesapeake Monitoring Cooperative and has refined the data evaluation process to incorporate three tiers of data quality.

MDE describes Tier III data as legally defensible data that can be used for regulatory decision-making purposes. Tier III data are used to list or delist waters on the IR and are subject to the highest data quality standards. Waters identified as impaired using Tier III data may require a TMDL or other regulatory actions. These data should be accompanied by a QAPP consistent with EPA guidance[8]. Tier III data analysis must also be consistent with MDE's assessment methodologies.

Tier II data are data with a defined methodology but do not meet Tier III data requirements and are not used to make regulatory assessment decisions by MDE. However, waters with this level of data may be placed in Category 3 of the IR, denoting that there are insufficient data to make an assessment and that follow up monitoring is necessary. Tier II data may be used to track performance of TMDL implementation, help target stream segments for WQS attainment assessments, or identify waters for MDE follow-up monitoring. These data should be accompanied by a QAPP consistent with EPA guidance[7] or other equivalent documentation. Tier II data may have an incomplete QAPP or may use a monitoring method similar to MDE protocols, but not fully approved by MDE due to differences in sampling or testing methodology.

Tier I data do not meet the requirements of Tier II and Tier III, but are of known quality, and as a result, still contribute to the understanding of the health of Maryland's waters. Tier I data may be used for educational or outreach purposes, location information where monitoring is taking place, baseline data, assessing the general conditions of surface waters in Maryland, and highlighting community projects that are implemented to improve the health of water bodies. These data do not require a QAPP consistent with EPA guidance[7], but uniform methodology is recommended. Tier I data may have a QAPP, standard operating procedures, and/or laboratory methods that do not meet MDE quality assurance and quality control methods. These data may include land use data, visual observations of water quality condition, or data not consistent with MDE's assessment methodologies.

Of the 31 organizations/programs that submitted water quality data to MDE for consideration in MDE's Combined 2020-2022 IR, 9 submitted Tier I data, 5 submitted Tier II data, and 18 submitted Tier III data. See table 3 of MDE's IR for a list of the organizations/programs that submitted data and notes on MDE's evaluation of those data.

In addition, MDE identifies certain water bodies as conditionally approved shellfish areas. A sub-set of these water bodies are restricted because they are closed for administrative reasons under guidance of the National Shellfish Sanitation Program. Typically, these waters are restricted due to their vicinity to wastewater treatment plants and the restriction is precautionary against the potential treatment system failure, rather than an expression of failure to meet WQS. In accordance with MDE's listing methodology and EPA guidance, both administratively restricted and conditionally approved shellfish waters are generally not listed on the Section 303(d) list.

EPA finds MDE's protocol for evaluating data described in its IR to be a reasonable rationale in

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[8] https://www.epa.gov/quality/guidance-quality-assurance-project-plans-epa-qag-5

determining the usage of outside data for the purposes of 130.7(b)(5) and (b)(6)(iii).

D) Any other reasonable information requested by the Regional Administrator (CFR §130.7(b)(6)(iv))

There are a total of 101 additions to the list of Category 5 (impaired, TMDL needed) waters in 2022. Two of the new Category 5 waterbody-pollutant combinations (also referred to as listings or assessment records) are for sulfate and are based on Biological Stressor Identification (BSID) analyses. In addition, there are 16 new fecal coliform listings in shellfish harvesting waters, three new chlorophyll *a* listings for lakes, two new listings for perfluorooctane sulfonate in fish tissue, three new listings for phosphorus, one new listing for high pH, and 74 new listings for high water temperatures in Class III or III-P cold water stream segments.

i) Rationale for delisting of waterbodies included on the previous Section 303(d) list

MDE has demonstrated, to EPA's satisfaction, good cause for not including certain waters on its list. As provided in 40 CFR §130.7(b)(6)(iv), EPA requested that MDE demonstrate good cause for not including waters that were on the previous Section 303(d) list for the prior IR cycle. For the Combined 2020-2022 Section 303(d) list, MDE submitted data and information demonstrating that certain previously listed waters either recovered to the point that the applicable water quality standards have been attained or were initially listed in error and/or are currently not impaired. A water may be delisted for various reasons including the following: more recent or accurate data; more sophisticated water quality modeling; flaws in the original analysis that led to the water being listed in the categories in section 130.7(b)(5); or changes in conditions (i.e., new control equipment, elimination of discharges). There may also be reassessments revealing that a WQLS is still impaired, but that the causes of impairment have changed; these waters therefore remain on the list but are identified as impaired by a different pollutant(s). For each water-pollutant combination proposed for removal from the Combined 2020-2022 Section 303(d) list, MDE provided EPA with sufficient documentation and justification.

Ten waterbody-pollutant combinations were removed from Category 5 in 2020-2022. One biological listing without a specified impairing substance has been replaced by a sulfate listing from the BSID analyses. Another listing was removed from Category 5 for temperature because the waterbody was erroneously assessed as a use Class III stream when it is actually an use Class I stream and is meeting the use Class I temperature criterion. One listing was removed from Category 5 for high pH and was replaced by another high pH listing covering a larger geographic area. The last seven listings removed from Category 5 included three for mercury in fish tissue and four for polychlorinated biphenyls (PCBs) in fish tissue. These seven listings were moved to Category 2 on the basis of new data that demonstrated water quality that met the applicable criterion or impairment threshold.

EPA reviewed these data and agrees that MDE has demonstrated good cause for why the waters or water-pollutant combinations are not included in the Combined 2020-2022 Section 303(d) list.

In addition, removal of water-pollutant combinations from the 2020-2022 Section 303(d) list also included those segments where EPA-approved TMDL(s) have been developed. These segments were moved to Category 4A. Implementation of the TMDL is not required prior to removal to Category 4A. Where a water was previously listed for more than one pollutant, only those pollutants addressed in an approved TMDL were moved to Category 4A.

ii) Rationale for excluding waterbodies from the Section 303(d) list pursuant to 40 CFR §130.7(b)(1) because the waterbodies are expected to meet water quality standards

MDE's decision not to include waters on its Combined 2020-2022 Section 303(d) list due to other required pollution controls is consistent with EPA regulations at 40 CFR §130.7(b)(1). These waters were identified in Category 4B of the IR. Under 40 CFR §130.7(b)(1), states are not required to list WQLSs still requiring TMDLs (i.e., the Section 303(d) list or waters listed in Category 5) where effluent limitations required by the CWA, more stringent effluent limitations required by state or local authority, or other pollution control requirements required by state, local, or federal authority, are stringent enough to implement applicable water quality standards. The regulation does not specify the timeframe in which these various requirements must implement applicable water quality standards to support a state's decision not to list particular waters. Consistent with EPA guidance on this issue, EPA expects that required controls will result in attainment in a reasonable time, based on the nature of the pollutant and actions that need to be taken to achieve attainment.

As indicated above, MDE has several listings in Category 4b. Consistent with a program of continuous assessment, EPA encourages MDE to continue efforts, including monitoring as appropriate, to provide updates on the status of these segments. Monitoring should be scheduled for these waters to verify either that water quality standards are attained or water quality standards are expected to be attained in a reasonable time. Where it is found that water quality standards will not be attained through implementation of the requirements listed in 40 CFR §130.7(b)(1) in a reasonable time, it is appropriate for the water to be placed on the Section 303(d) list to ensure that implementation of the required controls, and progress towards compliance with applicable water quality standards, is tracked. If it is determined that the water is, in fact, meeting applicable water quality standards when the next Section 303(d) list is developed, it would be appropriate for the state to remove the water from the Section 303(d) list or Category 4B of the IR at that time.

2) TMDL Priority Ranking and Targeting (CFR §130.7(b)(4))

EPA reviewed MDE's priority ranking of Section 303(d) listed waters for TMDL development and concludes that MDE properly took into account the severity of pollution and the uses to be made of such waters. Beyond these two statutory factors, states retain considerable discretion and may consider other factors when prioritizing and scheduling TMDLs, including: vulnerability of particular waters; recreational, economic, and aesthetic importance of particular waters; restoration potential; degree of public interest and support; state or national policies and priorities; technical considerations, such as the complexity of the impairment; availability of adequate data and models; and implementation of watershed-based permitting programs or basin planning cycles. *See, e.g.,* 57 Fed. Reg. 33040, 33,044-45 (July 24, 1992).

MDE used the same priority ranking methodology used in previous lists. Documentation describing this prioritization was incorporated as part of MDE's 2016 Integrated Report[9]. Within the Section 303(d) list, MDE has provided both a priority ranking of high, medium, or low, and a separate indication for waters targeted for TMDL development in the next two years. In general, criteria that affect human health or have an extreme effect on natural resources are ranked high, criteria that indicate a continuing downward trend in the loss of a significant resource, create a serious nuisance, or constitute a significant loss of a natural resources are ranked as medium, and the remaining cases rank low.

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[9] https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Pages/2016IR.aspx

In addition, EPA has reviewed MDE's identification of WQLSs targeted for TMDL development in the next two years and concludes that that schedule is reasonable. Scheduling takes into account additional considerations other than priority designations, such as programmatic consideration (e.g., efficient allocation of resources, basin planning cycles, coordination with other programs or states) and technical considerations (e.g., data availability, problem complexity, availability of technical tools).

3) Public Participation

MDE released its draft Combined 2020-2022 IR and the Section 303(d) list of impaired waters for public review and comment on December 6, 2021, with a public comment period, open for 42 days, until January 17, 2022. A notice of availability of the draft Combined 2020-2022 IR and the Section 303(d) list was published in the Maryland Register. In addition, announcements were sent via e-mail to MDE's stakeholder listserve. All materials, including the IR narrative and supporting documentation and information, were made available on MDE's webpage[10]. Paper copies could also be requested. A public meeting was held virtually to present and summarize the draft IR on January 5, 2022.

Comments were submitted from EPA on January 13, 2022. MDE received no additional comments from any other organizations/individuals, and MDE addressed EPA comments in a comment response document included within the final IR submission to EPA. In addition, MDE made changes to the IR in response to EPA comments, as appropriate. Comments submitted by EPA requested monitoring and assessment updates to existing 4b listings, as available, and re-consideration of the TMDL priority ranking for one water listed in Category 5. EPA has determined that MDE adequately addressed all public comments received.

4) Coordination with the U.S. Fish and Wildlife Service and National Marine Fisheries Service

On December 13th, 2021, EPA notified the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) of the availability of MDE's draft Combined 2020-2022 IR and Section 303(d) list. EPA provided this notification as a courtesy and to facilitate informal coordination between the agencies regarding potential impacts the proposed listings may have on threatened and endangered species and critical habitat. No comments were received from USFWS or NMFS.

In reaching its conclusions on approving Maryland's Combined 2020-2022 303(d) list, EPA collected and appropriately considered information on the endangered and threatened species and their critical habitat in Maryland's waters identified by NMFS and FWS.

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[10] https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Pages/index.aspx

Attachment 5

The Nature Conservancy
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October 29, 2019

Via electronic filing and first class mail

Secretary Kimberly D. Bose
Federal Energy Regulatory Commission
Office of Energy Projects
888 First Street, NE
Washington, DC 20426

Re: Conowingo Hydroelectric Project (P-405-106)

Dear Secretary Bose,

The Nature Conservancy (TNC or the Conservancy) provides new information gathered since the publication of the final Environmental Impact Statement (EIS) in March 2015[1] that is relevant to the Office of Energy Project (OEP) Staff's environmental analysis of Exelon Corporation LLC's (Exelon) Conowingo Hydroelectric Project (project). The three documents TNC submits are:

1. Maryland's Final 2018 Integrated Report;[2]
2. U.S. Environmental Protection Agency's (EPA) April 9, 2019 approval letter for the Final 2018 Integrated Report;[3] and

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[1] FERC, "Final Multi-Project Environmental Impact Statement for Hydropower Licenses: Susquehanna River Hydroelectric Projects" eLibrary no. 20150311-4005 (Mar. 11, 2015).

[2] Available at https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Documents/Integrated_Report_Section_PDFs/IR_2018/2018IR_Part_F.6_Final.pdf (Attachment 1).

[3] Available at https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Documents/Integrated_Report_Section_PDFs/IR_2018/2018_EPA_Approval_Letter.pdf (Attachment 2).

3. Final EPA-USGS Technical Report: Protecting Aquatic Life from Effects of Hydrologic Alteration. EPA Report 822-R-16-007/USGS Scientific Investigations Report 2016-5164 (USGS & EPA (2016)).[4]

The Commission will rely on the EIS as a primary basis for its relicensing decision. Although the EIS in this proceeding was issued more than four years ago,[5] the Commission has not issued a licensing decision, due in part to the pendency of related administrative and judicial proceedings related to the protection of water quality under the Clean Water Act.

TNC requests that OEP Staff reconsider its alternatives analysis and findings in the EIS, based on the new information provided in the attached documents. Such reconsideration is necessary because the project's potential impacts on water quality, particularly the designated use of aquatic life and wildlife, are material to the Commission's decision regarding which license alternative will be best adapted to a comprehensive plan of development for the lower Susquehanna River and Chesapeake Bay for the next 30 to 50 years.

I. **Conowingo Dam operations cause impairment of the aquatic life and wildlife designated use on the Lower Susquehanna River mainstem.**

Maryland's 2018 Final Integrated Report (April 9, 2019), Section "F.6 Category 4c Waters," newly lists the Lower Susquehanna River mainstem below Conowingo dam as an impaired waterbody under the Clean Water Act. The Lower Susquehanna is listed as impaired

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[4] Available at https://www.epa.gov/sites/production/files/2016-12/documents/final-aquatic-life-hydrologic-alteration-report.pdf (Attachment 3).

[5] Under 40 C.F.R. § 1502.9(c), federal agencies are required to supplement an EIS if: (i) The agency makes substantial changes in the proposed action that are relevant to environmental concerns; or (ii) There are significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts." Further, there is a presumption that the federal agencies will revisit the analysis in EISs that are more than five years old to determine whether the analysis is still valid: "[a]s a rule of thumb, if the proposal has not yet been implemented, or if the EIS concerns an ongoing program, EISs that are more than 5 years old should be carefully reexamined to determine if the criteria in Section 1502.9 compel preparation of an EIS supplement." Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations, 46 Fed. Reg. 18026-01 (Mar. 23, 1981).

for non-attainment of the designated use of supporting *aquatic life and wildlife*. The cause of impairment is listed as flow alteration and changes to stream hydraulics, and the pollution source is listed as dam or impoundment. The report notes that both assessment of the flow regime and measured biological impacts were used to demonstrate that "Conowingo Dam operations cause impairment of the aquatic life and wildlife designated use." The Environmental Protection Agency (EPA) approved Maryland's listing on April 9, 2019.

This listing is supported by the best available data, models and literature in the record, which show that existing project operations, particularly Exelon's combined minimum flows (0 to 10,000 cfs), maximum generation flows (86,000 cfs), and ramping rates (86,000 cfs/hour), have resulted in:

- Between a 75% and 95% loss in migration and spawning habitat for diadromous fish (*see* TNC's Motion to Intervene (TNC MOI)[6] p. 14 and Attachment 1 Table 4 and Figures 6-12, 23-30 and 32-41);
- Alteration of the resident fish community toward habitat generalists and estimated loss of 50 to 80% of persistent spawning habitat (*see* TNC MOI, Attachment 1 Table 4 and Figures 17, 26 and 41-43);
- Loss of freshwater mussel recruitment below the dam (*see id.* at pp. 14-15 and Attachment 1 Table 4 and Figure 13, RSP 3.19[7] pp. ii.);
- 'Hydrologically impaired' macroinvertebrate community (*see id.* at pp 15 and RSP 3.18[8] pp. 16-17);

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[6] *See* "The Nature Conservancy's Motion to Intervene, Recommended Alternatives for Environmental Analysis, and Preliminary Terms and Conditions," eLibrary no. 201440131-5199 (Jan. 31, 2014). The TNC MOI includes a complete description of the Conservancy and its interests in these proceedings.

[7] Final Study Report Freshwater Mussel Characterization Study below Conowingo Dam RSP 3.19. Conowingo Hydroelectric Project FERC Project Number 405, available at https://mde.maryland.gov/programs/Water/WetlandsandWaterways/Documents/ExelonMD/FERC/Conowingo-FRSP-3.19.pdf.

[8] Final Study Report Characterization of Downstream Aquatic Communities RSP 3.18, Conowingo Hydroelectric Project, FERC Project Number 405, available at https://mde.maryland.gov/programs/Water/WetlandsandWaterways/Documents/ExelonMD/FERC/Conowingo-FRSP-3.18.pdf.

- Fish stranding and mortality due to ramping and resulting dewatering, thermal stress and predation (*see id.* at p. 14, Attachment 1 Table 4, Figure 14);
- Loss of state and federally endangered species habitat for reproductive growth and hibernation (*see id.* at p. 15, Attachment 1 Table 4, Figures 18 and 22 (map turtles), Figures 11, 16, 25, 29, 35-37 (Shortnose sturgeon));
- Sediment-starved lower river and flats (*see id.* at pp. 15-16); and
- Absence or reduction of Submerged Aquatic Vegetation (SAV) communities below the dam (*see id.* at p. 15).

II. **The record does not show that the Staff Alternative will provide meaningful biological improvements to address the impairment**

As shown by the habitat and data analyses TNC submitted in its Motion to Intervene, and comments on the draft EIS and final EIS, the staff alternative will not be sufficient to address the impaired status for the newly listed reach below Conowingo dam. In light of this designation, we ask OEP Staff to revisit TNC's comments on the EIS (*see* eLibrary no. 20150416-5198 (TNC EIS comments)) and recommendations including the expert testimony from Dr. Stalnaker (*id.* at Attachment 1, pp. 1-7), a global leader in instream flow science. In summary, these comments show that:

- The Staff Alternative recommends minimum flow releases that are lower than historic minimum flows for much of the year (*see* TNC EIS comments, pp. 5-6);
- This approach for developing an operational recommendation below a hydro-peaking facility focuses on a measure of instantaneous habitat (Maximum Weighted Usable Area) and is characteristic of scientific understanding 50 years ago. However, contemporary scientific methods to compare and develop operational recommendations below a hydro-peaking facility require the use of persistent habitat measures and time-series analysis to track the availability of habitat throughout daily and weekly hydro-peaking cycles (*see id.* at pp. 7-10); and
- The documentation in the EIS does not demonstrate that the comparison of alternatives is based on a valid scientific method (*see id.* at pp. 7-8, Figure 2).

Accordingly, the rationale in the EIS for eliminating the NGO-Agency alternative, an alternative supported by the FWS in its FPA 10(j) recommendations,[9] the Susquehanna River Basin Commission,[10] and others, should be reconsidered.

Further, USGS & EPA (2016) explicitly provides scientific and technical support for states and Tribes in protecting aquatic life from the adverse effects of hydrologic alteration in streams and rivers under the Clean Water Act water quality standards. The report documents the importance of a rivers' flow magnitude, timing, duration, frequency and rate of change in supporting the chemical, physical and biological integrity of streams and related beneficial uses. USGS & EPA (2016), pp. 7-11, 13-40. It highlights methodologies to develop flow standards that support Clean Water Act water quality standards and their beneficial uses (pp. 41-51). Further, the report references the methodology used in the Susquehanna River basin and Lower Susquehanna River ecosystem flow recommendations, as a model framework for developing quantitative standards for protecting aquatic life designated uses from the adverse effects of hydrologic alteration. *Id.* at pp. 69-76.

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[9] U.S. Department of Interior, "Letter Dated January 31, 2014: Re: Review of Notice of Application Ready for Environmental Analysis: Comments, Recommendations, Preliminary Terms and Conditions, and Preliminary Prescriptions," eLibrary no. 20140131-5194 (Jan. 31, 2014).

[10] Susquehanna River Basin Commission, "Letter Dated September 29, 2014: Re: Comments Regarding Draft Environmental Impact Statement for Susquehanna River Hydroelectric Projects," eLibrary no. 20140929-5315 (Sept. 29, 2014).

III. The record remains incomplete with regard to the finding in the EIS that the Agency-NGO Alternative would have major adverse effects on project economics or ancillary services

The EIS finds that the Agency-NGO Alternative[11] would be too costly: "Our primary reason for not adopting the TNC Flow Regime is the benefits to some species life stages would not justify the effects on project operation and costs" (EIS, p. 429).

This finding is not supported by the record. As described above, Staff analysis lacks a scientific basis for comparing benefits and specific to operation and costs:

- Average annual revenue from Conowingo and Muddy Run operations is estimated as $207M (Conowingo Hydroelectric Project and Muddy Run Application for New License)[12] (in both documents, *see* Exhibit D, Table 5-1, pp. D-6);
- The estimated loss in annual revenue from the Agency-NGO alternative is $1.6M (subtracting financial gains at Conowingo from losses at Muddy Run) (*see* EIS pp. 429);
- As this is estimated to be a less than 1% loss in annual revenue, and would provide significant ecological benefits, the Agency-NGO alternative merits review under the equal consideration provision of Section 4(e) of the Federal Power Act.

The EIS also finds that the Agency-NGO Alternative would have unacceptable impacts on the project's ancillary services over the period of the license: "Operation under the TNC Flow Regime would be restrained and would eliminate many of the peaking and ancillary services benefits to the PJM regions from the Conowingo Project … Ancillary services include those services necessary to maintain the reliability of the interconnected transmission system" (EIS, p. 429).

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[11] EIS, pp. 146-147, Table 3-19.

[12] Exelon, "Application for New License for Major Water Power Project-Existing Dam: Conowingo Hydroelectric Project FERC Project Number 405," eLibrary no. 20120831-5024 (Aug. 31, 2012); Exelon, "Application for New License for Major Water Power Project-Existing Dam: Muddy Run Pumped Storage Project FERC Project Number 2355," eLibrary no. 20120829-5102 (Aug. 29, 2012).

However, the EIS does not provide a specific description of the ancillary services provided by the facilities. This omission prevents the clear comparison of alternatives required under the National Environmental Policy Act (*see* 40 C.F.R. § 1502.14).

Further, the EIS does not include a comparison of the costs and benefits of integrating alternative storage technologies over the term of the license. It does not address evidence that, over the proposed term of the license, energy storage technologies and economics are predicted to change exponentially with utility-scale battery storage playing an increasingly significant role.[13] In the U.S., as of March 2019, there are two 40 MW facilities and sixteen with 20 MW or more. By 2021 two facilities with more than 300 MW capacity each are expected to come online in Parrish, Florida and Queens, New York.[14] In fact, Exelon has recently partnered with a major lithium ion supplier to create Volta Energy Technologies.[14] OEP Staff should consider integration of this technology with the 40-year operation of Conowingo and Muddy Run.

IV. Conclusion

The Nature Conservancy respectfully requests that OEP Staff reconsider the alternatives analysis and findings in the EIS based on the information provided herein. Although this information was developed subsequent to the publication of the EIS in March 2015, it is nonetheless material to Staff's evaluation of the costs and benefits of the action alternatives considered in the EIS, and Staff's finding that the Staff Alternative will be the best adapted to a comprehensive plan of development for the Susquehanna River.

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[13] Energy Information Agency 2019, available at https://www.eia.gov/todayinenergy/detail.php?id=40072.

[14] Renewable Energy Magazine 2017, *available at* https://www.renewableenergymagazine.com/energy_saving/exelon-and-albermarle-partner-to-form-volta-20171207.

TNC also requests the opportunity to meet with Staff, Exelon, and other interested stakeholders to discuss this new information and try to narrow or resolve remaining disputed issues, which are contributing to delay in license issuance and may lead to challenges to the new license if left unresolved.

Respectfully submitted,

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Maryland Department of the Environment
Susquehanna River Basin Commission
U.S. Environmental Protection Agency
Council for Environmental Quality
American Rivers
Earth Justice
Chesapeake Bay Foundation
FERC's eService list for docket P-405

Attachment 1

F.6 Category 4c Waters

Maryland's 2018 Final Integrated Report - Category 4c Waters

Assessment Unit Basin Name	County Cycle Listed	Designated Use Water Type Detail	Cause	Indicator Pollution Sources	Notes
MD-02120201-Lower_Susquehanna_Mainstem Lower Susquehanna River	CE, HA 2018	Aquatic Life and Wildlife River Mainstem	Flow Alteration-Changes in Depth and Flow Velocity	Habitat Evaluation Dam or Impoundment	Assessment of flow regime and biological impacts demonstrate that Conowingo Dam operations cause impairment of the aquatic life and wildlife designated use.
MD-02130203 Upper Pocomoke River	WI, WO 2012	Aquatic Life and Wildlife 1st thru 4th order streams	Riparian Buffer, Lack of	Direct Measurement Agriculture	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130203 Upper Pocomoke River	WI, WO 2012	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicates that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130305 Nanticoke River	CA, DO, WI 2016	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicated that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130306 Marshyhope Creek	CA, DO 2012	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicated that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130404 Upper Choptank River	TA, QA, CA 2012	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicates that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130510 Upper Chester River	KE, QA 2012	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicates that stream channelization due to agricultural ditching is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.

Assessment Unit *Basin Name*	*County* *Cycle Listed*	*Designated Use* *Water Type Detail*	*Cause*	*Indicator* *Pollution Sources*	*Notes*
MD-02130701 Bush River	HA 2014	Aquatic Life and Wildlife 1st thru 4th order streams	Riparian Buffer, Lack of	Direct Measurement Urban Development in Riparian Buffer	The Biostressor analysis indicated that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130701 Bush River	HA 2014	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicated that channelization is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130704 Bynum Run	HA 2012	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130705 Aberdeen Proving Ground	HA 2014	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Fish and Benthic IBIs Channelization	The Biostressor analysis indicated that channelization is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130802 Lower Gunpowder Falls	BA 2012	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130805 Loch Raven Reservoir	BA, CR 2014	Aquatic Life and Wildlife 1st thru 4th order streams	Riparian Buffer, Lack of	Direct Measurement Urban Development in Riparian Buffer	The Biostressor analysis indicates that lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130901 Back River	BA, BC 2012	Aquatic Life and Wildlife 1st thru 4th order streams	Riparian Buffer, Lack of	Direct Measurement Loss of Riparian Habitat	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02130901 Back River	BA, BC 2012	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.

Assessment Unit	*County*	*Designated Use*	*Cause*	*Indicator*	*Notes*
Basin Name	*Cycle Listed*	*Water Type Detail*		*Pollution Sources*	
MD-02130903	AA, BA, BC	Aquatic Life and Wildlife	Habitat Alterations	Habitat Evaluation	The Biostressor analysis indicates that stream channelization is a major stressor affecting biological integrity in this watershed. This listing, along with others, replace the biological listing.
Baltimore Harbor	2014	1st thru 4th order streams		Channelization	
MD-02130903	AA, BA, BC	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Habitat Evaluation	The Biostressor analysis indicates that the lack of an adequate riparian buffer is a major stressor affecting biological integrity in this watershed. This listing, along with others, replaces the biological listing.
Baltimore Harbor	2014	1st thru 4th order streams		Urban Development in Riparian Buffer	
MD-02130904	BA, BC	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Jones Falls	2012	Non-tidal 8-digit watershed		Channelization	
MD-02130905	BA, BC	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Gwynns Falls	2012	Non-tidal 8-digit watershed		Channelization	
MD-02130906	AA, BA, BC, HO, CR	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Patapsco River Lower North Branch	2012	1st thru 4th order streams		Channelization	
MD-02131003	AA	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Direct Measurement	The Biostressor analysis indicates that the lack of an adequate riparian buffer is a major stressor affecting biological integrity in this watershed. This listing, along with others, replaces the biological listing.
South River	2014	1st thru 4th order streams		Urban Development in Riparian Buffer	
MD-02140201	PG, CH	Aquatic Life and Wildlife	Habitat Alterations	Direct Measurement	The Biostressor analysis indicated that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Potomac River Upper tidal	2018	1st thru 4th order streams		Channelization	
MD-02140205	MO, PG	Aquatic Life and Wildlife	Riparian Buffer, Lack of	Direct Measurement	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
Anacostia River	2012	1st thru 4th order streams		Loss of Riparian Habitat	

Assessment Unit *Basin Name*	*County* *Cycle Listed*	*Designated Use* *Water Type Detail*	*Cause*	*Indicator* *Pollution Sources*	*Notes*
MD-02140205 Anacostia River	MO, PG 2012	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02140207 Cabin John Creek	MO 2012	Aquatic Life and Wildlife Non-tidal 8-digit watershed	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicates that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02140301-Wadeable_Streams Potomac River Frederick County	FR, WA 2018	Aquatic Life and Wildlife 1st thru 4th order streams	Riparian Buffer, Lack of	Direct Measurement Urban Development in Riparian Buffer	The Biostressor analysis indicates that the lack of an adequate riparian buffer is a major stressor affecting biological integrity in this watershed. This listing, along with others, replaces the biological listing.
MD-02140302 Lower Monocacy River	CR, FR, MO 2012	Aquatic Life and Wildlife Non-tidal 8-digit watershed	Riparian Buffer, Lack of	Direct Measurement Agriculture	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02140502 Antietam Creek	WA 2014	Aquatic Life and Wildlife 1st thru 4th order streams	Habitat Alterations	Habitat Evaluation Channelization	The Biostressor analysis indicates that channelization is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02140502 Antietam Creek	WA 2014	Aquatic Life and Wildlife 1st thru 4th order streams	Riparian Buffer, Lack of	Habitat Evaluation Agriculture	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02141002 Evitts Creek	AL 2012	Aquatic Life and Wildlife Non-tidal 8-digit watershed	Riparian Buffer, Lack of	Direct Measurement Loss of Riparian Habitat	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.
MD-02141003 Wills Creek	AL, GA 2012	Aquatic Life and Wildlife Non-tidal 8-digit watershed	Habitat Alterations	Direct Measurement Channelization	The Biostressor analysis indicated that stream channelization due to urban development is a major stressor affecting biological integrity in this watershed. This listing replaces the biological listing.

Assessment Unit Basin Name	County Cycle Listed	Designated Use Water Type Detail	Cause	Indicator Pollution Sources	Notes
MD-05020201-Wadeable_Streams Youghiogheny River	GA 2014	Aquatic Life and Wildlife 1st thru 4th order streams	Riparian Buffer, Lack of	Habitat Evaluation Urban Development in Riparian Buffer	The Biostressor analysis indicates that the lack of a riparian buffer is a major stressor affecting biological integrity in this watershed. This listing addresses a portion of the biological listing and therefore replaces it on the list.

Attachment 2

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

APR 09 2019

Mr. Lee Currey, Director
Water and Science Administration
Maryland Department of the Environment
1800 Washington Blvd., Suite 540
Baltimore, Maryland 21230-1718

Dear Mr. Currey:

The U.S. Environmental Protection Agency (EPA), Region III, has conducted a complete review of Maryland's 2018 Section 303(d) List, and supporting documentation and information. Based on this review, EPA has determined that Maryland's list of water quality limited segments still requiring Total Maximum Daily Loads, meets the requirements of Section 303(d) of the Clean Water Act and EPA's implementing regulations. Therefore, with this letter, EPA hereby approves Maryland's 2018 Section 303(d) List. The statutory and regulatory requirements, and EPA's review of Maryland's compliance with each requirement, are described in the enclosure.

We commend you and your staff for the thorough work and exemplary effort in establishing the list and in responding to the comments received.

If you have any questions regarding this decision, please feel free to contact Ms. Evelyn S. MacKnight, Associate Director, at 215-814-5717, or Macknight.Evelyn@Epa.gov.

Sincerely,

Catherine A. Libertz

Catherine A. Libertz, Director
Water Protection Division

Enclosure

cc : Matthew Stover, MDE-WSA

EPA Region III Approval Rationale for Maryland's 2018 Section 303 (d) List

EPA has conducted a complete review of Maryland's 2018 Section 303(d) list and supporting documentation and information, which was submitted to EPA on March 11, 2019. Based on this review, EPA has determined that Maryland's list of water quality limited segments (WQLSs) still requiring Total Maximum Daily Loads (TMDLs) meets the requirements of Section 303(d) of the Clean Water Act ("CWA" or "the Act") and EPA's implementing regulations. Therefore, EPA hereby approves Maryland's Section 303(d) list. The statutory and regulatory requirements, and EPA's review of Maryland's compliance with each requirement, are described in detail below.

Statutory and Regulatory Background

Identification of WQLSs for Inclusion on Section 303(d) List

Section 303(d)(1) of the Act directs States to identify those waters within its jurisdiction for which effluent limitations required by Section 301(b)(1)(A) and (B) are not stringent enough to implement any applicable water quality standard, and to establish a priority ranking for such waters, taking into account the severity of the pollution and the uses to be made of such waters. The Section 303(d) listing requirement applies to waters impaired by point and/or non-point sources, pursuant to EPA's long-standing interpretation of Section 303(d).

EPA regulations provide that States do not need to list waters where the following controls are adequate to implement applicable standards: (1) technology-based effluent limitations required by the Act; (2) more stringent effluent limitations required by State, local, or federal authority. See 40 CFR 130.7(b)(1). EPA's review and action on Maryland's 2018 list is generally consistent with EPA guidance, including *Guidance for 2006 Assessment, Listing, and Reporting Requirements Pursuant to Sections 303(d), 305(b), and 314 of the Clean Water Act* (July 29, 2005), and the memorandum titled "*Information Concerning 2018 Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions*".

Consideration of Existing and Readily Available Water Quality-Related Data and Information

In developing Section 303(d) lists, States are required to assemble and evaluate all existing and readily available water quality-related data and information, including, at a minimum, consideration of existing and readily available data and information about the following categories of waters: (1) waters identified as partially meeting or not meeting designated uses, or as threatened, in the State's most recent Section 305(b) report; (2) waters for which dilution calculations or predictive modeling indicate non-attainment of applicable standards; (3) waters for which water quality problems have been reported by governmental agencies, members of the public, or academic institutions; and (4) waters identified as impaired or threatened in any Section 319 nonpoint assessment submitted to EPA. See 40 CFR 130.7(b)(5). In addition to these minimum categories, States are required to consider any other data and information that is existing and readily available.

While States are required to evaluate all existing and readily available water quality-related data and information, States may decide to rely or not rely on particular data or information in determining whether to list particular waters.

In addition to requiring States to assemble and evaluate all existing and readily available water quality-related data and information, EPA regulations at 40 CFR 130.7(b)(6) require States to include as part of their submissions to EPA, documentation to support decisions to rely or not rely on particular data, information, and decisions to list or not list waters. Such documentation needs to include, at a minimum, the following information: (1) a description of the methodology used to develop the list; (2) a description of the data and information used to identify waters; and (3) any other reasonable information requested by the Region.

Priority Ranking

EPA regulations also codify and interpret the requirement in Section 303(d)(1)(A) of the Act that States establish a priority ranking for listed waters. The regulations at 40 CFR 130.7(b)(4) require States to prioritize waters on their Section 303(d) lists for TMDL development, and also to identify those WQLSs targeted for TMDL development activities in the next two years. In prioritizing and targeting waters, States must, at a minimum, take into account the severity of the pollution and the uses to be made of such waters. See Section 303(d)(1)(A). As long as these factors are taken into account, the Act provides that States establish priorities. States may consider other factors relevant to prioritizing waters for TMDL development, including immediate programmatic needs, vulnerability of particular waters as aquatic habitats, recreational, economic, and aesthetic importance of particular waters, degree of public interest and support, and State or national policies and priorities. See 57 FR 33040, 33045 (July 24, 1992).

Analysis of Maryland's Submission

Identification of Waters and Consideration of Existing and Readily Available Water Quality-Related Data and Information

EPA has approved Section 303(d) lists submitted by Maryland including, but not limited to, Section 303(d) lists, for the years 1996, 1998, 2002, 2004, 2006, 2008, 2010, 2012, 2014 and 2016. To the extent that these prior lists have been incorporated into the 2018 Section 303(d) list, EPA's rationale for approving those lists remains operative. EPA's review of the 2018 Section 303(d) list focused on changes from the prior lists.

Maryland Department of the Environment (MDE) public noticed the draft 2018 Section 303(d) list for a comment period of 32 days, from February 16, 2018 through March 19, 2018. The draft list was posted on several outlets including among others, MDE's internet world-wide-web, Maryland Register, and several of MDE's social media outlets (e.g. Facebook). MDE held an informational public meeting on February 27, 2018, at MDE Headquarters in Baltimore, Maryland. Comments were received in writing and all were responded to appropriately.

EPA received MDE's final 2018 Section 303(d) list package on March 11, 2019 through the Assessment, Total Maximum Daily Load (TMDL) Tracking and Implementation System (ATTAINS), which is EPA's new electronic system to accept and track 303(d) submissions and actions. Specifically, Maryland's 2018 Category 5 data in ATTAINS represents Maryland's 2018 303(d) list of impaired waters. Maryland also submitted a narrative report in ATTAINS. The 2018 Section 303(d) package included: (1) an overview of the process for development of the 2018 Section 303(d) list; (2) surface water monitoring strategy, assessment units, links to the listing methodologies used by MDE (all listing methodologies have undergone public review, but further public comment was welcomed during the 303(d) list public comment period); (3) assessment results associated with biological impairments, toxics, bacteria, temperature, and solids from rivers/streams, lakes/ponds, estuarine and ocean waters; (4) the public process related to the 303(d) list; and (5) the integrated Section 305(b) report and Section 303(d) list, consisting of parts 2, 3, 4, and 5. MDE also provided a list of TMDLs approved (Table 29) and anticipated for completion for Fiscal Year 2018 and 2019 (Table 69 and 70, respectively). The package also included a responsiveness summary to comments received during the public review. In taking this action, EPA considered the information in its record, including but not limited to, Maryland's 2018 Category 5 data in ATTAINS and Maryland's narrative submissions.

EPA concludes that the State properly assembled and evaluated all existing and readily available data and information, including data and information relating to the categories of waters specified in 40 CFR 130.7(b)(5). In addition, the State provided its rationale for not relying on particular existing and readily available water quality-related data and information as a basis for listing waters.

In total, MDE received 36 written comments from five parties during the public comment period and responded to all appropriately. EPA appreciates MDE's identification on Category 5 certain waters that do not meet Maryland's numeric criterion for temperature based on EPA's draft Integrated Report comments. EPA encourages MDE to continue working with stakeholders to consider whether any temperature standard should be revised. EPA supports MDE's efforts to work with stakeholders to determine whether temperature standards should be revised based upon sound scientific rationale and scientifically defensible methods. EPA agrees with the subsequent changes made to the final 2018 303(d) list.

In regards to the comments submitted by Waterkeepers Chesapeake, EPA notes that Waterkeepers Chesapeake incorporated by reference its members' comments on MDE's 2012, 2014, and 2016 Integrated Reports regarding moving the entries for total nitrogen, total phosphorus, and total suspended solids on 53 Chesapeake Bay tidal segments from Part 5 (waters that may require a TMDL) to Part 4a (waters that are still impaired but have an approved TMDL) of Maryland's Integrated Report, where applicable. Each of these 53 segments is a tidal portion of one of the Chesapeake Bay tributaries, and each segment was classified as a Chesapeake Bay segment in 2008. As part of the 2010 Chesapeake Bay TMDLs, [1] TMDLs were established for each of these 53 Chesapeake Bay tidal segments at a level necessary to meet the applicable water quality standards for that segment for total nitrogen, total phosphorus, and total suspended solids

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[1] EPA agrees with MDE's observation that the December, 2010 action is more properly characterized as the "Chesapeake Bay TMDLs." While for ease of reference, the action is often referenced in the singular (i.e., "Chesapeake Bay TMDL"), the action consists of 276 separate TMDLs for 92 separate tidal waterbody segments adjoining the Chesapeake Bay.

(totaling to 139 segment-pollutant combinations). Because the TMDLs were established, those Chesapeake Bay segment-pollutant combinations that were previously in Part 5 were moved to Part 4a. MDE incorporated its previous responses to Waterkeepers Chesapeake's comments by reference. EPA agrees with MDE's previous responses and with MDE's response to comments on the 2018 Integrated Report. EPA incorporates by reference its Decision Rationale approving MDE's 2014 and 2016 Section 303(d) list, which also addressed Waterkeepers' previous comments on this topic. MDE's categorization of waters that have TMDLs on Part 4a of the Integrated Report rather than Part 5 is consistent with EPA guidance [Memorandum titled "*Information Concerning 2018 Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions*"].

A. Description of the methodology used to develop this list, Section 130.7(b)(6)(i)

For the 2018 reporting cycle, no changes were made to any of MDE's assessment methodologies, but further public comment on the methodologies was welcomed during the 303(d) list public comment period and no related comments were received. All assessment methodologies are available on MDE's Web site at http://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Pages/ir_listing_methodologies.aspx.

B. Description of the data and information used to identify waters, including a description of the data and information used by Maryland as required by Section 130.7(b)(5).

1. Section 130.7(b)(5)(i), Waters identified by Maryland in its most recent Section 305(b) report as "partially meeting" or not meeting designated uses or as "threatened."

Maryland's Section 303(d) list is mostly defined by the data collection and assessment contained in the 305(b) report of the State's water quality. In Maryland, responsibility for collection and compilation of this information is shared between the Maryland Department of Natural Resources (MDNR) and MDE. MDE compiles Maryland's Inventory of the Water Quality, the Section 305(b) Report, every two years pursuant to Section 305(b) of the CWA. MDNR collects many of the data that goes into the assessments. Also, MDE sets water quality standards (WQS), regulates discharges to Maryland waters through environmental permitting, enforcement and compliance activities, identifies waters for inclusion on the Section 303(d) list, and develops TMDLs. Since 2002 and consistent with EPA guidance, Maryland has submitted an integrated report combining the Section 303(d) list and the Section 305(b) report (Integrated Report). Beginning this cycle in 2018, MDE submitted these data through EPA's electronic ATTAINS system. The following categories are used to describe water quality in Maryland's Integrated Report. Category 1 of the Integrated Report identifies waters that meet all water quality standards and no use is threatened. Category 2 identifies waters meeting water quality standards for at least one designated use, but with insufficient information to determine if WQS are being met for other designated uses. Category 3 identifies waters where there is insufficient information to determine if any water quality standard is being attained, and includes subcategories for insufficient data quantity and insufficient data quality. Category 4 identifies waters where one or more WQS are impaired or threatened, but for which a TMDL is not required because a TMDL has already been approved or established by EPA (Subcategory 4a), other pollution control requirements are expected to attain WQS (Subcategory 4b), or the impairment is not caused by a pollutant (Subcategory 4c). Categories 1-4 comprise the Section 305(b) portion of the integrated report. Category 5 is the Section 303(d) list and identifies waters that are not attaining WQS and for which a TMDL may be necessary.

Maryland considers a waterbody as "impaired" (and therefore subject to listing pursuant to Section 303(d)) when it does not attain a designated use pursuant to Maryland's WQS. Maryland has developed numerous methodologies for assessing whether waters are achieving their designated uses. MDE has provided the public with notice and an opportunity to comment on its assessment methodologies as they are developed and/or amended and during public comment on the Integrated Report.

In September 2004, Maryland updated its Comprehensive Water Quality Monitoring Strategy for all State waters consistent with current EPA guidance (see "Elements of a Water Monitoring and Assessment Program," EPA document 841-B-03-003). This Strategy describes Maryland's water quality monitoring framework and covers all State waters, including rivers and streams, lakes, tidal waters, ground water and wetlands. These water quality monitoring programs support the assessment of Maryland's designated uses as well as integrated reporting activities under Sections 303(d) and 305(b) of the CWA.

In the fall of 2007, MDE initiated monitoring strategy discussion with MDNR in anticipation of a revised strategy for 2009-2010. This 2009 Strategy has been completed and submitted to EPA and represents Maryland's last update of its comprehensive water monitoring strategy. Maryland's water quality monitoring programs are designed to support State Water Quality Standards (Code of Maryland Regulations Title 26, Subtitle 08) for the protection of both human health and aquatic life. This strategy identifies the programs, processes and procedures that have been institutionalized to ensure state monitoring activities continue to meet defined programmatic goals and objectives. The strategy also discusses data management and quality assurance/quality control procedures implemented across the State to preserve data integrity and assure that data are of sufficient quality and quantity to meet the intended use. Finally, this document serves as a road map for assigning monitoring priorities and addressing gaps in current monitoring programs. (http://www.mde.state.md.us/programs/ResearchCenter/EnvironmentalData/Documents/www.mde.state.md.us/assets/document/Maryland_Monitoring_Strategy2009.pdf).

EPA concludes that the Section 303(d) list identifies waters identified by Maryland on its Section 305(b) report as "partially meeting" or not meeting designated uses.

2. Section 130.7(b)(5)(ii), Waters for which dilution calculations or predictive models indicate non-attainment of applicable water quality standards.

Maryland supports the use of computer models and other innovative approaches to water quality monitoring and assessment. Maryland and the Bay partners also relied heavily on the Chesapeake Bay model to develop loading allocations, assess the effectiveness of best management practices, and guide implementation efforts. Several different modeling approaches have also been used in TMDL development. With the growing number of biological impairments in Category 5 of the list, Maryland will be relying more heavily on land use analyses, Geographic Information System (GIS) modeling, data mining, and other innovative approaches to identify stressors, define ecological processes, and develop appropriate TMDLs.

3. Section 130.7(b)(5)(iii), Waters for which water quality problems have been reported by local, state, or federal agencies; members of the public; or academic institutions

A MDE data request letter was widely advertised for the solicitation of data for the 2018 list. With the integration of Sections 305(b) and 303(d) of the CWA and the adoption of a multi-category reporting structure, Maryland has developed a two-tiered approach to data quality. Tier 1 data are those used to determine impaired waters (e.g., Category 5 waters or the traditional 303(d) list) and are subject to the highest data quality standards. Maryland waters identified as impaired using Tier 1 data may require a TMDL or other regulatory actions. These data should be accompanied by a Quality Assurance Project Plan (QAPP) consistent with EPA data guidance specified in Guidance for Quality Assurance Project Plans. Dec 2002. EPA /240/R-02/009 available at https://www.epa.gov/quality/guidance-quality-assurance-project-plans-epa-qag-5. Tier 1 data analysis must also be consistent with Maryland's Assessment Methodologies.

Tier 2 data are used to assess the general condition of surface waters in Maryland and may include land use data, visual observations of water quality condition, or data not consistent with Maryland's Assessment Methodologies. Such data may not have a QAPP or may have one that is not consistent with EPA guidance. Waters with Tier 2 data may be placed in Categories 2 or 3 of the Integrated Report, denoting that water quality is generally good or that there are insufficient data to make an assessment, respectively. However, Tier 2 data alone are not used to make impairment decisions (i.e., Category 5 listings requiring a TMDL) because the data are of insufficient quantity and/or quality for regulatory decision-making. MDE notes that it will be reevaluating the current data quality tier system to determine if changes are necessary to establish consistency with the Chesapeake Bay Monitoring Cooperative and further refine the data evaluation process. As a result of the data solicitation, 24 organizations/programs submitted water quality data for consideration in the 2018 Integrated Report. Of those 24 organizations/programs, 13 submitted Tier 1 data. MDE coordinates with the remaining organizations providing Tier 2 data to improve data quality and further promote the use of Tier 1 data for assessment purposes.

Maryland has made significant efforts to incorporate non-state government data in ways that increase the resolution of the state's water quality assessments. Datasets used included those collected by federal agencies, county governments, water utility agencies, and non-profit watershed organizations. The 2018 Integrated Report includes a GIS submittal that provides coverages for streams, impoundments, and estuarine waters which depict assessment information at appropriate scales. MDE also makes Integrated Reporting data available to the public in several user-friendly formats. Accessible via the web, users can query MDE's searchable Integrated Report database to find individual assessments or groups of assessments that are of interest. The searchable Integrated Report database and companion clickable map application are available online at http://www.mde.maryland.gov/programs/water/tmdl/integrated303dreports/pages/303d.aspx .

New this year is a revamped online map which displays water quality assessment information overlaid on top of TMDL watersheds. This newly reformatted map is meant to highlight the spatial relationship between the specific water body impaired for a given pollutant and the TMDL that accounts for all sources of that pollutant in that water body's watershed. Users can select as few or as many pollutants to display as they like with this fully interactive map. This map therefore replaces the previously provided single-pollutant maps and provides users with a one-stop map for visualizing water quality assessment information. The newly created map can be found at http://mdewin64.mde.state.md.us/WSA/IR-TMDL/index.html.

In addition to MDE's new online resources, EPA has transitioned 305(b) and 303(d) reporting to the new ATTAINS, which is an electronic system that holds all water quality assessment decisions for states and territories. ATTAINS transformed and modernized paper reporting into an electronic system, which allows EPA, states, and the public to access, search, and track all water quality assessment decisions.

4. Section 130.7(b)(5)(iv), Waters identified by Maryland as impaired or threatened in a non-point assessment submitted to EPA under section 319 of the CWA or in any updates of the assessment.

MDE considered waters identified in a Section 319 assessment during the development of the 1996 Section 303(d) list, and all such water segments were included on the 1996 list, which was incorporated into all subsequent lists, including the 2018 Section 303(d) list. The Clean Water Action Plan of 1998 required a statewide Unified Watershed Assessment which set priorities for Section 319 activities. Maryland's Unified Watershed Assessment, Category I assignments were based on the 1998 Section 303(d) list.

5. Other data and information used to identify waters (besides items 1-4 discussed above).

In addition to waters identified as impaired on the 2016 Section 303(d) List that have not been delisted, the 2018 Section 303(d) lists 42 additional impaired waters. Six of the new listings resulted from MDE's Biological Stressor Identification Analyses. Of these six new 'biostressor' listings, three are for total suspended solids, two are for sulfates, and one is for chlorides. In addition, there are four new fecal coliform listings in shellfish harvesting waters, one new listing for PCBs in fish tissue, one new listing for phosphorus, and, as discussed above, 30 new listings for temperature, which were moved from category 3 in the draft list to Category 5 in the final list in response to EPA's comments.

C. A rationale for any decision to not use any existing and readily available data and information for any one of the categories of waters as described in Sections 130.7(b)(5) and 130.7(b)(6)(iii).

Starting in 2002, Maryland developed and published for public review the Listing Methodologies to describe the State's interpretation of its WQS and establish scientifically defensible approaches for determining water body impairment. Listing Methodologies are not considered rules, but rather provide a means to provide consistency and transparency in Integrated Reporting so that the public and other interested stakeholders understand why listing decisions are made and can independently verify listing decisions. The methodologies are living documents that are revised as new statistical approaches, technologies, or other improved methods are adopted by the State. When changes are proposed to the Listing Methodologies, Maryland advertises the revised methodologies for public review via the biennial Integrated Report.

In Maryland's Section 305(b) Report, certain water bodies are conditionally approved shellfish areas. A sub-set of these water bodies are restricted because they are closed for administrative reasons under guidance of the National Shellfish Sanitation Program. Typically, these waters are restricted due to their vicinity to wastewater treatment plants and the restriction is precautionary against the potential treatment system failure, rather than an expression of failure to meet WQS. In accordance with MDE's listing methodology, both administratively restricted and conditionally approved shellfish waters are not listed on the Section 303(d) list.

D. Rationale for delisting of waterbodies from the previous 303(d) list[2].

Maryland has indicated, in the Integrated Report (Table 2), that 11 delistings have occurred during this cycle. Four biological listings without a specified impairing substance have been replaced by specific pollutant listings enumerated by the Biological Stressor Identification analyses (BSID). Another three (of the 11) listings, originally listed as impaired for exceedances above the pH criteria (i.e. > 8.5 pH units), were removed from Category 5 because new data showed that water quality standards were being met. The last four listings removed from Category 5 included two for fecal coliform in shellfish harvesting areas, one for mercury in fish tissue, and one for PCBs in fish tissue. All of these four listings were moved to Category 2 on the basis of new data that demonstrated water quality that met the applicable criterion.

In addition, there were seven other water quality listings removed from Category 4a (impaired, TMDL approved) and placed in Category 2 (meeting some standards). Four of these assessment records were tidal tributaries to the Chesapeake Bay that now meet the submerged aquatic vegetation (SAV)/water clarity criteria. The other three assessment records all relate to streams in the Casselman River watershed (Garrett County) where MDE recently (2013) implemented acid mine remediation projects. In all three cases, at Alexander, Spiker, and Tarkiln Run, MDE measured stream pH after the remediation project for a minimum of 3 years and found these streams to be consistently meeting Maryland's pH criteria range of 6.5 – 8.5. Management of these streams will still be ongoing to ensure that they continue to meet pH criteria moving forward.

There were also three partial removals of Category 4a (impaired, TMDL approved) listings on the 2018 Integrated Report. A partial Category 4a removal can occur in cases where an assessment unit that was previously entirely listed as impaired (with a TMDL established) had new data collected that demonstrated use support in some smaller geographic portion. In order to reflect this new information and the fact that a portion of the original water segment now meets standards, MDE may split the original assessment unit into two assessment units, one which is still impaired and another that is not. All of the three partial removals occurred in shellfish

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[2] Public comments received during the 2018 Integrated Reporting cycle concerning delistings that occurred on MDE's 2012 Integrated Report have been addressed above.

harvesting areas due to new data demonstrating that a portion of the water body now meets water quality criteria.

Maryland has demonstrated, to EPA's satisfaction, its rationale for these delistings.

E. Rationale for Maryland's decision not to list waters pursuant to 40 CFR 130.7(b)(1) because they are expected to meet water quality standards.

Maryland's decision not to include waters on its 2018 Section 303(d) list due to other required pollution controls is consistent with EPA regulations at 40 CFR 130.7(b)(1). These waters were identified in Category 4b of the Integrated Report. Under 40 CFR 130.7(b)(1), states are not required to list WQLSs still requiring TMDLs where effluent limitations required by the CWA, more stringent effluent limitations required by state or local authority, or other pollution control requirements required by state, local, or federal authority, are stringent enough to implement applicable WQS. The regulation does not specify the timeframe in which these various requirements must implement applicable WQS to support a state's decision not to list particular waters. EPA expects that required controls will result in attainment in a reasonable time, based on the nature of the pollutant and actions that need to be taken to achieve attainment.

Monitoring should be scheduled for these waters to verify that the water quality standard is attained as expected in a reasonable time frame. Where standards will not be attained through implementation of the requirements listed in 40 CFR 130.7(b)(1) in a reasonable time, it is appropriate for the water to be placed on the Section 303(d) list to ensure that implementation of the required controls, and progress towards compliance with applicable standards, is tracked. If it is determined that the water is, in fact, meeting applicable standards when the next Section 303(d) list is developed, it would be appropriate for the state to remove the water from the list at that time.

As indicated above, Maryland has several listings in Category 4b. All of these listing records still require more data collection and analysis to either confirm impairment or to demonstrate water quality standards attainment.

Consistent with a program of continuous assessment, EPA encourages MDE to continue efforts, including monitoring as appropriate, to provide updates on the status of the segments and to confirm that previous delistings remain supportable. As part of the Integrated Report, MDE would review the remainder of waters identified in Category 4b to determine whether the water quality standards are expected to be attained in a reasonable time or whether the waters need to be moved to Category 5. EPA recommends that MDE collect and analyze ambient water quality data as part of its analysis.

F. TMDL Priority Ranking and Targeting

MDE used the same priority ranking methodology used in previous lists. Documentation describing this prioritization was incorporated as part of Maryland's 2016 Integrated Report and can be accessed at http://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Pages/2016IR.aspx.

Within the Section 303(d) list, Maryland has provided both a priority ranking of high, medium, or low, and a separate indication for waters targeted for TMDL development in the next two years. In general, criteria that affect human health or have an extreme effect on natural resources are ranked high, criteria that indicate a continuing downward trend in the loss of a significant resource, create a serious nuisance, or constitute a significant loss of a natural resources are ranked as medium, and the remaining cases rank low.

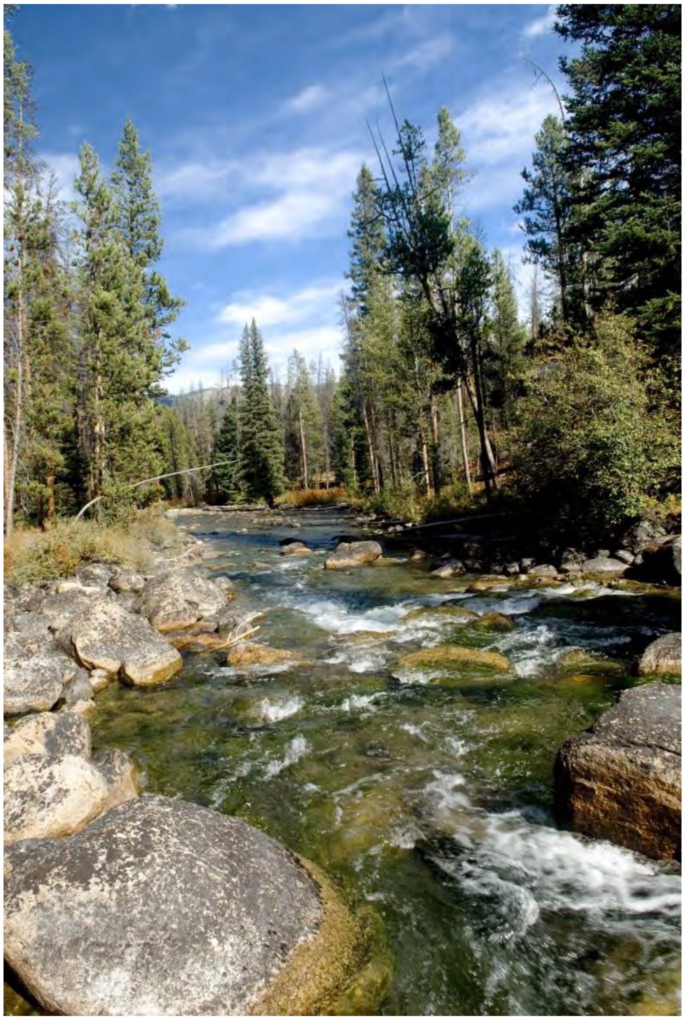
EPA concludes that MDE's TMDL prioritization plans are acceptable as the State properly took into account the severity of pollution and the uses to be made of such waters. Scheduling, however, takes into account additional considerations other than priority designations, such as programmatic consideration (e.g., efficient allocation of resources, basin planning cycles, coordination with other programs or states) and technical considerations (e.g., data availability, problem complexity, availability of technical tools). This is consistent with EPA guidance. In addition, EPA reviewed the State's identification of WQLSs targeted for TMDL development in the next two years (i.e., those targeted as a high priority), and agrees that the targeted waters are appropriate for TMDL development in this timeframe.

G. Consultation with Other Agencies

EPA sought review and comments from the U.S. Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) (collectively the Services) through a letter sent on March 5, 2018. This letter included website links to the draft 2018 Integrated Report. In reaching its conclusions on approving Maryland's 2018 303(d) list, EPA collected and appropriately considered information on the endangered and threatened species and their critical habitat in Maryland's waters identified by NMFS and FWS.

Attachment 3

Final EPA-USGS Technical Report: Protecting Aquatic Life from Effects of Hydrologic Alteration



EPA Report 822–R–16–007

USGS Scientific Investigations Report 2016–5164

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Cover. Redfish Lake Creek, Stanley, Idaho. (Photo by Daniel Hart, U.S. Environmental Protection Agency)

Final EPA-USGS Technical Report: Protecting Aquatic Life from Effects of Hydrologic Alteration

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Foreword

This report, developed collaboratively by the U.S. Environmental Protection Agency (EPA) and the U.S. Geological Survey (USGS), provides scientific and technical support for efforts by states and Tribes to advance the protection of aquatic life from the adverse effects of hydrologic alterations in streams and rivers. The report presents: a literature review of the natural flow regime and description of the potential effects of flow alteration on aquatic life (Section 4); examples of narrative criteria that some states have developed to support the natural flow regime and maintain healthy aquatic biota (Section 5); and a flexible, non-prescriptive framework that can be used by states, Tribes, and territories to quantify targets for flow regime components that are protective of aquatic life (Section 6).

This document is not a law or a regulation; nor does it change or substitute for any laws or regulations. This document does not impose legally binding requirements on the EPA, states, Tribes, or the regulatory community. Nor does this document confer legal rights or impose legal obligations on any member of the public.

The USGS and the EPA have made every effort to ensure the accuracy of the technical information in this document. Depending on individual circumstances, the general descriptions provided here may not apply to a given situation. Interested parties are free to raise questions and objections about the substance of this document and the appropriateness of the application of the information presented to a specific situation. This document does not make any judgment regarding any specific data collected or determinations made as part of a state or tribal water-quality program. State and tribal decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from the approaches described in this report.

The USGS, in accordance with its mission to collect and disseminate reliable, impartial, and timely scientific information that is needed to understand the Nation's water resources, collaborated with the EPA on Sections 1-4, 6, and Appendix B only.

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Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
meter (km)	3.2808	foot (ft)
kilometer (km)	0.6213	mile (mi)
	Area	
square meter (m^2)	0.00025	Acre
square kilometer (km^2)	0.3861	square mile (mi^2)
hectare (ha)	2.4710	Acre
	Volume	
cubic meter (m^3)	35.3147	cubic foot (ft^3)
cubic meter (m^3)	0.00026	million gallon (gal)
	Flow rate	
cubic meter per second per square kilometer [(m^3/s)/km^2]	91.47	cubic foot per second per square mile [(ft^3/s)/mi^2]
cubic meter per second (m^3/s)	22.8244	million gallons per day (Mgal/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F = (1.8 × °C) + 32.

Acronyms

Acronym/Abbreviation	Definition
CADDIS	Causal Analysis/Diagnosis Decision Information System
CFR	Code of Federal Regulations
CWA	Clean Water Act
ELOHA	Ecological Limits of Hydrologic Alteration
EPA	U.S. Environmental Protection Agency
ERA	Ecological Risk Assessment
GCM	General Circulation Model
GIS	Geographic Information System
HSP	Healthy Streams Partnership
IBI	Index of Biotic Integrity
IPCC	Intergovernmental Panel on Climate Change
MS4	Municipal Separate Storm Sewer System
NHD	National Hydrography Dataset
NID	National Inventory of Dams
NPDES	National Pollutant Discharge Elimination System
STORET	EPA Storage and Retrieval Data Warehouse
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Load
USGS	U.S. Geological Survey
WQS	Water Quality Standards

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1 Abstract

The natural flow regime of a water body, defined as its characteristic pattern of flow magnitude, timing, duration, frequency, and rate of change, plays a critical role in supporting the chemical, physical, and biological integrity of streams and rivers and the services they provide[1]. Human-induced alteration of the natural flow regime can degrade a stream's physical and chemical properties, leading to loss of aquatic life and reduced aquatic biodiversity. Protecting aquatic life from the effects of flow alteration involves maintaining multiple components of the flow regime within their typical range of variation. This report was developed[2] (1) to serve as a source of information for states, Tribes, and territories on the natural flow regime and potential effects of flow alteration on aquatic life and (2) to provide a flexible, nonprescriptive framework that can be used to quantify targets for flow regime components that are protective of aquatic life. As a supplementary resource, Appendix A was added to provide examples where states and Tribes have applied Clean Water Act (CWA) tools to protect aquatic life from altered flow.

Anthropogenic landscape change and water management activities are modifying flood flows, base flows, peak-flow timing, and other flow characteristics in streams and rivers throughout the United States. Under natural conditions, a stream's flow regime is determined by hydrologic properties at two scales, the upstream drainage area (catchment) and the local, reach scale. At the catchment scale, climate determines patterns of water and energy input over time, whereas physical characteristics like soils, geology, and topography

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[1] The objective of the Clean Water Act (CWA) is to "restore and maintain the chemical, physical and biological integrity of the Nation's waters" (Section 101(a)).

[2] The two sections of the CWA related to the development of the information presented in this report are CWA Sections 304(a)(2) and 304(f). CWA Section 304(a)(2) generally requires EPA to develop and publish information on the factors necessary to restore and maintain the chemical, physical, and biological integrity of navigable waters. Section 304(a)(2) also allows EPA to provide information on the conditions necessary for the protection and propagation of shellfish, fish, and wildlife in receiving waters and for allowing recreational activities in and on the water. CWA Section 304(f) requires EPA to issue information to control pollution resulting from, among other things, "changes in the movement, flow, or circulation of any navigable waters."

determine pathways, rates of runoff, and routing through the stream network. Reach-scale factors such as local groundwater dynamics further influence natural flow regime characteristics. Human activities that alter the natural flow regime also occur at both the catchment and reach scales and include impoundments, channelization, diversions, groundwater pumping, wastewater discharges, urban development, thermoelectric power generation, and agricultural practices. Many of these activities alter hydrologic processes like infiltration, groundwater recharge, channel storage, or routing and lead to flow conditions outside the natural range of variation. Others directly add or remove water from a stream such that flows are uncommonly high or low over long periods of time. Occurring in conjunction with these activities is climate change. Climate trends observed in recent decades and future projections (for example, rising ambient air temperatures, increasing frequency of heavy precipitation events, reductions in the thickness of snow pack and ice) may magnify the effects of other anthropogenic processes on the natural flow regime.

Alteration of the natural flow regime can have cascading effects on the physical, chemical, and biological properties of riverine ecosystems. Effects on physical properties include altered channel geomorphology (channel incision, widening, bed armoring, etc.), reduced (or augmented) riparian and flood-plain connectivity, and reduced (or augmented) longitudinal (upstream-downstream) and vertical (surface water/groundwater) connectivity. Effects on water quality can also result from altered flow magnitudes. For example, salinity, sedimentation, and water temperature can increase when flow volumes are reduced, whereas erosion and sediment transport can increase with amplified flow volumes. These changes to a stream can in turn lead to the degradation of aquatic life as a result of the loss and disconnection of high-quality habitat. Furthermore, altered flows can fail to provide the cues needed for aquatic species to complete their life cycles and can encourage the invasion and establishment of non-native aquatic species. The ability of a water body to support aquatic life is tied to the maintenance of key flow-regime components.

Efforts to implement strategies to protect aquatic life from flow alteration will be most effective if numeric targets are identified for flow-regime components that equate to intact and healthy aquatic communities. This report presents a flexible framework that can be used to quantify flow targets that incorporate U.S. Environmental Protection Agency Guidelines for Ecological Risk Assessment (ERA) and concepts from contemporary environmental flow literature. The framework consists of eight steps that begin with identifying biological goals and assessment endpoints and end with an evaluation of effects on aquatic life under varying degrees of flow alteration. The framework does not prescribe any particular analytical approach (for example, statistical or mechanistic modeling methodology), but rather focuses on the process and information needed to evaluate relations between flow and aquatic life and the development of narrative or numeric flow targets.

2 Introduction

Healthy aquatic ecosystems provide an array of services to individuals and society, including clean drinking water, irrigation supplies, and recreational opportunities (U.S. Environmental Protection Agency, 2012c). Sound and sustainable management of aquatic ecosystems is an integral part of managing water resources to meet the needs of society and the goals of the Clean Water Act (CWA; see Box A).

Box A. Goals of the Clean Water Act

In 1972, with the objective of protecting lakes, rivers, streams, estuaries, wetlands, coastal waters, oceans, and other water bodies, the U.S. Congress enacted the Clean Water Act (CWA). The overall objective of the CWA is to "restore and maintain the chemical, physical and biological integrity of the Nation’s waters" (Section 101(a)). In addition, the CWA establishes as an interim goal "water quality which provides for the protection and propagation of fish, shellfish and wildlife and provides for recreation in and on the water," wherever attainable (Section 101(a)(2)).

Freshwater aquatic ecosystems are the most altered ecosystems globally; they exhibit declines in biodiversity that far outpace those of terrestrial or marine ecosystems (Dudgeon and others, 2006; Strayer and Dudgeon, 2010). Although discharge of contaminants ranks as a top threat to aquatic biodiversity, other important sources of stress include urbanization, agriculture practices, and engineered structures used for water-resource development (Vörösmarty and others, 2010). These factors directly and indirectly alter the natural hydrology of a catchment and can have cascading effects on aquatic organisms (Poff and others, 1997). Today's water-resource managers face a common challenge: balancing the needs of a growing human population with the protection of natural hydrologic regimes to support aquatic life, ecosystem health, and services of crucial importance to society (Annear and others, 2004; Postel and Richter, 2003). Further complicating this challenge are expected changes to historic hydrologic conditions as a result of climate change, which add complexity to the task of estimating acceptable levels of hydrologic variation (Milly and others, 2008).

The natural flow regime, defined as the characteristic pattern of flow magnitude, timing, duration, frequency, and rate of change, plays a critical role in supporting the ecological integrity of streams and rivers and the services they provide (Figure 1). Human-induced alteration of the natural flow regime can degrade the physical, chemical, and biological properties of a water body (Annear and others, 2004; Bunn and Arthington, 2002; Naiman and others, 2002; Poff and others, 1997; Poff and Zimmerman, 2010; and many others). For example, an increase in the duration and frequency of high flows can degrade aquatic habitat through scouring and streambank erosion. More frequent low-flow conditions can degrade water quality through elevated concentrations of toxic contaminants resulting from decreased dilution, increased temperatures, or a decrease in dissolved-oxygen concentration. Lower flows can reduce sensitive taxa diversity and abundance, alter life cycles, cause mortality in aquatic life, and promote the expansion of invasive plants and animals (Bunn and Arthington, 2002; Poff and Zimmerman, 2010).

Hydrologic alteration (also referred to as "flow alteration" in this document) can be a primary contributor to the impairment of water bodies that are designated to support aquatic life. Addressing flow conditions can contribute to a comprehensive approach to managing and protecting water quality, improving aquatic restoration efforts, and maintaining designated and existing uses (for example, aquatic life, cold-water or warm-water fisheries, economically or recreationally important aquatic species). As the science of flow ecology has uncovered aquatic life needs across the full spectrum of the flow regime (base flows, high flows, etc.), water resource-managers are starting to recognize that protecting aquatic life from the adverse effects of flow alteration involves maintaining multiple components of the flow regime within their typical range of variation. This perspective requires an understanding of natural flow variability over space and time and the many ways in which biota respond to varied flow conditions.

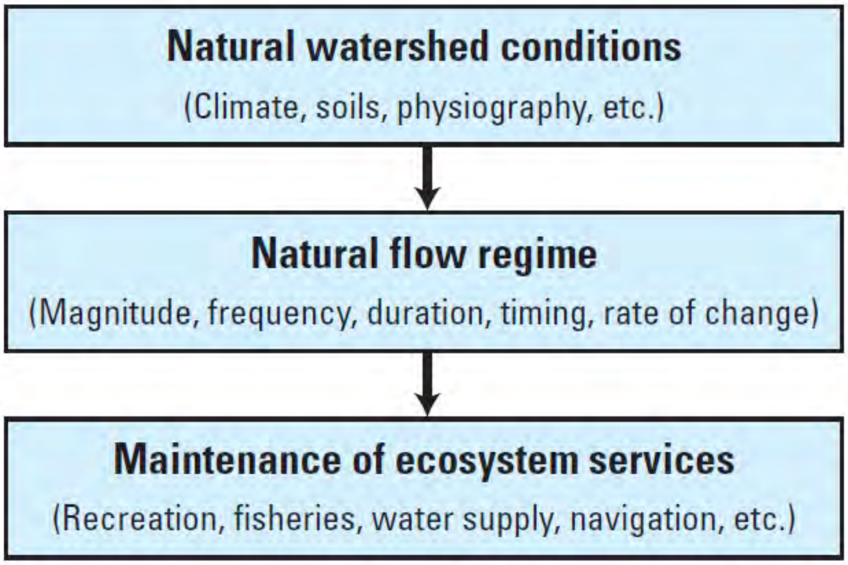

Figure 1. Schematic diagram depicting the interaction between the natural flow regime, natural watershed conditions and the many ecosystem services it helps to maintain.

3 Purpose, Scope, and Overview

3.1 Purpose and Scope

The purpose of this report is threefold. First, it describes the effects of flow alteration on aquatic life designated uses in streams, rivers, and other natural flowing water bodies. Second, it gives examples of states and Tribes that have narrative flow standards. Third, it provides a flexible, nonprescriptive framework that can be used to quantify flow targets to protect aquatic life from the effects associated with flow alteration. As a supplementary resource, Appendix A was added to provide examples where states and Tribes have applied CWA tools to protect aquatic life from altered flow. Non-flowing waters (lakes or wetlands, for example) and non-freshwater systems (estuaries, tidal waters) are not discussed in this report, nor are other designated uses such as recreation or drinking water, although they also can be affected by hydrologic alteration and can benefit from measures to maintain or restore hydrologic conditions.

This report was developed by the U.S. Environmental Protection Agency (EPA) in collaboration with the U.S. Geological Survey (USGS) in response to evidence that flow alteration has adversely affected the biological integrity of water bodies throughout the United States (Bunn and Arthington, 2002; Carlisle and others, 2010; Poff and Zimmerman, 2010). The information presented is drawn from the Guidelines for Ecological Risk Assessment (U.S. Environmental Protection Agency, 1998), relevant environmental flows literature (for example, Bunn and Arthington, 2002; Petts, 2009; Poff and Zimmerman, 2010), and the experience of states and Tribes that have adopted narrative flow criteria to protect aquatic life uses in their waters.

3.2 Overview

Section 4 is a summary of available scientific information about the effects of flow alteration on ecosystems, including the role of climate change, which can exacerbate the stresses that result from flow alteration. Section 5 provides examples of states and Tribes that have established narrative flow standards and Section 6 presents a flexible, nonprescriptive framework that can be used to quantify targets for flow regime components that are protective of aquatic life. Section 6 includes examples of quantification to support states, authorized Tribes, and territories (hereinafter, “states”) that wish to adopt flow criteria to protect aquatic life designated uses in their Water Quality Standard regulations. This section also describes the potential role of using narrative criteria as a tool to manage flow to restore and maintain aquatic ecosystems. Appendix A contains examples where states and Tribes have applied CWA tools to protect aquatic life from altered flow.

Climate change is one category among a range of stressors that is likely to increase the vulnerability of rivers and streams to flow alteration and affect the ecosystem services they provide (see Section 4.3.6). Given the inherent difficulties associated with climate change assessment, many natural-resource management agencies will likely encounter increasing challenges as they work to protect and restore the health of aquatic ecosystems. Appendix B provides examples of vulnerability assessments of freshwater aquatic life and environmental flows related to climate change.

3.3 Who Can Use This Information?

This report presents scientific information that can help water-resource managers improve the protection of flow for aquatic life uses. Additionally, it serves as a source of information for a broad stakeholder audience involved in water-resource management and aquatic life protection.

4 Effects of Altered Flow on Aquatic Life

This section describes the scientific principles of the natural flow regime, hydrologic alteration, and ecological responses to altered flows and presents a general conceptual model of the effects of flow alteration on aquatic life. Potential causes of various types of hydrologic change are outlined and pathways to degraded biological conditions are discussed.

4.1 Conceptual Model of the Biological Effects of Flow Alteration

In Ecological Risk Assessment (Box B, below), a conceptual model consists of a written description and diagram of the relations and pathways between human activities (sources), stressors, and direct and indirect effects on ecological entities (U.S. Environmental Protection Agency, 1998). A conceptual model links one or more stressors to ecological assessment endpoints that are important for achieving management goals. Under the CWA, management goals are established by states as designated uses of waters (for example, to support aquatic life) and criteria to protect those uses.

Box B. Ecological Risk Assessment

Ecological Risk Assessment (ERA) provides a framework for evaluating the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors (U.S. Environmental Protection Agency, 1998). It can apply to a range of environmental problems associated with chemical, physical, and biological stressors, including evaluating the risk posed to aquatic life by flow alteration. A key step in the first phase of the ERA process, problem formulation, is the development of a conceptual model that explicitly demonstrates the hypothesized relations between ecological entities and the stressors to which they may be exposed.

The flow alteration conceptual model (Figure 2) describes in a general way how various stressors can alter the natural flow regime, how flow alteration affects the chemical and physical conditions of an aquatic ecosystem, and how those changes may ultimately reduce the ability of a stream to support aquatic life. The general model is intended only to provide a foundation for detailed regional or catchment models; for a specific area, specific types of flow alteration and biological responses should be identified.

The general conceptual model of the biological effects of flow alteration presented in this report (Figure 2) is a broad framework relating hydrologic alteration and its sources to degraded aquatic life. The model is constructed around the following concepts and relations.

- A stream's natural flow regime is primarily a function of climate and physical catchment-scale properties, and is further affected by local, reach-scale conditions.
- The natural flow regime supports the integrity of aquatic life by maintaining habitat of sufficient size, character, diversity, and connectivity by supporting natural sediment, organic material, water temperature, and water chemistry regimes and by providing cues for spawning, migration, and other life-history strategies.
- A variety of human activities that change pathways and rates of runoff, modify channel storage and dimensions, or directly add water to or remove water from streams can alter the natural flow regime.
- Alteration of the natural flow regime leads to changes in water temperature and chemistry and (or) the physical properties of streams and adjacent riparian areas and flood plains. Feedback between altered flow and altered physical properties can further modify flow characteristics. Changes to stream chemical and physical condition following flow alteration can lead to the reduction, elimination, or disconnection of optimal habitat for aquatic biota.
- Biological responses to flow-mediated changes in stream chemistry and physical habitat can have cascading effects across trophic levels and aquatic communities, which may result in degraded aquatic life as determined by measures of effect (for example, survival, growth, and reproduction of aquatic biota).

The following sections describe the components of the general conceptual model. A detailed conceptual model of flow alteration with explicit directional relations is provided in Section 6.4. For detailed conceptual models developed for the EPA Causal Analysis/Diagnosis Decision Information System (CADDIS), see U.S. Environmental Protection Agency (2012a), https://www3.epa.gov/caddis/.

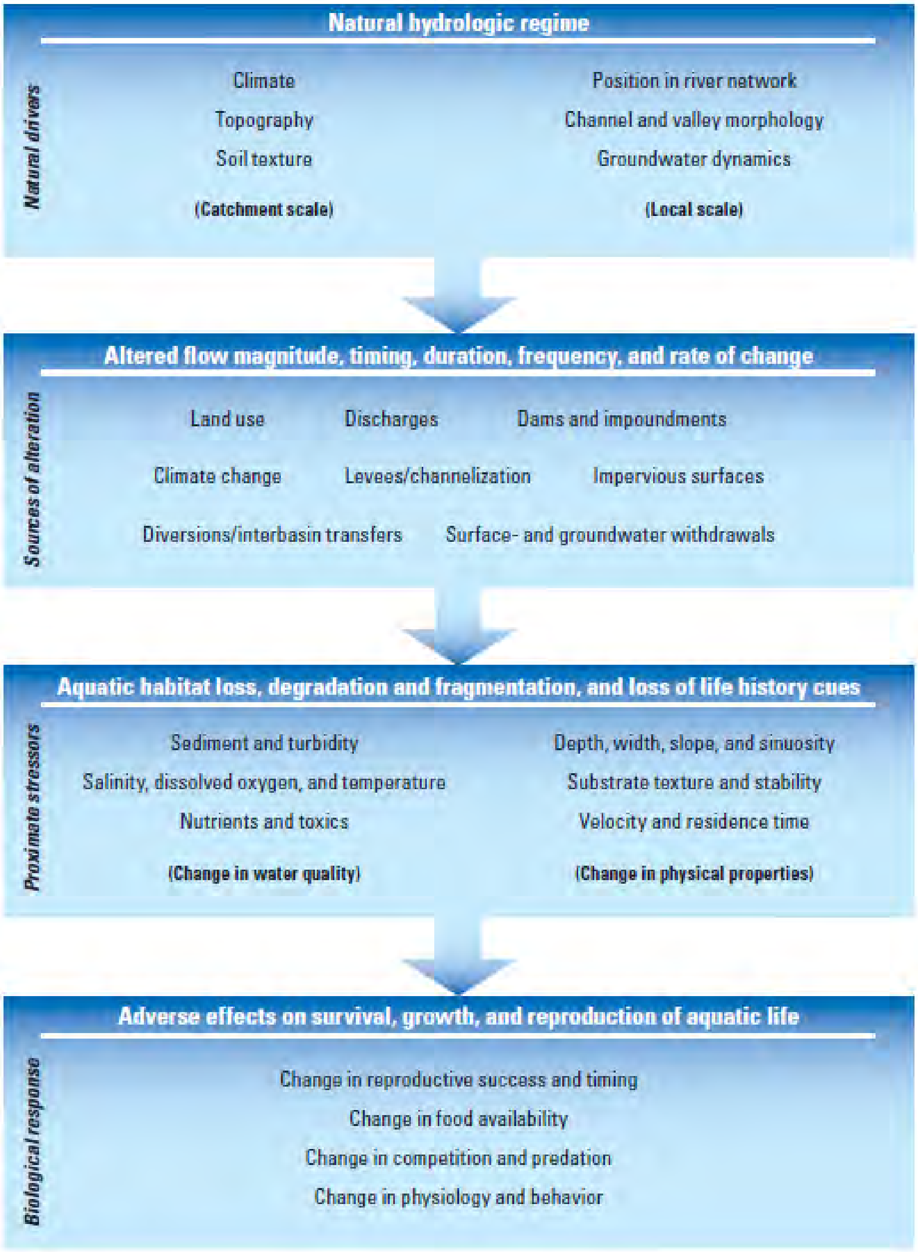

Figure 2. Schematic diagram illustrating a generalized conceptual model of the biological effects of flow alteration.

4.2 Drivers of the Natural Flow Regime

The natural flow regime is the characteristic pattern of flow in a stream under natural conditions. Poff and others (1997) present five components of the natural flow regime that are critical to aquatic ecosystems:

- the *magnitude* of flow over a given time interval (for example, average flow rate [reported in either cubic feet per second or cubic meters per second] during the month of April, or the spring season);
- the *frequency* with which flow is above or below a threshold value (for example, the number of times that flow exceeds the long-term average in one year);
- the *duration* of a flow condition over a given time interval (for example, the number days in a year during which the flow exceeds some value);
- the *timing* of a flow condition (for example, the date of the annual peak flow); and
- the *rate of change* of flow (for example, how rapidly flow increases during a storm event).

A stream's natural flow regime is largely a function of the climate and physical properties of its unique upstream drainage area (catchment[3]). Climate determines patterns of water and energy input over time, whereas physical catchment characteristics such as soils, geology, vegetation, and topography determine infiltration pathways (surface or subsurface) and rates of runoff and routing of streamflow through the drainage network. For example, a large proportion of rainfall in a catchment dominated by steep slopes and poorly-permeable soils will be converted to surface runoff that is quickly routed through the channel network. The flow regime of a stream in such a catchment would be characterized by high peak flows relative to average conditions, high rates of hydrologic change during and after storm events, and relatively low dry-

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[3] The term "catchment" throughout this report refers specifically to the unique drainage area upstream from a stream reach of interest. Although the term "watershed" also fits this definition, catchment is used in this report because managers use the term "watershed" to describe larger geographic or planning units within a state or region.

weather flows. In contrast, in a catchment dominated by well-drained soils and abundant natural vegetation, peak flows would more closely match average flows as a result of higher rates of infiltration and groundwater routing to the stream channel.

Although the natural flow regime is driven primarily by catchment-scale properties, flow characteristics are also affected by local-scale drivers specific to individual stream reaches and the location of the reach within the river network. Heterogeneity of local topography and geology, for example, can result in variable groundwater inputs among reaches with similar catchment-scale properties. Other potential local-scale drivers of the natural flow regime include channel morphology and riparian vegetation, although such characteristics are themselves affected by the flow regime.

4.3 Sources of Flow Alteration

The natural flow regime is driven by both catchment and local properties; human activities that alter the natural flow regime also occur at both of these scales. Changes to water quantity (flow volume) may result in loss of the designated use, such as when perennial streams or rivers are anthropogenically dewatered or intermittent streams are dewatered permanently or well beyond their natural variability. This section describes the major potential sources of flow alteration and their typical effects on the natural flow regime. Other sources of flow alteration (for example, artificial perennialization of intermittent streams [see Section 4.3.4]) may need to be considered depending on local or regional circumstances.

Recent assessments indicate that hydrologic alteration is pervasive in the Nation's streams and rivers. In a national assessment, the USGS found that human alteration of waterways has affected the magnitude of minimum and maximum streamflows in more than 86 percent of monitored streams (Carlisle and others, 2013). In addition, human-caused depletion of minimum and maximum flows was associated with a twofold increase in the likelihood of effects on fish and macroinvertebrate communities[4] (Carlisle and others, 2011). Sources of such effects may include groundwater and surface-water withdrawals, new and existing dams, impoundments and reservoirs, interbasin transfers, altered channel morphology, impervious cover, culverts, stream crossings and water diversions. Human adaptations to increased drought, including expansion of surface- and groundwater uses, may compound these effects by decreasing the magnitude of low flows and increasing the frequency and duration of low flows in streams and rivers. Alterations in high flows can affect use; for instance, an increase in impervious surface area may cause an increase in flow, resulting in deleterious alterations to habitat or the biological community. The following sections describe potential stressors in more detail.

4.3.1 Dams and Impoundments

Dams and impoundments (for example, reservoirs) are designed to control and store streamflow for various purposes and can provide multiple societal benefits through increased recreation opportunities, flood attenuation, hydroelectric power, irrigation, public water supply, and transportation (Collier and others, 1996). However, dams are also a cause of flow alteration throughout the United States, as only about 40 large rivers (defined as longer than 200 kilometers) remain free-flowing (Benke, 1990). At a national scale, when interregional flow variation before and after dam construction is compared, streams below dams can be subject to reduced high and low flows, augmented low flows, reduced seasonal variation, and other changes relative to predam conditions, resulting in a regional homogenization of the flow regime (Poff and others,

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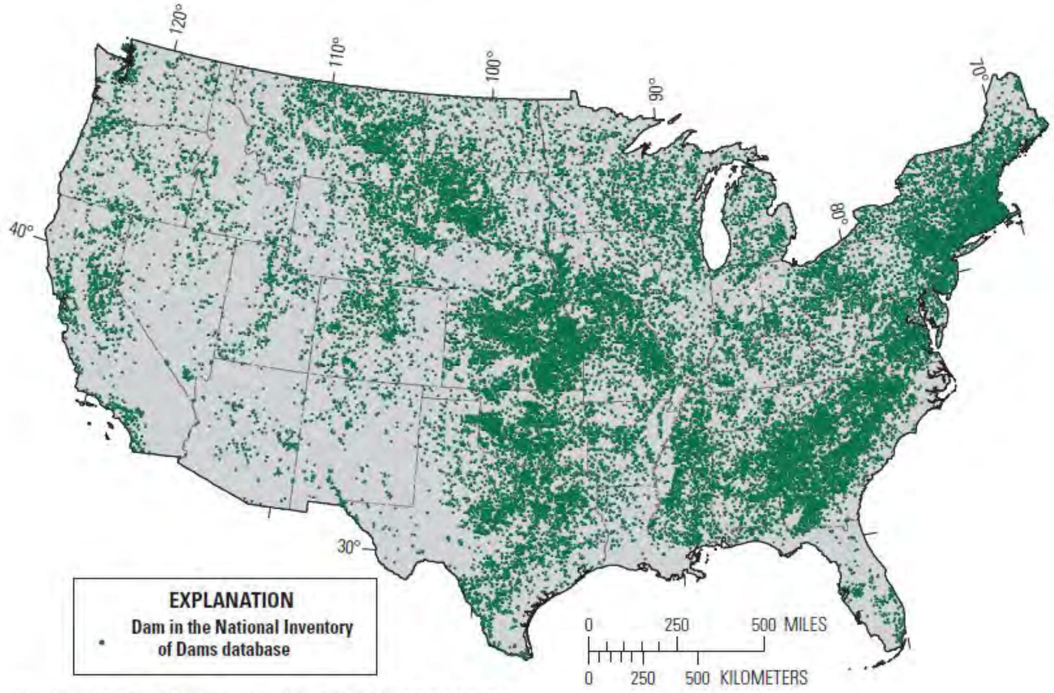
[4] Carlisle and others (2011) use the term “impairment” to describe this effect on the aquatic community, defining it as occurring when the value of the ratio of the observed condition to the expected reference condition (O/E) was less than that at 90 percent of reference sites within the same region. The aquatic community at a site was considered “unimpaired” when the O/E did not meet this condition. Although the term “impairment” is used in the original publication, the term “affected” is used for the purposes of this report to avoid confusion with the specific use of the term “impaired” in CWA programs.

2007). At a finer scale, however, within a more homogenous hydroclimatic region, dams can create new flow regimes (McManamay and others, 2012). The ecological costs of controlling natural flows can have wide-ranging effects on the chemical, physical, and biological integrity of streams and rivers (Collier and others, 1996; Dynesius and Nilsson, 1994; Magilligan and Nislow; 2005; Poff and others, 2007; Wang and others, 2011; Zimmerman and others, 2010). The various types of effects are highly dependent on dam purpose, size, and release operations (Poff and Hart, 2002).

As of 2013, more than 87,000 dams were represented in the U.S. National Inventory of Dams (NID) (U.S. Army Corps of Engineers, 2013). Not included in this total are small impoundments for farm ponds, fishing ponds, community amenities that fragment stream networks (for example, impoundments less than 2 meters [m] high), and larger dams that have not yet been included in the national database. New geographic information system (GIS) and remote-sensing tools are used to identify the extent and number of small impoundments, which may be in the tens of thousands per state. For example, a study in the Apalachicola-Chattahoochee-Flint River Basin in the southeastern United States identified the presence of more than 25,362 impoundments (Ignatius and Stallins, 2011), whereas the NID database recognized 1,415 (fewer than 6 percent of the reported total) in the same basin. The extensive presence of dams on United States waterways in the NID (U.S. Army Corps of Engineers, 2013) is shown in Figure 3. Estimates made by Poff and Hart (2002), identify more than 2,000,000 dams across the country, which includes small and large sized dams.

Studies have shown that dam reoperation (when operational guidelines for the dam are modified to address environmental management concerns about downstream fisheries, riparian habitats, recreation, flow, etc.) and removal of obsolete dams have the potential to restore ecological function downstream of dams (Watts and others, 2011). Although the ability to modify operations varies on the basis of the type and purpose of the dam (that is, hydropower, flood control, irrigation, etc.), virtually all dams, regardless of size, have the potential to be modified (Arthington, 2012). Since 2000, large-scale flow experiments have become an important component of water-management planning, with considerably more than 100 large-scale flow experiments documented worldwide, including 56 in the United States alone (Olden and others, 2014). Alterations to dam operations, including changes in the magnitude, frequency, and duration of high-flow events; changes to minimum releases; and alteration of reservoir drawdown regimes or restoration of flows to bypassed reaches; can result in ecological benefits, including recovery of fish and shellfish, improved water quality, reactivation of flood-plain storage, and suppression of non-native species (Konrad and others, 2011; Olden and others, 2014; Richter and Thomas, 2007; Poff and Schmidt, 2016; Kennedy and others, 2016.). Key components of successful dam reoperation include clearly articulating objectives and expectations prior to beginning reoperation, inclusion of a process to monitor or model the short -and long-term effects of proposed release operations, and the ability to adaptively manage the dam operations (Konrad and others, 2011; Richter and Thomas, 2007). Similar to the benefits noted for dam reoperation, restoration of stream and river flows through removal of obsolete dams may re-establish natural habitat connectivity for aquatic life, expose shoal and riffle habitat, restore water quality (for example, dissolved oxygen, pH, temperature and ammonia), and re-establish sediment transport dynamics and downstream sediment deposition (Poff and Hart, 2002; Kornis and others, 2015; Pess and others, 2014; Tuckerman and Zawiski, 2007).



Base from U.S. Census Bureau cartographic boundary file, 2013, 1:500,000
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Standard parallels 29°30′N and 45°30′N
Central meridian 96°00′W

Figure 3. Map showing dams in the conterminous United States listed in the National Inventory of Dams (NID) (U.S. Army Corps of Engineers, 2013).

The NID database contains the most comprehensive set of dam information in the United States and lists dams with at least one of the following criteria: high hazard classification, significant hazard classification, equals or exceeds 25 feet in height and exceeds 15 acre-feet in storage, and (or) equals or exceeds 6 feet in height and exceeds 50 acre-feet in storage.

4.3.2 Diversions

Diversions remove a specified volume of flow from a stream channel; direct diversions respond directly to demands for water, which are usually highest during the dry season, and storage diversions can transport water during any flow, often intended to be released at a later time for future water needs. Diversions include permanent or temporary structures and water pumps designed to divert water to ditches, canals, or storage structures; storage diversions are commonly coupled with reservoirs. Diverted waters are used for hydropower, irrigation, recreational, municipal, industrial, and other purposes. Permanent infrastructure to convey diverted waters (pipelines, canals, ditches, etc.) exists throughout the United States; a large number of these structures are found in certain areas of the country (Figure 4).

The effects of diversions on the flow regime depend on the quantity and timing of the diversion (for example, see Figure 5) (Bradford and Heinonen, 2008). Although the largest diversions by volume occur during storm events, a greater proportion of flow is generally removed during low-flow periods, when plants and wildlife are already under stress. Although diversions result in an immediate decrease in downstream flow magnitude, some of the diverted water may eventually return to the stream as irrigation return flow or point-source discharge (see Section 4.3.4). This is not the case, however, for interbasin water transfers, a distinct class of diversion in which water is transported out of one basin and used in another, affecting both donor and receiving streams. Regardless of the fate of the water, the quantity and timing of the diversion can alter the natural flow regime.

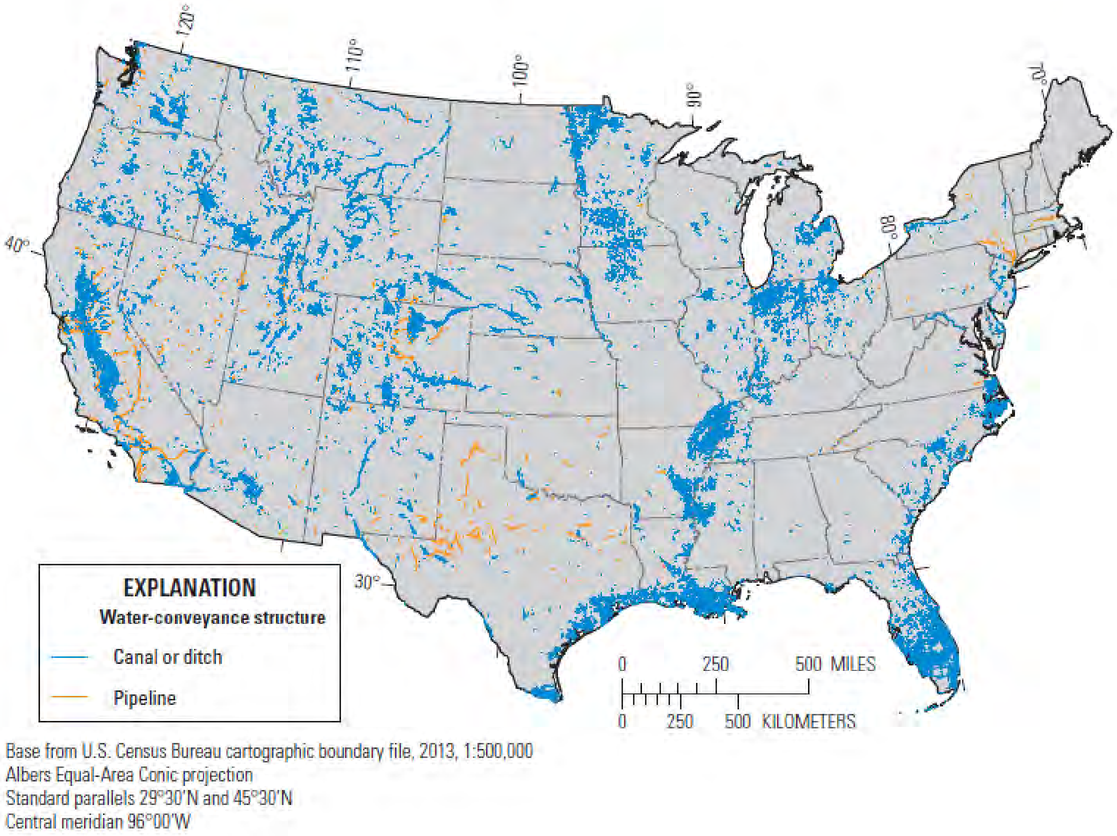

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Figure 4. Map showing location of water-conveyance structures in the medium-resolution National Hydrography Dataset (NHD) (U.S. Geological Survey, 2012), illustrating the widespread extent of canals, ditches, and pipelines in the conterminous United States.

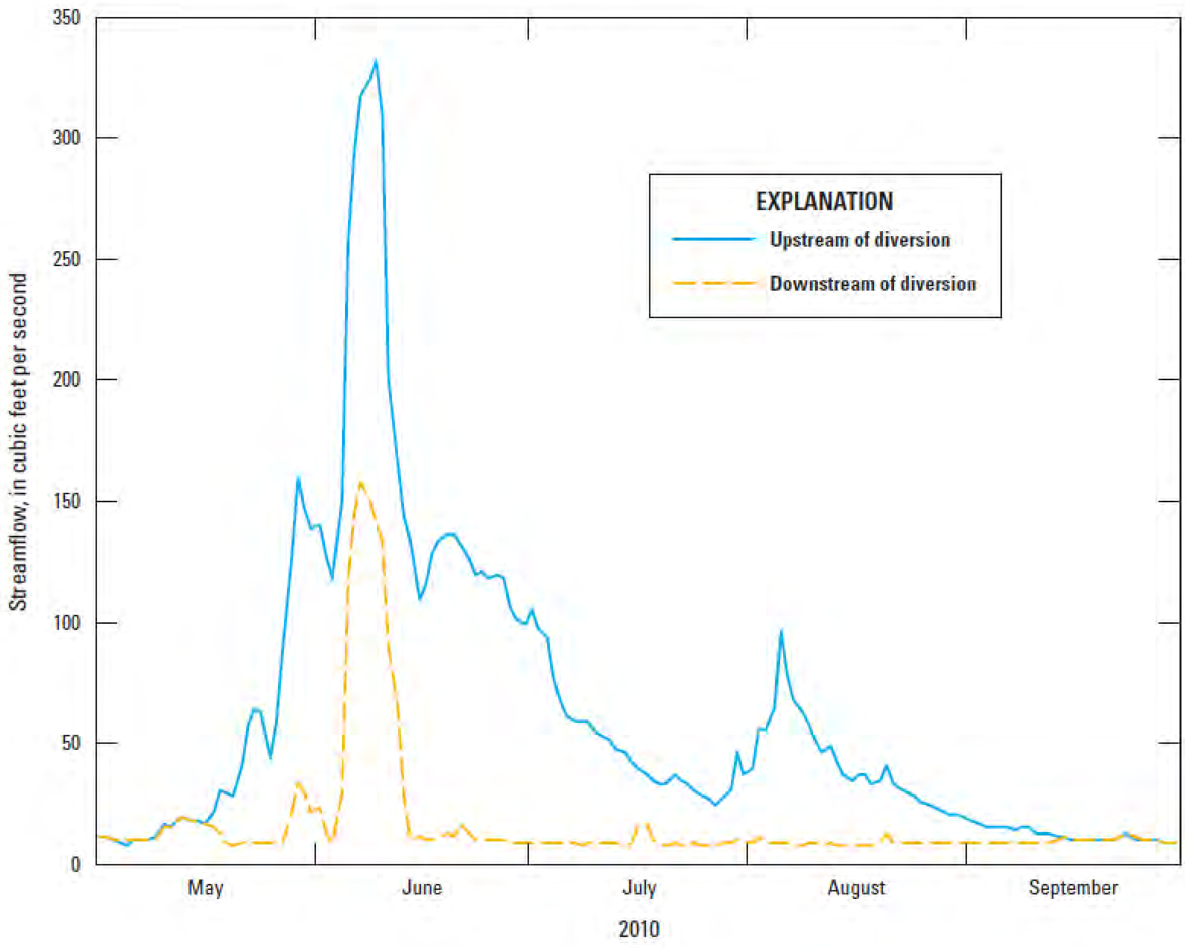


Figure 5. Graph showing streamflow at Halfmoon Creek, Colorado (U.S. Geological Survey station number 7083000), May–September, 2010.
(Streamgages are located upstream and immediately downstream from the diversion structure. Diverted water is stored in a nearby reservoir for irrigation.)

4.3.3 Groundwater Withdrawals

Most surface-water features interact with shallow groundwater, serving as points of discharge or recharge to local and regional aquifers. In many parts of the United States, groundwater contributes to streamflow and is the primary natural source of water during periods without substantial precipitation and runoff. Groundwater is also a major source of water for irrigation, public water supplies, industrial, and other uses (Maupin and others, 2014). Once thought to be limited to the arid West, groundwater depletion has been identified throughout the United States. The rate of groundwater depletion continues to increase and has been recognized globally as a threat to sustainability of water supplies (Konikow, 2013). Groundwater withdrawals can lower the water table, resulting in reduced discharge to streams (Barlow and Leake, 2012; Reeves and others, 2009; Winter and others, 1998; Zarriello and Ries, 2000; Zorn and others, 2008; Wahl and Tortorelli, 1997). In some cases, particularly where wells are located close to a stream, the water table can be lowered to such a degree that the hydraulic gradient at the stream-aquifer boundary is reversed, and streamflow is induced to flow into the aquifer (Barlow and Leake, 2012). Some of the important factors that affect the timing of groundwater-withdrawal impacts on streamflow are the distance of individual wells from streams, the hydraulic properties of the aquifer and streambed materials, and the timing of withdrawals (Barlow and Leake, 2012). Groundwater withdrawals for irrigation increase during drought, when the only source of streamflow may be base flows from groundwater. The ecological effects of reduced groundwater contributions to streamflow, like those of other reductions in stream base flows, include the desiccation of aquatic and riparian habitat, reduced velocities and increased sedimentation, increased water temperature, and reduced connectivity of the stream network (discussed in Sections 4.4 and 4.5). These effects are exacerbated by groundwater demand, which spikes at times of the year when adequate flows are needed to support important biological behaviors and processes (for example, in summer when certain fish migrate and reproduce). Wahl and Tortorelli (1997) provide an example of the long-term impacts on streamflow due to groundwater withdrawals in a basin in western Oklahoma.

4.3.4 Effluents and Other Artificial Inputs (Discharges)

In contrast to diversions, surface- and groundwater withdrawals, and other human activities that remove water from streams, effluents, and other artificial inputs add water to streams but can also alter natural flow patterns. Examples of discharges and other artificial inputs include industrial facilities, municipal wastewater-treatment facilities, tile drainage systems, agriculture return flows, pumping and drainage from stormwater control structures and others. The effects on streamflow from these additions are amplified when they consist of water that is not part of the natural water budget of the stream, such as deep groundwater or water derived from other basins, as in the case of interbasin transfers (Jackson and others, 2001). Such exogenous contributions shift the hydrograph upward and may be especially noticeable during natural low-flow periods as well as during flood flows resulting from storm events (Figure 6). This flow augmentation distorts the flow-sediment balance characteristic of undisturbed catchments, leading to effects such as channel downcutting and bank erosion as the stream strives to attain a new balance between water and sediment flux (as discussed in Section 4.4.1). In many arid environments, streamflow during dry seasons is composed almost entirely of treated effluent from wastewater-treatment facilities (Brooks and others, 2006). These inputs can cause a change in the stability of natural systems by artificially raising the water level during low-flow periods.

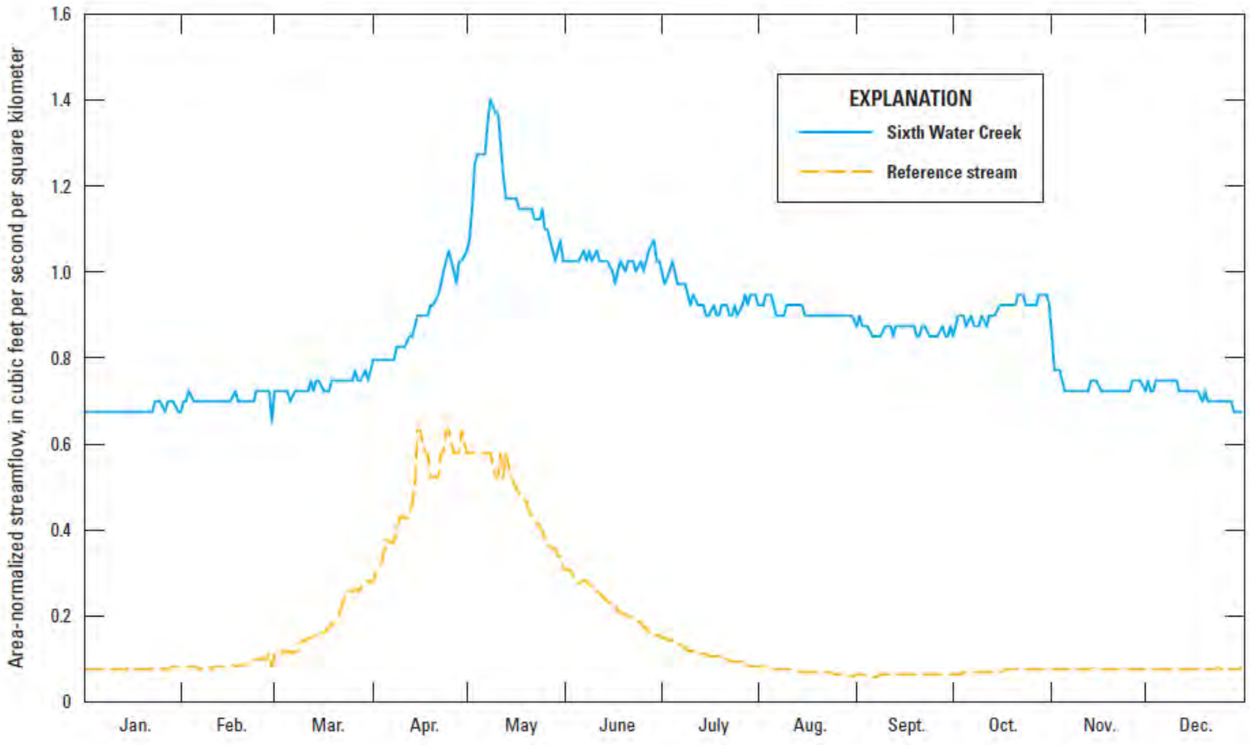


Figure 6. Graph showing artificially augmented daily streamflow at Sixth Water Creek, Utah (U.S. Geological Survey station number 10149000), January–December, 2000.

4.3.5 Land-Cover Alteration (Land Use)

The alteration of natural land cover for agricultural, forestry, industrial, mining, or urban use can modify several hydrologic processes that govern the amount and timing of runoff from the land surface, as well as other important processes and characteristics (for example, sediment dynamics, temperature). Such land-cover alterations may involve the removal of or change in vegetation cover, construction of impervious surfaces (for example, parking lots and rooftops), land grading, stream-channel alteration, or construction of engineered drainage systems. These changes reduce the potential for precipitation to be stored in shallow depressions and soils (Blann and others, 2009; Konrad and Booth, 2005) and allow a greater fraction of precipitation to enter stream channels through surface runoff, rather than infiltrate into the ground or evaporate. Moreover, engineered drainage systems (for example, municipal stormwater systems) and road networks can directly route runoff to receiving waters, increasing the rate of change to streamflow during a storm event. As a result, streams in developed areas exhibit extreme flashiness, characterized by a rapid rise in flow during storm events to a high peak-flow rate followed by rapid recession of flow after precipitation ceases (Dunne and Leopold, 1978; Walsh and others, 2005a, 2005b).

In addition, impervious surfaces may reduce base flow in the days, weeks, or even months after a storm event as a result of reduced infiltration and groundwater recharge. In agricultural areas, the opposite effect is observed with subsurface drainage structures (or tile drains), which discharge groundwater that would otherwise be held in storage or lost through evapotranspiration. However, agricultural drainage systems can reduce base flow, particularly when drainage lowers the water table and decreases groundwater recharge (Blann and others, 2009). During prolonged drought, differences in low-flow conditions between developed and natural streams generally are less pronounced than during average or high-flow conditions because developed areas tend to have a smaller effect on the deep groundwater recharge that supports flow during drought conditions than on the shallow groundwater and runoff that contribute water to a stream when precipitation is more plentiful (Konrad and Booth, 2005).

Urban and agricultural land uses can accompany water-use and management practices such as interbasin transfers, irrigation and other surface-water withdrawals, on-site wastewater disposal, impoundment, and groundwater pumping. Each of these practices affects the direction and magnitude of flow alteration in urban and agricultural streams and can compound hydrologic effects, as discussed previously.

The effects of mining on streamflow depend on the size and type of mining, subsidence of underground mines, catchment characteristics and vegetative cover, the geology of the mine and degree of valley fills, the extent of underground mine pools and sediment ponds, the amount of soil compaction and infiltration, and type and timing of reclamation. For example, valley fills resulting from surface mining have been found to increase peak flows, unless other transport pathways, such as substantial connections to underground mines, intercept the stormwater discharges to streams (Messinger, 2003).

Finally, other management activities can cause flow alteration. Improperly sized road stream crossings may cause flooding, erosion, and sedimentation modifying the flow regime (Hoffman and others, 2012). Timber harvesting in forested areas generally increases peak flows and base flows as a result of decreased evapotranspiration and increased snowpack resulting from decreased canopy interception (Harr and others, 1982; Hewlett and Hibbert, 1961). The magnitude and duration of the effects are dependent on the size and type of harvest and the rate of vegetation regeneration.

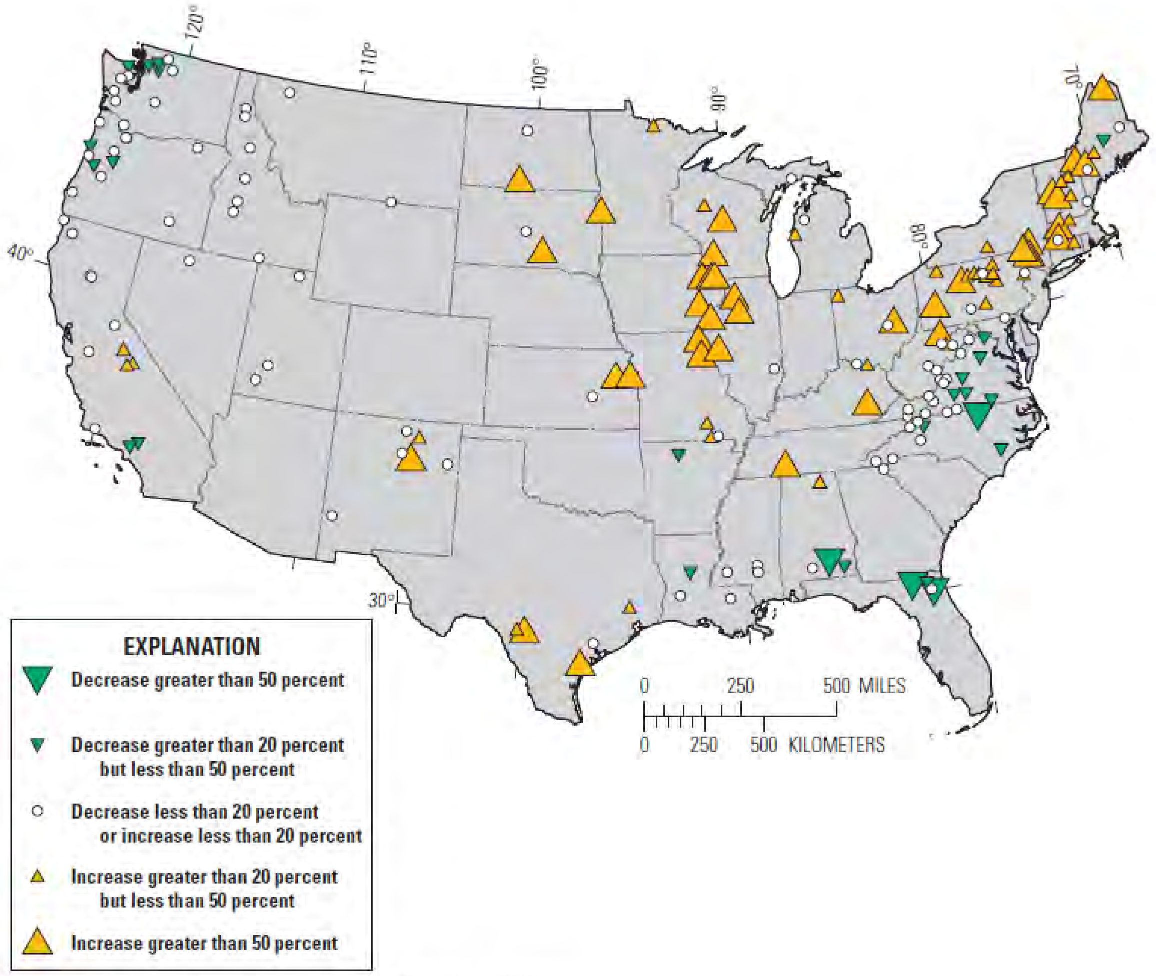
4.3.6 Climate Change

Climate change is an important and complex source of flow alteration because of the broad geographic extent of its effects and the lack of management options for direct mitigation at the watershed scale. Recent climate trends have included rising ambient air and water temperatures, increased frequency of extreme weather such as heavy precipitation events, increased intensity of droughts, altered fire regimes, longer growing seasons, and reductions in snow and ice, all of which are expected to continue in the coming years and decades (Karl and others, 2009). Some of these changes have occurred or are projected to occur throughout the United States, such as increases in the frequency of very heavy precipitation events during the 20th century (Melillo and others, 2014). Increasing terrestrial disturbances from climate change (for example more frequent wildfires, debris flows, biological invasions, and insect outbreaks) can alter terrestrial inputs to streams (for example hydrologic runoff, sediment, and large wood) thereby affecting the flow regime (Davis and others, 2013). Other changes have been or are projected to be limited to certain regions, such as a projected increase in winter and spring precipitation in the northern United States and a decrease in winter and spring precipitation in the southwestern United States (Melillo and others, 2014).

Each of these aspects of climate change can substantially alter historic flow patterns. Projected nationwide increases in the frequency of heavy storm events and summer droughts have the potential to result in more frequent flooding and extreme low flows in streams and rivers across the United States. Specific effects on streamflows, however, will vary by region on the basis of regional climate change and hydrologic regimes. For example, observed trends in the magnitude of 7-day low flows at streamgages with minimal landscape effects vary across the United States, with some regions exhibiting a trend of decreasing low flows (longer dry spells) and others trending toward higher low flows (Figure 7) (U.S. Environmental Protection Agency, 2014b). Anthropogenic alterations that reduce streamflow may be further exacerbated by this climate-change trend. In areas where flow regimes are strongly affected by snowmelt, observations show a trend toward earlier timing of spring high flows (Figure 8) that corresponds to declines in the spring snowpack and earlier snowmelt (Melillo and others, 2014). These examples demonstrate the exposure of aquatic ecosystems to climate-driven flow alteration. Exposure analysis is an essential part of an assessment of the vulnerability of aquatic life to climate change. Additional discussion and examples of climate-change vulnerability assessments related to altered flow and aquatic life are included in Appendix B.

Climate change is occurring in conjunction with other anthropogenic stressors related to population increase and land-use change and may magnify the hydrologic and biological effects of those existing stressors (Intergovernmental Panel on Climate Change, 2007; Karl and others, 2009; Kundzewicz and others, 2008; Palmer and others, 2009; Pittock and Finlayson, 2011). For example, the combination of earlier spring snowmelt and increased water withdrawals can reduce summer flows to levels that would not otherwise occur in response to either stressor alone and that reduce the survival of aquatic biota. An additional example is the compounding effect of increased storm intensity on flood frequency in areas where impervious cover already drives flood flows at a frequency that degrades stream habitat (Intergovernmental Panel on Climate Change, 2007). These and other changes to the flow regime may further benefit invasive species to the detriment of native species (Rahel and Olden, 2008).

Adaptive capacity, or the ability of a stream ecosystem to withstand climate-driven stresses, may be seen in rivers whose flow patterns more closely resemble the natural flow regime. These rivers may be buffered from the harmful effects of climate-related disturbances on aquatic life (Palmer, 2009; Pittock and Finlayson, 2011). Understanding and enhancing adaptive capacity, along with an assessment of climate-change vulnerability, is a key part of climate-change adaptation planning.



Base from U.S. Census Bureau cartographic boundary file, 2013, 1:500,000
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Figure 7. Map showing trends in the magnitude of 7-day low streamflows in the United States, 1940-2009.

(Minimum streamflow is based on data from 193 long-term U.S. Geological Survey streamgages over the 70-year period whose drainage basins are only minimally affected by changes in land use and water use. Modified from U.S. Environmental Protection Agency, 2014b)

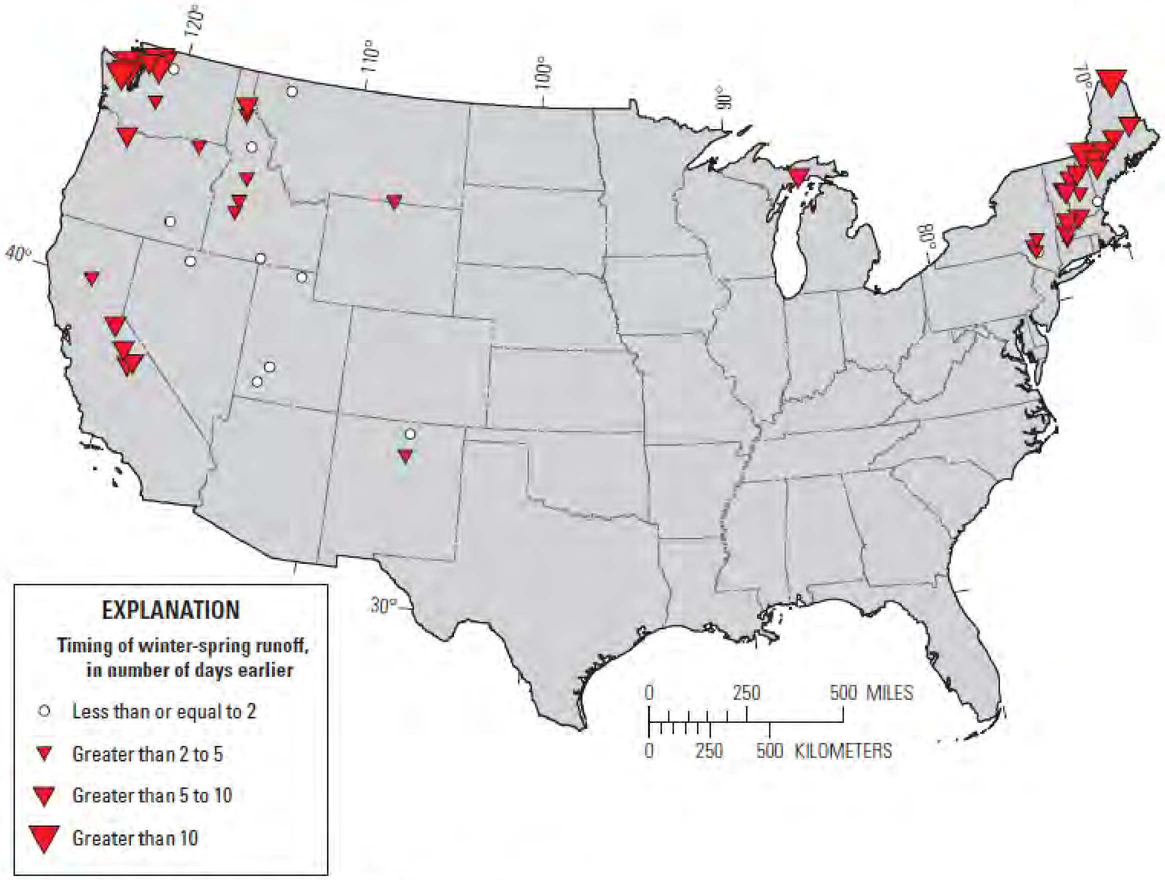

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Figure 8. Map showing trends in the timing of winter-spring runoff in the United States, 1940-2009.

(Streamflow trends are based on data from 193 long-term U.S. Geological Survey streamgages over the 70-year period whose drainage basins are only minimally affected by changes in land use and water use. Modified from U.S. Environmental Protection Agency, 2014b).

4.4 Physical and Chemical Effects of Flow Alteration

Changes to the natural flow regime resulting from land-use and water-management practices can affect physical and chemical properties of riverine ecosystems, including geomorphology, connectivity, and water quality (Annear and others, 2004). This section provides an overview of the effects of flow alteration on each of these properties.

4.4.1 Effects on Geomorphology

The natural geomorphology of stream channels and flood plains is shaped largely by watershed hydrology and resulting flow patterns. Geomorphology is the expression of the balance between flow strength (for example, flow magnitude, slope) and flow resistance and sediment supply (for example, grain size, vegetation, sediment load), with a tendency toward channel erosion and degradation when flow strength increases and a tendency toward channel deposition and aggradation when flow resistance and sediment supply increase. Channel geometry, bed substrate, and the presence of geomorphic features such as oxbow lakes, point bars, or riffle-pool sequences vary according to the frequency of bankfull flows, the magnitude of floods, and other flow characteristics (Trush and others, 2000). Research has uncovered a variety of geomorphic responses to flow alteration, with specific effects depending on the type and severity of hydrologic change. These effects can include channel incision, narrowing, or widening; increased deposition of fine sediment or bed armoring (coarsening of the surface of gravel bed rivers relative to the subsurface); and reduced channel migration (Poff and others, 1997).

A primary mechanism for geomorphic change is a shift in energy and sediment dynamics following flow alteration. For example, increased peak flows resulting from urban land use can increase bed erosion and drive channel incision or widening. In contrast, reduced flooding as a result of dam regulation can lower the distribution of nutrient-bearing sediments to flood plains, starve downstream channel and coastal areas of needed sediment, and increase sedimentation upstream from the dam (Syvitski and others, 2005). These processes can lead to simplified channels that are disconnected from their natural flood plains. Natural mosaics of geomorphic features serve as important habitats for a range of aquatic and flood-plain species, and the loss of habitat diversity following hydrologic alteration can have adverse effects on the health of biological communities.

4.4.2 Effects on Connectivity

Hydrologic connectivity is the water-mediated transfer of matter, energy, and (or) organisms within or between elements of a hydrologic system (Pringle, 2003). In aquatic ecosystems, it encompasses longitudinal connectivity of the stream network and specific habitat types, as well as lateral connectivity among stream channels, riparian zones, flood plains, and wetlands. The vertical connection between surface water and groundwater is a third dimension of connectivity along the various flow paths that connect points of recharge (beginning at the water table) to points of discharge (for example, a river or stream) (Ward, 1989).

Longitudinal, lateral, and vertical connectivity naturally vary spatially and temporally with climate, geomorphology, groundwater dynamics, and other factors. Longitudinal connectivity, for example, may be continuous from headwaters to lower reaches in one catchment but interrupted by intermittent or ephemeral reaches in another (Larned and others, 2010a, 2010b, 2011). Lateral connectivity is restricted to short-duration flooding of narrow riparian areas in headwater reaches, whereas meandering and braided lower reaches are subject to longer periods of inundation over broader flood plains (Ward and Stanford, 1995). Aquatic biota have adapted to connectivity patterns through space and time, with life-history traits such as migration and spawning closely linked to the timing, frequency, and duration of upstream-downstream and channel/flood-plain connections (Junk and others, 1986; U.S. Environmental Protection Agency, 2015).

Hydrologic alteration can affect connectivity in several ways. Longitudinal connectivity of the stream network is disrupted by dams, weirs, diversions, culverts, stream crossings and other manmade structures that obstruct upstream-downstream passage by fish and other organisms. For instance, culverts can affect the movement of fish species during critical life stages due to outlet drops, increased velocity or reduced flows (Diebel and others, 2015). Longitudinal connectivity is also disrupted by fragmentation of aquatic habitat without manmade barriers. For example, an increase in the frequency of zero-flow conditions in a stream reach as a result of water withdrawals can cause the disconnection of upstream areas from the rest of the stream network (U.S. Environmental Protection Agency, 2015). Lateral connectivity among the stream channel, riparian areas, flood plains, and wetlands is reduced as a result of the decreased frequency of high flows and floods caused by geomorphic change (for example, channel incision) or of direct modification of stream channels (channelization, levee construction, etc.). Vertical connectivity is altered directly and indirectly through practices that alter infiltration and runoff (for example, impervious surface), which can affect recharge to groundwater and outflow to surface water. Other activities (for example, drainage) can alter surface-runoff rates and potentially reduce recharge and contribute to flooding. Other practices may cause a rise in the water table and, subsequently, the base level of a stream (for example, reservoirs) (Winter and others, 1998). For systems characterized by an absence of connectivity, flow alterations such as stream channelization, irrigation, and impervious surface area can increase flashiness and increase connectivity (U.S. Environmental Protection Agency, 2015).

4.4.3 Effects on Water Temperature and Chemistry

The water quality effects of flow alteration are varied and can include changes in water temperature, salinity (which is measured by specific conductance), dissolved-oxygen concentration, pH, nutrient concentrations, and other parameters. For example, dilution of dissolved salts or toxic contaminants are reduced because of a decrease in flow magnitude when water is diverted or groundwater is pumped (Caruso, 2002; Olden and Naiman, 2010; Sheng and Devere, 2005). Stream temperature is also closely linked to flow magnitude (Cassie, 2006; Gu and Li, 2002; Wehrly and others, 2006); artificially low flows can result in increased water temperatures as a result of reduced depths and (or) reduced input of cool groundwater. Low flows also increase the likelihood of stagnant water with a low dissolved-oxygen concentration. In contrast, dam tailwaters can become supersaturated with gases and harm aquatic life (Weitkamp and Katz, 1980). Additionally, dam tailwaters, particularly those drawing water from the depths of stratified reservoirs, show elevated levels of nutrients and metals, low dissolved-oxygen concentrations, and altered temperature relative to downstream waters (Arnwine, 2006; De Jalon and others, 1994; McCartney, 2009; Olden and Naiman, 2010; Poff and Hart, 2002; Preece and Jones, 2002; Sherman and others, 2007; Vörösmarty and others, 2003). Thermal regime modifications can include an increase in temperatures when warm water is released from the reservoir surface (common in smaller dams and diversions), or lower temperatures when water is released from beneath a reservoir's thermocline (Olden and Naiman, 2010). In urban areas, stream temperatures are elevated during high-flow conditions (constituting an increase in the rate of change) as a result of the input of runoff that has come in contact with warm impervious surfaces. Moreover, runoff from developed lands can transport nutrients, organic matter, sediment, bacteria, metals, and other contaminants to streams (Grimm and others, 2005; Hatt and others, 2004; Morgan and Good, 1988; Mulholland and others, 2008; Paul and Meyer, 2001). Effects may differ among water-body types (for example, lentic and lotic waters).

4.5 Biological Responses to Flow Alteration

The combined physical and chemical effects of flow alteration (summarized in the previous section) may result in the degradation, loss, and disconnection of ecological integrity within a stream system. Moreover, flow modification can eliminate hydrologic cues needed to stimulate spawning or flow volume and timing needed to aid seed dispersal, resulting in a mismatch between flow and species' life-history needs, and can encourage the invasion and establishment of non-native species (Bunn and Arthington, 2002). The ability of a water body to support healthy aquatic life is therefore tied to the maintenance of key flow-regime components.

Specific biological effects of a given type of flow alteration vary by location and degree of alteration; however, some generalities can be made. Literature summarizing biological responses to altered flows, compiled and reviewed by Bunn and Arthington (2002) and Poff and Zimmerman (2010), includes studies showing overall reductions in the abundance and diversity of fish and macroinvertebrates, excessive growth of aquatic macrophytes, reduced growth of riparian vegetation, and shifts in aquatic and riparian species composition. Similarly, a meta-analysis of research in the South Atlantic United States noted consistently negative ecological responses to anthropogenically induced flow alterations, with fish tending to respond negatively and algae positively, while macroinvertebrates and riparian vegetation often responded negatively, but were more inconsistent (McManamay and others, 2013). These changes are tied to altered habitat. For example, the stabilization of flow downstream of dams tends to reduce habitat diversity and, therefore, species diversity. Reduced longitudinal connectivity of habitat types can reduce the survival of migratory fish species, and reduced lateral connectivity between stream channels and flood-plain wetlands limits access to important reproduction and feeding areas, refugia, and rearing habitat for native and resident fishes. Reduced lateral connectivity can reduce the availability of habitat needed for aquatic life stages of macroinvertebrates and amphibians, and can reduce the potential for gene flow (mixing individuals from different locations). Altered flows may disrupt the cues needed for gametogenesis and spawning and result in loss of habitat occurring during all life stages of freshwater mollusks. Fish spawning is disrupted by changes to the natural seasonal pattern of flow. For some fish species, spawning is triggered by rising flows in the spring; therefore, a shift in the timing of high flows can result in aseasonal reproduction during periods when conditions for larval survival are suboptimal. In addition, changes in species abundance and richness, ecosystem functions such as contaminant removal and nutrient cycling rates, can degrade in the environment due to flow alteration (Palmer and Febria, 2012; Poff and others, 1997; Vaugh and Taylor, 1999).

The relations among variables such as flow, temperature, habitat features, and biology are key in controlling species distribution (for example, Zorn and others, 2008). Water temperature is an associated hydrologic characteristic and has a particularly strong effect on aquatic organisms in summer months, when streamflows are lowest and temperatures are highest (Brett, 1979; Elliot, 1981; Wehrly and others, 2003). Increases in water temperature that result from alterations such as withdrawals, especially during critical summer low-flow periods, have detrimental biological effects. Dam operations can have diverse effects on biology through modifying the thermal regime, and these modifications depend on the size, purpose, and release operations of the dam. For example, depressed spring and summer temperatures due to dam releases from the deep, cool layer in a stratified reservoir, may result in delayed or reduced spawning of fish species or extirpation of native warm-water biological communities in favor of cool- and cold-water assemblages (Olden, 2006; Preece and Jones, 2002). Dam releases in the winter result in warmer water temperatures, which may eliminate developmental cues and increase growth, leading to earlier aquatic insect emergence. These changes in temperature can create a mismatch between life-history stages and environmental conditions that may increase mortality as a result of high-flow events, predation, reduction in resource availability earlier in the season, and other stresses (Olden and Naiman, 2010; Vannote and others, 1980; Ward and Stanford, 1982).

The result of these hydrologic alterations may be impairment of a water body due to the physical, chemical, or biological effects discussed above. The most severe of alterations, the complete dewatering of a perennial stream or river, will result in complete extirpation of aquatic species in those water bodies. In addition to directly contributing to impairments through ecologically deleterious physical changes (that is, hydrologic, geomorphic, and connectivity change), hydrologic alteration may also be the underlying source of other impairments such as low dissolved oxygen, modified thermal regimes, increased concentrations of sediment, anoxic byproducts (such as downstream of dams), and nutrients or toxic contaminants. While the focus of this report is primarily on those direct physical factors (for example, geomorphic and hydrologic) that can affect biological communities, addressing these hydrologic alterations may also help to mitigate the effects of contaminants such as those mentioned above.

5 Examples of States that have Adopted Narrative Flow Standards

This section provides examples of states and Tribes that have used the CWA tools to address the effects of altered flows on aquatic life. Figure 9 illustrates how water-quality management programs are based on Water Quality Standards (WQS) under the CWA.

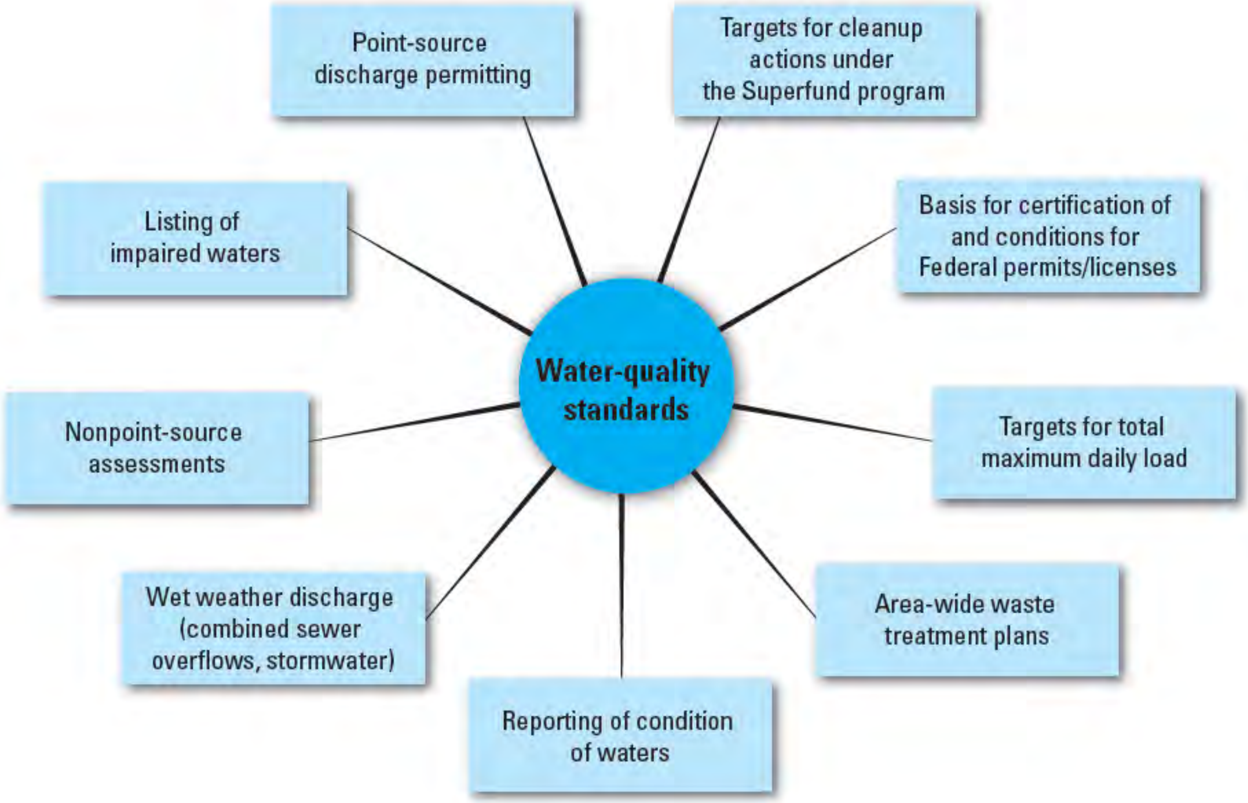

Figure 9. Schematic diagram illustrating environmental management programs utilizing water quality standards developed under the Clean Water Act.

5.1 Narrative Criteria in State and Tribal Water Quality Standards

One set of CWA tools that some states and Tribes have used to address the effects of hydrologic alteration on aquatic life is water quality standards (WQS), which include designated uses, criteria, and antidegradation requirements. The goals and provisions of the CWA and corresponding EPA regulations provide for states to adopt narrative and (or) numeric chemical-specific criteria, as well as criteria that address the physical and biological integrity of the Nation’s waters (see CWA sections 101 and 303(c); see also Title 40 of the Code of Federal Regulations (40 CFR) part 131.11(b)). Table 1 of this section presents examples of narrative flow criteria that some states and Tribes have developed.

Table 1. Examples of states and Tribes that have adopted narrative flow criteria for the protection of aquatic life.

[Key terms are shown in bold for emphasis; see U.S. Environmental Protection Agency (2014e) for complete text of individual criteria; %, percent; 7Q10, the 7-day, 10-year annual low-flow statistic; WMT, Water Management Type]

State/Tribe	Water Quality Standard description of protected resource and corresponding goal
Kentucky	Section 4. "Aquatic Life. (1) Warm water aquatic habitat. The following parameters and associated criteria shall apply for the protection of productive warm water aquatic communities, fowl, animal wildlife, arboreous growth, agricultural, and industrial uses:…(c) Flow shall not be altered to a degree which will adversely affect the aquatic community."
Missouri	"Waters shall be free from physical, chemical, or **hydrologic changes** that would impair the natural biological community."
New Hampshire	"**surface water quantity** shall be maintained at levels adequate to protect **existing and designated uses**" "These rules shall apply to any person who causes point or nonpoint source discharge(s) of pollutants to surface waters, or who undertakes hydrologic modifications, such as dam construction or water withdrawals, or who undertakes any other activity that affects the beneficial uses or the level of water quality of surface waters."
New York	Classes N and AA-special fresh surface waters … "There shall be **no alteration to flow** that will impair the waters for their **best usages**." Classes AA, A, B, C, D, and A-special waters…."**No alteration** that will impair the waters for their **best usages**."
Rhode Island	"**quantity** for protection of… **fish and wildlife**…adequate to protect **designated uses**" "For activities that will likely cause or contribute to flow alterations, streamflow conditions must be adequate to support **existing and designated uses.**"
Tennessee	Rule 0400-40-03-.03, Criteria for Water Uses: Section (3) The criteria for the use of Fish and Aquatic Life are the following, subsection (n) Habitat—"The quality of stream habitat shall provide for the development of a **diverse aquatic community** that meets regionally-based biological integrity goals. Types of habitat loss include, but are not limited to: channel and substrate alterations….stream **flow** changes….for wadeable streams, the instream habitat within each subecoregion shall be generally similar to that found at **reference streams**. However, streams shall not be assessed as impacted by habitat loss if it

State/Tribe	Water Quality Standard description of protected resource and corresponding goal
	has been demonstrated that the biological integrity goal has been met." Subsection (o) Flow—"Stream or other waterbody **flows shall support the fish and aquatic life criteria**." "Section (4) The criteria for the use of Recreation are the following: Subsection (m) Flow—Stream **flows** shall support **recreational uses."**
Vermont	Class A(1)—"Changes from **natural flow regime** shall not cause the natural flow regime to be diminished, in aggregate, by more than 5% of 7Q10 at any time;" Class B WMT 1 Waters—"Changes from the **natural flow regime**, in aggregate, shall not result in **natural flows** being diminished by more than a minimal amount provided that **all uses** are fully supported; and when flows are equal to or less than 7Q10, by not more than 5% of 7Q10." Class A(2) Waters and Class B Waters other than WMT1—"Any change from the **natural flow regime** shall provide for maintenance of flow characteristics that ensure the **full support of uses** and comply with the applicable water quality criteria."
Virginia	"**Man-made alterations in stream flow** shall not contravene designated uses including protection of the propagation and growth of **aquatic life**."
Bad River Band of the Lake Superior Tribe of Chippewa Indians	"**Water quantity** and quality that may limit the growth and propagation of, or otherwise cause or contribute to an adverse effect to wild rice, wildlife, and other flora and fauna of cultural importance to the Tribe shall be prohibited." "**Natural hydrological conditions** supportive of the **natural biological community**, including all flora and fauna, and physical characteristics naturally present in the waterbody shall be protected to prevent any adverse effects." "Pollutants or human-induced changes to Tribal waters, the sediments of Tribal waters, or area hydrology that results in changes to the natural biological communities and wildlife habitat shall be prohibited. The migration of fish and other aquatic biota normally present shall not be hindered. **Natural daily and seasonal fluctuations of flow** (including naturally occurring seiche), level, stage, dissolved oxygen, pH, and temperature shall be maintained."
Seminole Tribe	"Class 2-A waters shall be free from activities....that....impair the **biological community** as it naturally occurs....due to....**hydrologic changes.**"

State/Tribe	Water Quality Standard description of protected resource and corresponding goal
of Florida	

Table 1 demonstrates that narrative flow criteria are written in various ways. However, the language commonly addresses two general components: (1) a description of the resource or attribute to be protected and (or) protection goal; and (2) one or more statements describing the hydrologic condition needed to be maintained to achieve the protection goal. The resource to be protected generally is an explicit reference to aquatic life designated uses or general language that targets the protection of a suite of designated and (or) existing uses (for example, “propagation and growth of aquatic life,” “biological community as it naturally occurs,” “diverse aquatic community,” etc.). For most existing narrative flow criteria, the flow condition to be maintained is written in general terms (for example, “There shall be no alteration to flow....,” “natural daily and seasonal fluctuations in flow,” etc.). The addition of language that references specific aquatic life endpoints, such as migration or other life-cycle events, may serve as important reminders of biological goals to guide the selection of assessment endpoints, measures of effect (biological and flow indicators), and flow targets to meet aquatic life needs taking into account both near-field and downstream impacts. These concepts are discussed in detail in Section 6.

More complete examples from New Hampshire and Rhode Island narrative flow criteria are as follows and illustrate additional attributes these states chose to emphasize, such as broad applicability across all surface waters:

“Unless flows are caused by naturally occurring conditions, surface water quantity shall be maintained at levels adequate to protect existing and designated uses.” (New Hampshire Code of Administrative Rules Env-Wq 1703.01 (d)). “These rules shall apply to any person who causes point or nonpoint source discharge(s) of pollutants to surface waters, or who undertakes hydrologic modifications, such as dam construction or water withdrawals, or who undertakes any other activity that affects the beneficial uses or the level of water quality of surface waters.” (New Hampshire Code of Administrative Rules Env-Wq 1701.02 (b)).

"General Criteria—The following minimum criteria are applicable to all waters of the State, unless criteria specified for individual classes are more stringent:….(h). For activities that will likely cause or contribute to flow alterations, streamflow conditions must be adequate to support existing and designated uses." (Rhode Island Department of Environmental Management Water Quality Regulations (2010) Rule 8(D)(1)(h)).

Although the narrative examples in Table 1 may be useful tools to help states make informed decisions about their water resources, they do not explicitly describe the specific components of the natural flow regime (that is, magnitude, duration, frequency, rate of change, and timing) to be maintained to protect aquatic life uses. The framework presented in Section 6 can help guide a state through a process to determine which of these components are most important to protect the designated use. Box C describes the physical and biological importance of considering the specific components of the natural flow regime in the development of environmental flow targets rather than relying on a more general minimum flow magnitude to protect aquatic life.

Box C. Addressing Flow Regime Components

It is critically important to maintain extremes (floods and droughts) within the bounds of the natural flow regime to support the ecological structure and function of streams and rivers. However, alterations in low or high flows that are human-induced, affect and can control many ecosystem patterns, such as habitat extent and condition, water quality, connectivity, and material and energy exchange. These patterns can in turn affect many ecosystem processes, including biological composition, distribution, recruitment of biota, and ecosystem production (Rolls and others, 2012).

Although low flows serve a critical role in ecosystem function, current scientific research indicates that flow criteria ideally should support the natural flow regime as a whole, and that criteria for minimum flow alone (that is, a single minimum discharge value or a minimum passing flow) are not sufficient for maintaining ecosystem integrity (Annear and others, 2004; Bunn and Arthington, 2002; Poff and others, 1997). Minimum flow criteria do not address the full range of seasonal and interannual variability of the natural flow regime in most rivers and streams.

The natural fluctuation of water volume and levels in rivers and streams is critical for maintaining aquatic ecosystems because aquatic biota have developed life-history strategies in response to these fluctuations (Hill and others, 1991; Lytle and Poff, 2004; Mims and Olden, 2012, 2013; Postel and Richter, 2003; Stalnaker, 1990). Comprehensive flow criteria not only identify flow needs (that is, magnitude) but may also address the rate, frequency, timing, and duration of streamflow required to support ecosystem health (Poff and others, 2010). The Instream Flow Council (a non-profit organization working to improve the effectiveness of instream flow programs and activities: http://www.instreamflowcouncil.org/) recommends developing criteria that incorporate natural patterns of intra- and interannual variability in a manner that maintains and (or) restores riverine form and function to effectively maintain ecological integrity (Annear and others, 2004). Therefore, narrative hydrologic criteria and their implementation ideally should address several flow-regime components (frequency, duration, timing, rate of change) in addition to flow magnitude. The components necessary are determined on a case-by-case basis, depending on which values are most ecologically relevant.

Minimum flow statistics such as the 7Q10 design flow (the minimum 7-day average flow likely to occur in a 10-year period) are recommended by the U.S. Environmental Protection Agency for the derivation of water quality-based effluent limits in the National Pollutant Discharge Elimination System permitting program, but, although they include magnitude, duration, and frequency components, they were not derived to support the hydrologic requirements of aquatic ecosystems (Annear and others, 2004). The main purpose of these design flows is to determine pollutant discharge values (or limits) rather than to support the flow requirements of aquatic ecosystems (see U.S. Environmental Protection Agency, 1991).

6 Framework for Quantifying Flow Targets to Protect Aquatic Life

The adoption of narrative flow criteria in WQS is a mechanism to address the effect of flow alteration on aquatic life. Narrative criteria are qualitative statements that describe the desired water quality condition needed to protect a specified designated use (for example, aquatic life uses). The adoption of explicit narrative flow criteria allows for a clear link between the natural flow regime and the protection of designated uses. Moreover, the adoption of narrative flow criteria ensures that flow conditions are considered under various other CWA programs (for example, CWA Section 401 certifications, monitoring and assessment, and permitting under CWA Sections 402 and 404).

The effectiveness of narrative flow criteria depends, in part, on the establishment of scientifically defensible methods to quantitatively translate and implement the narrative. Quantitative translation of narrative flow criteria requires an understanding of the principles of the natural flow regime, hydrologic alteration, and ecological responses to altered flows (Knight and others, 2012; Knight and others, 2014). (The term “quantitative translation” encompasses the qualitative approaches described further in this section.)

A fundamental goal of any effort to translate narrative flow criteria is to establish scientifically sound, quantitative flow targets that are readily implemented in State water quality management programs. This section describes a framework (illustrated in Figure 10) for developing quantitative flow targets for protection of aquatic life uses that incorporates elements of the EPA Guidelines for Ecological Risk Assessment (ERA) (U.S. Environmental Protection Agency, 1998), recent environmental flow literature (Arthington, 2012; Kendy and others, 2012; Poff and others, 2010), and procedures outlined in EPA guidance documents (U.S. Environmental Protection Agency 2000a, 2000b, 2001, 2008, 2010b). The framework is intended to be flexible; decisions regarding whether and how each step is applied depend on project-specific goals and resources.

The framework presented in this section is organized into eight discrete steps that integrate science and policy (Figure 10). Steps 1 through 4 correspond to the “problem formulation phase” of the EPA ERA framework;

Steps 5 through 7 represent the “analysis phase”; and Step 8 incorporates concepts from the “risk characterization” phase as an “effects characterization”. Throughout the process, opportunities for public and stakeholder involvement should be considered. Certain steps within this framework are particularly well suited for public participation (see discussion of Steps 1 and 8). The benefits of public involvement are two-fold. First, public input can help strengthen the study design by incorporating suggested methods or addressing deficiencies identified in proposed approaches. Second, public involvement can foster a sense of support and ownership in the resulting flow targets, leading to streamlined implementation (Annear and others, 2004; Locke and others, 2008).

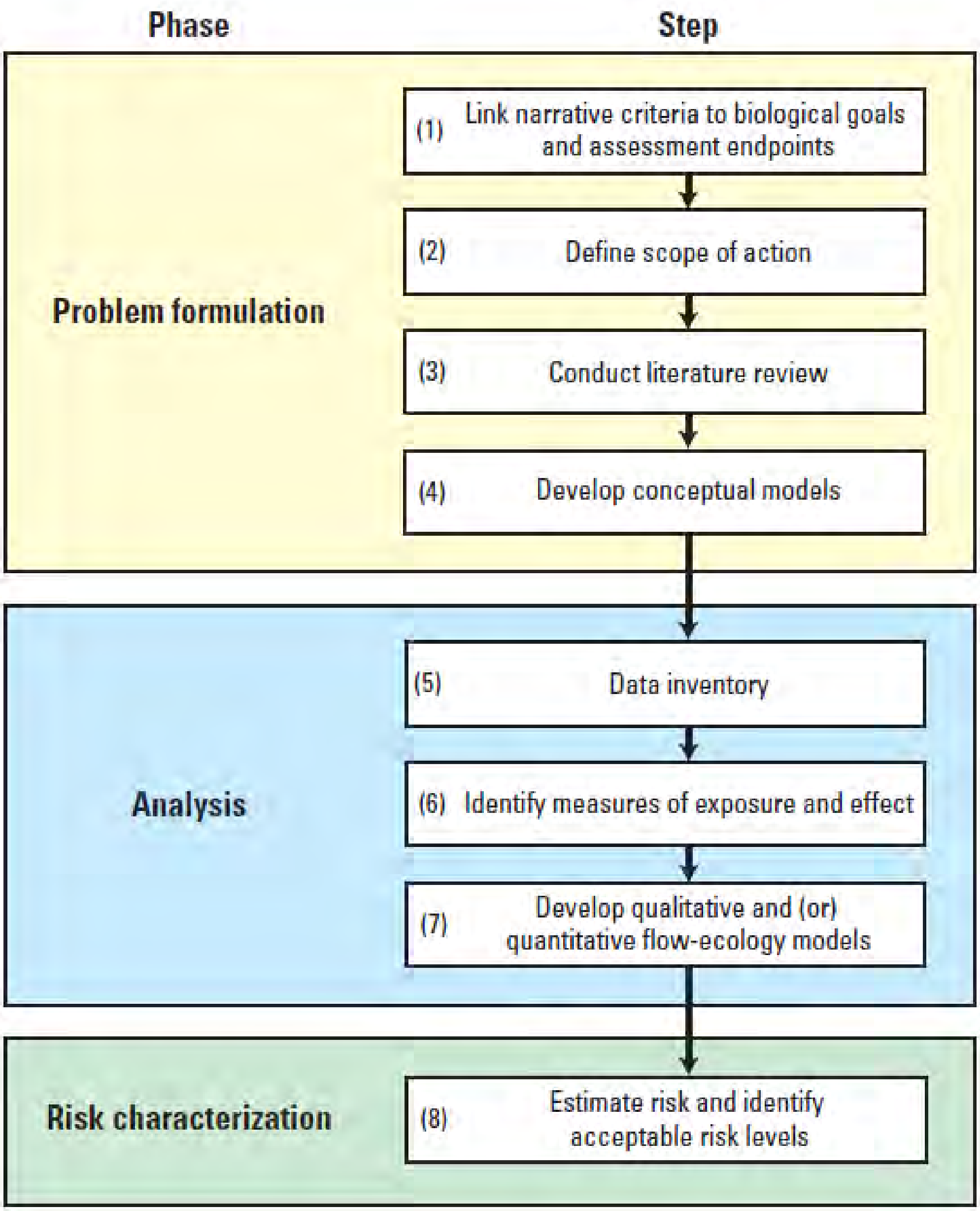

Figure 10. Flow diagram illustrating a framework for quantifying flow targets to protect aquatic life. (Adapted from EPA Guidelines for Ecological Risk Assessment; http://www.epa.gov/sites/production/files/2014-11/documents/eco_risk_assessment1998.pdf)

6.1 Link Narrative Criteria to Biological Goals and Assessment Endpoints

As described in Section 4, narrative flow criteria (see Table 1) are generally composed of (1) a description of the resource to be protected and the protection goal, and (2) statements describing the flow condition needed to be maintained to achieve the protection goal.

The first step in the framework for quantifying flow targets is to link narrative flow criteria to biological goals and assessment endpoints for the purpose of directing subsequent steps. A biological goal is a specific type of management goal that focuses on the biological characteristics of an aquatic system, such as fish or macroinvertebrate populations. Biological goals clearly state the desired condition of biological attributes relevant to flow target development (for example, “restore and maintain cold-water fisheries”). In most cases, a narrative flow criterion will already provide or suggest biological goals for a particular community or species that are tied to aquatic life designated uses. For narrative criteria worded in general terms, biological goals are derived through interpretation of narrative statements or are based on existing biological criteria to protect aquatic life designated uses. Examples of linking narrative flow criteria to biological goals are provided in Section 6.9.

Assessment endpoints are “explicit expressions of the actual environmental value that is to be protected” (U.S. Environmental Protection Agency, 1998). Whereas biological goals describe the desired condition of aquatic biota and communities, assessment endpoints specify which biological attributes are used to evaluate whether goals are met. If, for example, a biological goal was to “maintain a cold-water fishery,” assessment endpoints could include spawning success rate and adult abundance for one or more cold-water fish species. Assessment endpoints use “neutral phrasing” in that they do not call for any desired level of achievement. The EPA document “Guidelines for Ecological Risk Assessment” (U.S. Environmental Protection Agency, 1998) outlines three main criteria for selecting assessment endpoints: (1) ecological relevance; (2) susceptibility to known or potential stressors; and (3) relevance to management goals. Selection of assessment endpoints can take into consideration available methods for measuring biological conditions, although endpoints without standard measurement protocols may be selected. Additional discussion of biological measures for quantitative analysis is provided in Section 6.6, and example endpoints are listed in Table 2.

Biological goals and assessment endpoints defined during this step may be shared with the public for comment. Soliciting feedback at this step can improve public awareness of a state's intent to quantitatively translate narrative flow criteria and promote transparency at the onset of the process, both of which are crucial to the successful development and implementation of flow targets.

6.2 Identify Target Streams

Flow targets are quantified for a single stream, all streams within a geographic area (for example, a catchment or a state), or a subset of streams that satisfy a set of selection criteria. The second step in the framework for quantifying flow targets is to clearly define the spatial extent of the project and the target stream population.

When multiple streams over a large area are the subject of study, it is advantageous to classify target streams according to their natural flow, geomorphic properties, temperature regimes, and other attributes. The purpose of stream classification is to identify groups of streams with similar characteristics so that data for each group are aggregated and extrapolated (Archfield and others, 2013; Arthington and others, 2006; Olden and others, 2011; Poff and others, 2010; Wagener and others, 2007). It is a key step described in EPA's "Biological assessment program review" (U.S. Environmental Protection Agency, 2013a), the EPA technical guidance for developing numeric nutrient criteria for streams (U.S. Environmental Protection Agency, 2000a) and the Ecological Limits of Hydrologic Alteration (ELOHA) framework for developing regional flow standards outlined in Poff and others (2010). Stream classification based on flow, geomorphology, or other attributes should not be confused with the definition of stream condition classes that may serve as the basis of tiered biological thresholds or effects levels [see Section 6.8]. Additionally, although stream classification offers several benefits (Box D), it is not a requirement for successful development of quantitative flow targets (Kendy and others, 2012).

Box D. Fundamentals of Stream Classification

Stream classification is the grouping of multiple streams into a smaller number of classes on the basis of shared hydrologic, physical, chemical, and (or) biological attributes. Stream classification is a valuable tool for quantifying flow targets because (1) data from multiple streams are pooled for analysis, and (2) conclusions drawn for a given class are reasonably applied to all streams in that class. A general goal of stream classification is to systematically arrange streams of the study area into groups that are unique in key attributes for environmental flow research and management (for example, catchment size and temperature regime, as in example Scenario A described in Section 6.9). The process requires compiling observed and modeled data for the streams of interest, identifying metrics to serve as the basis of classification, and determining appropriate breakpoints for these metrics. Statistical methods such as correlation analysis, principal component analysis, regression, and cluster analysis are used to select metrics for classification and determine stream groupings. Important considerations include the types of data and attributes such as the number of classes, analytical methods, approaches to data gaps and uncertainty, and methods for evaluating results. As an example, a simple classification scheme may reflect the dependence of flow characteristics on catchment size and would require a database of stream drainage areas and the definition of drainage-area breakpoints for stream-size classes (for example—small, less than 50 square miles [mi^2]; medium, 50–100 mi^2; large, greater than 100 mi^2). A comprehensive review of stream classification to support environmental flow management is provided in Olden and others (2011) and Melles and others (2012). Example approaches are found in Seelbach and others (2006), Kennard and others (2010b), Kennen and others (2007), Reidy Liermann and others (2012), Melles and others (2012), and Archfield and others (2013).

6.3 Conduct Literature Review

A review of existing literature provides a foundation for understanding how the natural flow regime supports aquatic life and the biological effects of flow alteration in target streams. The literature review can include any published or unpublished journal articles, reports, presentations, and other documents that are relevant to the target streams. The literature review ideally should identify the most important aspects of flow regimes that are vital to support aquatic life and include both direct and indirect connections between flow variables and ecological response (Richter and others, 2006). Studies that characterize natural flow and biological conditions are valuable even if they do not specifically address flow alteration (Mims and Olden, 2012; McMullen and Lytle, 2012; Rolls and others, 2012). For example, studies of the historical and current biological condition of target streams, the physical and chemical conditions that support aquatic life, and the life-history strategies of aquatic species are all relevant for subsequent analysis steps. Literature reviews are aided by existing databases of flow-ecology literature for the region of interest (for example, McManamay and others, 2013, Southeast Aquatic Resources Partnership—Flow-ecology literature compilation, and The Nature Conservancy, 2015, ELOHA bibliography). Global-scale literature reviews, such as Bunn and Arthington (2002) or Poff and Zimmerman (2010), may also help to identify candidate sources of flow alteration, and the relevance of these potential effects are evaluated on the basis of local information.

The literature review can help to identify data gaps that could be filled through subsequent studies. It can provide a set of references for characterizing the types and sources of flow alteration in target streams. Past studies may provide detailed descriptions of observed flow modifications below dams and diversions or in urbanized catchments. Studies of observed and projected climate change may be reviewed, particularly those conducted at the state or regional scale. Information on climate-mediated changes in flow will be most valuable for subsequent steps; however, historical and projected trends in climate variables (precipitation, temperature, etc.) may be used to model flow regime changes for a state.

6.4 Develop Conceptual Models

The literature review is used to guide the development of one or more conceptual models that depict hypothesized relations between biological conditions and flow alteration in target streams. A conceptual model consists of a diagram and accompanying narrative describing hypothesized cause-and-effect relations. Poff and others (2010) recommend that these hypotheses focus on process-based relations between a particular flow-regime component and ecological change. The conceptual models, therefore, ideally depict how a specific change in a flow-regime component is believed to drive one or more biological responses. The pathways leading to indirect biological responses to flow alteration (that is, those mediated by habitat or water-quality change) are clearly depicted. Conceptual models developed as part of this process are therefore much more detailed than the general model presented in Section 4 (Figure 2).

The EPA Causal Analysis/Diagnosis Decision Information System (CADDIS) Web site includes a conceptual diagram of potential biological responses to several types of flow alteration (Figure 11) that may serve as a useful starting point for conceptual model development; other existing conceptual diagrams can be considered. Although this example does not include climate change as a source of flow alteration, climate effects on flow and biota can be conceptualized to more accurately reflect climate as a dynamic component of the ecosystem. Relations among climate, flow, and aquatic life might already be apparent from past studies, particularly if a state has undertaken a climate-change vulnerability assessment. (See Appendix B for additional discussion and examples of climate-change vulnerability and assessments.) Where information on climate change effects does not already exist, available climate, hydrologic, and biological literature may be synthesized to infer potential types of flow alteration and potential biological responses.

The conceptual models resulting from this step of the framework are used to guide subsequent analysis of flow targets, including the selection of biological and flow variables and analysis methods. In general, conceptual models created for flow target development contain a similar structure, but focus on stressors and responses specific to the streams of study. Biological responses to flow-mediated changes in water chemistry and temperature can be included which are not explicitly depicted in Figure 11. A detailed conceptual model may also identify alternative pathways (that is, other than flow alteration) to a given biological response. This approach also facilitates identification of potential confounding variables for consideration in flow-ecology modeling. The topic of confounding variables is discussed further in Section 6.6.

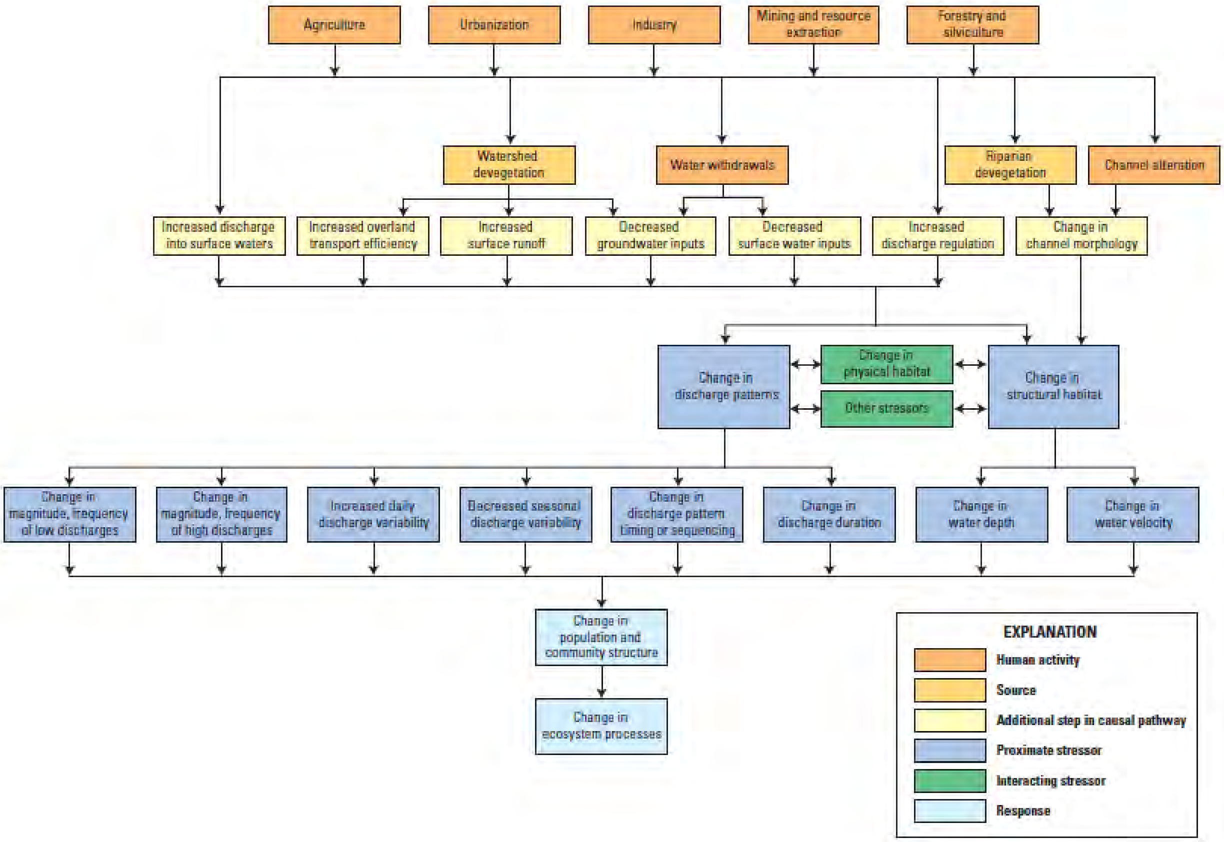

Figure 11. Example conceptual diagram illustrating the ecological effects of human-induced flow alteration from the U.S. Environmental Protection Agency Causal Analysis/Diagnosis Decision Information System (CADDIS).

(Modified from CADDIS Volume 2: Sources, Stressors and Responses, http://www3.epa.gov/caddis/ssr_flow4s.html).

6.5 Perform Data Inventory

Existing streamflow and ecological data from target streams ideally are compiled, inventoried, and reviewed for use in quantifying flow targets. Data quality objectives are determined and the data inventory may reveal that more data needs to be collected before proceeding. A common source of streamflow data is the USGS National Water Information System database (http://waterdata.usgs.gov/nwis), in which catchment attributes for many streams monitored by the USGS have been compiled in geographic information system (GIS) datasets (Falcone and others, 2010; Falcone, 2011). Existing mechanistic or statistical models of streamflow can provide continuous flow estimates, estimates of historical summary statistics, or estimates of flow under projected future climate scenarios (for example, Archfield and others, 2010; Holtschlag, 2009; Stuckey and others, 2012).

Potential sources of biological data include the EPA Wadeable Streams Assessment program (http://water.epa.gov/type/rsl/monitoring/streamsurvey/web_data.cfm), the USGS BioData retrieval system (https://aquatic.biodata.usgs.gov/landing.action), and databases maintained by the U.S. Forest Service, the Bureau of Land Management, the National Fish Habitat Partnership[5], or state agencies. Sampling methods, including the attributes measured, timing, equipment used, habitat type sampled, and taxonomic classification, are reviewed for each biological dataset. These and other sampling protocols are important for evaluating whether and how data from multiple sources are synthesized. A thorough discussion of potential data compatibility issues is provided in Cao and Hawkins (2011) and Maas-Hebner and others (2015).

The literature and data review will likely reveal information gaps that hinder the quantification of flow targets. Common issues include a lack of biological data for streams with long-term flow data or a lack of reference

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[5] The National Fish Habitat Partnership data are available at http://www.tandfonline.com/doi/full/10.1080/03632415.2011.607075#.VPc9VGjF-4I. The fish data are available at .

biological or flow data with which to evaluate alteration. Depending on the scope of the effort, additional monitoring or modeling may be required to fill such gaps.

6.6 Identify Flow and Biological Indicators

Streamflow and biological indicators are specific measures that are used to analyze the relations between flow alteration and biological response (termed "flow-ecology" relations). Flow indicators correspond to "measures of exposure" in the EPA ERA framework, whereas biological indicators correspond to "measures of effect." Biological indicators reflect narrative flow criteria and can include various measures of the diversity, abundance, or specific life-history traits of fish, macroinvertebrates, mollusks and aquatic vegetation. Many flow indicators have been proposed to characterize the flow regime; these indicators describe the magnitude, timing, frequency, duration, and rate of change of various flow conditions. They are calculated from long-term daily flow datasets, and software tools are available to automate this process (for example, Henriksen and others, 2006; The Nature Conservancy, 2009; and the USGS EflowStats "R" package, which is available at https://github.com/USGS-R/EflowStats. Example flow and biological indicators that have been used in past studies of flow-ecology relations are listed in Table 2. These examples are only a small subset of the full universe of indicators that could be considered for a target-setting effort.

The biological indicators selected for analysis ideally are consistent with narrative flow criteria and the biological goals and assessment endpoints developed under Step 1 of this framework. Ideally, the biological indicators selected directly reflect the biological attributes of concern described by assessment endpoints (for example, fish diversity). In cases where assessment endpoints cannot be directly measured or have limited observational data for flow-ecology modeling, surrogate biological indicators are linked to assessment endpoints through additional analysis. For example, if an assessment endpoint involves a rare fish species with few monitoring records, a surrogate biological indicator is selected by identifying a data-rich species with similar life-history traits. (See Merritt and others [2010] or Mims and Olden [2012, 2013] for examples of methods for grouping biota by life-history strategies.)

The flow and biological indicators selected for analysis should be consistent with the conceptual models developed as part of Step 4 of this framework. Biological indicators (that is, measures of effect) may include measurements along the scales of ecological organization, but they should be quantitatively related to survival, reproduction, or growth, as indicated in the general conceptual model presented in Figure 2. In most cases, the ability to analyze each and every hypothesized relation will be prohibited by data limitations and the project schedule and resources. Moreover, multiple flow indicators may be relevant to a particular relation. For example, analysis of a hypothesized relation between peak flow magnitude and fish-species diversity could use one of several peak-flow indicators (peak daily flow, peak 7-day flow, etc.). It may therefore be beneficial to establish a set of guidelines for flow indicator selection. Guidelines proposed in Apse and others (2008) include the use of flow indicators that are readily calculated, replicated, and communicated. Also recommended by Apse and others (2008) is the use of nonredundant flow indicators (that is, those that are not strongly correlated with one another). Olden and Poff (2003) and Gao and others (2009) describe the use of principal component analysis to identify nonredundant indicators and Archfield and others (2013) used a subset of fundamental daily streamflow statistics to capture the stochastic properties of the streamflow signal while minimizing the potential for redundancy. Other studies have addressed redundancy by investigating the correlation between pairs of potential flow indicators and discarding one indicator from highly correlated pairs (U.S. Army Corps of Engineers and others, 2013). The uncertainty associated with potential flow indicators and attempt to select indicators with low measurement uncertainty can be considered (Kennard and others, 2010a). Finally, identification of flow indicators that are most sensitive to sources of flow alteration can be attempted. For example, if climate change is considered to be an important source of flow alteration, available climate-vulnerability information to identify flow indicators that are sensitive to observed and projected climate trends and that are amenable to management changes can be evaluated (See Appendix B for additional discussion of climate-change vulnerability).

Table 2. Example flow and biological indicators used to evaluate relations between streamflow characteristics and aquatic assemblage response.

Flow component	Flow indicators (measures of exposure)	Biological component	Biological indicators (measures of effect)	Reference
Magnitude	Mean June–July flow; Mean August flow	Fish	Fish density; Fish abundance	Peterson and Kwak (1999); Zorn and others (2008)
Magnitude	Spring maximum flow; Summer median flow	Fish	Fish abundance; Fish-assemblage composition	Freeman and others (2001)
Magnitude	Magnitude of 10-year low-flow event	Fish	Fish Index of Biotic Integrity; Fish-species richness	Freeman and Marcinek (2006)
Magnitude	Mean annual flow; Base-flow index	Macroinvertebrates	Macroinvertebrate abundance; Macroinvertebrate assemblage; composition	Kennen and others (2014); Castella and others (1995)
Magnitude	Maximum flow; Ratio of maximum to minimum flow	Macroinvertebrates	Macroinvertebrate Index of Biotic Integrity; Macroinvertebrate species richness	Morley and Karr (2002)
Magnitude	Magnitude of 1-, 2-, 5-, 10-, and 20-year flood events	Macroinvertebrates	Macroinvertebrate O/E (ratio between the observed and expected) scores; Macroinvertebrate-assemblage	Nichols and others (2006)

Flow component	Flow indicators (measures of exposure)	Biological component	Biological indicators (measures of effect)	Reference
			composition	
Magnitude	Summer diversion magnitude	Macroinvertebrates	Macroinvertebrate abundance	Wills and others (2006)
Timing	Date of annual maximum flow; Date of annual minimum flow	Fish	Fish abundance; Fish-assemblage composition	Koel and Sparks (2002)
Frequency	Number of days above mean annual flow; Number of events above 75% exceedance flow value	Macroinvertebrates	Macroinvertebrate Index of Biotic Integrity; Macroinvertebrate richness	Booth and others (2004); Kennen and others (2010)
Frequency	Number of flood events; Number of low-flow events	Riparian vegetation	Riparian tree abundance	Lytle and Merritt (2004)
Duration	Duration of high-flow events; Duration of low-flow events	Fish	Fish abundance; Fish-assemblage composition	Koel and Sparks (2002)
Rate of change	Mean rise rate; Mean fall rate	Fish	Fish abundance; Fish-assemblage composition	Koel and Sparks (2002)

6.7 Develop Qualitative or Quantitative Flow-Ecology Models

A flow-ecology model is a specific type of stressor-response model that describes the relation between a flow indicator and a biological indicator in absolute terms (for example, fish diversity as a function of annual peak flow magnitude) or relative to reference conditions (for example, the percent change in fish diversity as a function of the percent change in annual peak flow magnitude).

Guided by the conceptual model, quantitative flow-ecology models are developed by using statistical methods and used to predict the value of a biological indicator under a variety of flow conditions (Figure 12). Quantitative flow-ecology models take the form of linear or nonlinear regression equations, but other approaches, such as regression tree analysis or change point analysis, also are available. Their development is guided by a variety of exploratory data analysis techniques to characterize individual indicator datasets (their range, average, distribution, etc.), evaluate potential relations, and determine appropriate modeling methods. A thorough review of statistical methods to employ for stressor-response modeling is provided in the report “Using stressor-response relations to derive numeric nutrient criteria” (U.S. Environmental Protection Agency, 2010b). An example approach to flow-target development using quantitative modeling is described in Section 6.9 (see Table 3 and Figure 13).

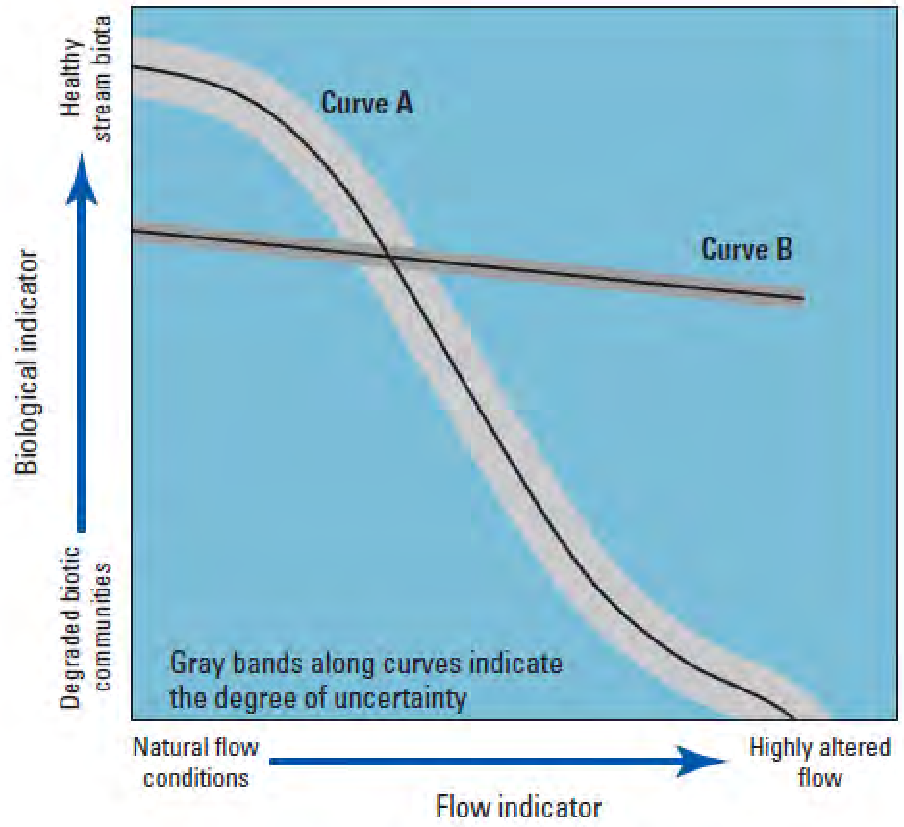

Figure 12. Example flow-ecology curves illustrating quantitative relations between flow and biological indicators.

(Quantitative models provide continuous predictions of biological responses to flow alteration. Curve A depicts a flow-ecology relation with higher sensitivity but greater uncertainty than those associated with Curve B.)

As introduced in Section 4.5, confounding variables are associated with alternative stressors and pathways (that is, other than flow alteration) to a given biological response. The presence of confounding variables at biological monitoring sites can limit the strength of causal inferences about the association between altered streamflow and biological indicators (U.S. Environmental Protection Agency, 2010b). Where feasible, confounding variables should be factored into the development of quantitative flow-ecology models. In practice, researchers have dealt with this issue by explicitly including possible confounding variables in preliminary models (for example, Carlisle and others,. 2010), by using modeling approaches that implicitly assume the presence of other confounding factors (for example, Konrad and others, 2008; Kennen and others, 2010), or, at a minimum, acknowledging that potential confounding factors were not included in modeling efforts, but that other evidence indicates that their influence likely was minimal (for example, Merritt and Poff, 2010).

Available data may be insufficient to support quantitative flow-ecology modeling, or that data or analytical limitations result in quantitative relations with a low level of statistical significance. In such cases, qualitative flow-ecology modeling is a practical alternative. Qualitative modeling does not attempt to uncover precise numerical relations between flow and biological indicators. Rather, the objective is to describe relations between variables based on hypothesized cause-effect associations using any available evidence. Qualitative modeling can help identify the direction of flow-ecology relations, and possible thresholds for degraded conditions, in data-limited environments.

The conceptual models discussed in Sections 4.1 and 6.4 are examples of qualitative models; however, it may be useful to reformulate conceptual models in terms of the flow and biological indicators selected for analysis. Qualitative models can incorporate numerical flow alteration and biological response thresholds reported in relevant literature, and (or) available data on reference flow and biological conditions. Such models are sometimes referred to as semiquantitative because they include numeric values but, unlike quantitative models, do not allow for precise predictions across the full spectrum of flow alteration. Qualitative modeling can incorporate a set of decision rules for combining and weighting conclusions from existing studies that used inconsistent study designs and data (Webb and others, 2013). An example approach to flow-target development using qualitative modeling is described in Section 6.9 (see Table 3 and Figure 14).

6.8 Estimate Effects and Identify Acceptable Levels

After modeling flow-ecology relations, dividing lines between acceptable and unacceptable flow alteration to select numeric flow targets can be determined. Effects estimation can guide this process. In general, effects estimation involves estimating effects levels that correspond to increasing magnitudes of a stressor. Effects estimation can define the likelihood that biological goals will not be achieved given a certain magnitude of flow alteration. Effects estimates are categorical (low, medium, high) or numeric (the probability of not meeting a certain biological condition). Effects estimation integrates quantitative or qualitative flow-ecology models, biological goals, and other available evidence.

In cases where quantitative flow-ecology models are available, effects estimation may be centered on the numerical relations between flow and biological indicators and their uncertainty. For example, descriptive effects levels are assigned to incremental flow-indicator values on the basis of predicted effects on stream biota and the degree of uncertainty associated with those predictions (for example, narrative effects statements based on the Biological Condition Gradient [Davies and Jackson, 2006] may provide useful examples). When quantitative models are not available, effects estimates are generated from qualitative flow-ecology models, results of past observational studies, information on current and expected levels of flow alteration, and any other lines of evidence. For more detailed information on characterization and estimation, see, “Guidelines for Ecological Risk Assessment” (U.S. Environmental Protection Agency, 1998) and “Risk Characterization Handbook” (U.S. Environmental Protection Agency, 2000c).

Effects estimation can be guided by threshold values or range of biological indicators, concentration of the stressor magnitude response, etc. that correspond to attainment or non-attainment of biological goals. For some biological indicators, point thresholds may be readily apparent from past studies or known reference conditions, or may be defined by existing biological criteria (for example, Index of Biotic Integrity = 90).

Alternatively, available evidence may point to a range of biological-indicator values as a suitable threshold (for example, Index of Biotic Integrity between 80 and 90).

After generating effects estimates, numeric flow targets are determined by identifying acceptable levels toward attainment of biological goals. For example, if flow-indicator values are divided into high, medium, or low effects ranges, the decision to set the flow target to the high-medium effects breakpoint, the low-medium breakpoint, or some alternative level is made. The process of identifying acceptable effects levels offers an opportunity to further incorporate uncertainty (for example, uncertainty caused by natural temporal and spatial variability of biological and hydrologic processes, sampling, etc.) in flow-ecology models and is helpful for soliciting and incorporating feedback from stakeholders and the public. The utility of feedback received at this step will likely be maximized if stakeholders have been kept informed and involved throughout the completion of prior steps. Decisions on whether and how to act on suggested modifications to acceptable effects levels and proposed numeric flow targets are weighed according to the strength of scientific support for the change and implications for meeting biological goals.

After acceptable effects levels have been identified and flow targets have been quantified, planning for implementation is enhanced by several key activities. Peer review can be used to evaluate the strength of flow-target values and highlight areas for improvement. Targeted monitoring or modeling can support validation of the ability of flow targets to achieve desired goals. Finally, an adaptive management approach allows flow targets to be periodically evaluated and adjusted to ensure that the desired goals are achieved. The adaptive management approach is continually informed and updated by results of monitoring, research, and experimentation to address specific uncertainties. (See Richter and others [2003] and Konrad and others [2011] for specific examples.)

6.9 Example Applications of the Flow-Target Framework

Two hypothetical efforts to quantify flow targets to protect aquatic life (referred to as Scenario A and Scenario B) are described in Table 3. Each scenario represents one potential application of the framework discussed in this section to quantitatively translate the following narrative flow criterion: Changes to the natural flow regime shall not impair the ability of a stream to support characteristic fish populations. The two scenarios differ in their approach to several framework steps. These scenarios are not intended to convey recommended methods, but rather describe example approaches for each step and demonstrate the adaptability of the framework to project-specific goals and available resources.

Scenario A is a case in which a state incorporates existing numeric biological condition criteria and an ample hydrologic and biological dataset for quantitative flow-ecology modeling, in which the resulting flow-ecology curves are used as a focal point for estimating effects, identifying acceptable effects levels, and selecting numeric flow targets. In Step 1, biological goals and assessment endpoints are selected from state WQS, which define minimum acceptable values of fish Index of Biotic Integrity (IBI) scores for attaining designated uses. In Step 2, statewide stream classification is undertaken to assign stream segments to one of 10 classes on the basis of catchment size and temperature regime (cold headwater, warm large river, etc.). In Step 3, the literature review uncovers extensive evidence for the effect of summer base-flow depletion on fish diversity and abundance. Conceptual models are developed in Step 4 to demonstrate pathways between anthropogenic sources of summer base-flow depletion and effects on fish populations. Data compiled in Step 5 include fish-survey results, flow-monitoring records, and modeled streamflow data for ungaged stream segments. In Step 6, fish IBI score and the percent reduction in August median flow are determined to be appropriate indicators for flow-ecology modeling because they reflect biological goals and sufficient data are available for analysis. Regression modeling is undertaken in Step 7 by using paired biological and flow data to generate response curves that quantify relations between fish IBI score and reduced August median flow.

Separate response curves are developed for each of the 10 stream classes defined for the project so that selected targets are transferable between stream segments within each class. In Step 8, fish response curves are used to guide discussions with stakeholders to identify appropriate targets for August median flow that are consistent with meeting the IBI scores for attaining designated uses identified in Step 1.

In Scenario B, qualitative flow-ecology models are generated and integrated with other lines of evidence to identify a set of flow indicators that, if altered, present an unacceptable effect to aquatic communities. In Step 1, the state's WQS do not include biological criteria that establish assessment endpoints defining biological goals, so the state takes appropriate actions, and includes stakeholder input, to identify specific biological goals that are consistent with its designated aquatic life uses. This effort identifies specific fish species and functional groups that are key to ensuring attainment of the state's designated aquatic life uses and, in turn, establishes the goals for interpreting the state's narrative flow criteria. In Step 2, the decision is made to include all streams in the state in the effort and opt not to address stream classification until after the literature review of flow-ecology relations is complete. Literature reviewed in Step 3 demonstrates clear links between fish health and a broad range of flow components. Because documented relations are consistent across stream size and ecoregion, stream classification is not pursued. The conceptual models developed in Step 4 summarize known and hypothesized flow needs of fish, organized by fish species/functional group, season, and flow characteristic. Data compiled in Step 5 focus on streamflow, with long-term records used to calculate reference and affected values of more than 50 flow metrics to evaluate the sensitivity of each metric to anthropogenic sources of flow alteration. On the basis of this analysis and evidence for biological sensitivity, a subset of flow metrics is selected in Step 6. A lack of biological data is determined to prohibit quantitative flow-ecology modeling; therefore, qualitative modeling is undertaken in Step 7 to reframe conceptual models in terms of the subset of flow indicators identified during Step 6. In Step 8, participating agencies review available evidence to estimate effects associated with increasing levels of hydrologic change and, with public input, use effects estimates to set targets that express the maximum allowable deviation from reference conditions for each flow indicator.

Although the examples in Scenarios A and B are largely hypothetical, components were drawn from real-world examples. Table 3 below provides an example where one indicator of many biological indicators and flow attributes is used to illustrate the potential relationship between stream flow processes and ecological response. Many more case studies of flow-target quantification can be found in Colorado Division of Water Resources and Colorado Water Conservation Board (2009), Cummins and others (2010), DePhilip and Moberg (2010), Kendy and others (2012), Kennen and others (2013), Richardson (2005), and Zorn and others (2008).

Table 3. Example applications of the framework to quantitatively translate the following narrative flow criterion: "Changes to the natural flow regime shall not impair the ability of a stream to support characteristic fish populations."

Framework Step	Scenario A: Quantitative Example	Scenario B: Qualitative Example
(1) Link narrative criteria to biological goals and assessment endpoints	Numeric biological goals are defined from existing biological condition criteria, expressed as minimum acceptable values of fish Index of Biotic Integrity (IBI) scores.	Narrative biological goals that are consistent with the designated aquatic life use are defined through interpretation of the narrative flow criterion with stakeholder input. Each biological goal identifies a specific fish species or functional group to protect. Example biological goal: to maintain the abundance of riffle obligate species.
(2) Define scope of action: identify target streams	Statewide stream classification is undertaken that builds on prior stream mapping and fish-ecology research. Individual stream segments are assigned to one of 10 stream classes according to catchment size and water-temperature regime, characteristics known to affect fish distributions. Example stream class: cold headwater.	All streams in the state are included in the effort to develop flow targets. As a result of data and resource constraints, the need for stream classification following the literature review is evaluated.
(3) Conduct literature review	Literature is reviewed to identify flow-regime changes that most affect the condition of fish communities. Relevant literature points to summer base-flow depletion as a factor in reduced fish diversity and abundance throughout the state.	Literature is reviewed to highlight flow-dependent life history and habitat traits of fish species/functional groups referenced in Step 1. Relevant literature demonstrates the importance of a wide range of flow conditions on the health of fish communities in the state, with consistent relations identified across stream size and ecoregion. On the basis of these findings, a systematic stream classification is not needed.

Framework Step	Scenario A: Quantitative Example	Scenario B: Qualitative Example
(4) Develop conceptual models	Conceptual models depict pathways between anthropogenic sources of summer base-flow depletion and effects on fish populations. Important relations include reduced food availability for both benthic and water-column taxa as a result of reduced wetted-channel perimeter and water depth.	Conceptual models summarize known and hypothesized flow needs of fish, organized by fish species/functional group, season, and flow characteristic.
(5) Conduct data inventory	A database of existing flow and fish-survey records is prepared. Observed data are augmented with predictions from previous hydrologic modeling efforts. Modeled data include reference and present-day values of median monthly streamflow for every stream segment in the state.	Long-term daily flow records, land-use information, and water-use data are compiled. Reference streams (those with minimal flow alteration) and affected streams are identified. Flow records for these sites are used to calculate reference and affected values of 50 or more flow metrics. The sensitivity of each flow metric to anthropogenic sources flow alteration is quantified by comparing reference and affected values.
(6) Identify flow and biological indicators to serve as measures of exposure and effect	Steps 6 and 7 are iterated to examine relationships between potential indicators and flow responses identified in Steps 3-5. Two indicators are selected for quantitative flow-ecology modeling: fish IBI score and the percent reduction in August median flow (relative to reference conditions).	A subset of the flow metrics quantified in Step 5 is selected for flow-target development. Metrics are evaluated according to their sensitivity to anthropogenic sources flow alteration and evidence of biological relevance. Flow indicators describe magnitude and frequency characteristics of high/flood flows, seasonal/average flows, and low/drought flows.
(7) Develop flow-ecology models	Regression modeling is undertaken by using monitoring and modeling data from sites with paired flow and biological data. Final models	Qualitative flow-ecology models are developed by reframing conceptual models in terms of the flow indicators selected in Step 6 (Figure 14).

Framework Step	Scenario A: Quantitative Example	Scenario B: Qualitative Example
	(termed "fish response curves"; see Figure 13) quantify the relation between fish IBI scores and reduced August median flow. Fish response curves are generated for each of the 10 stream classes defined in Step 2.	
(8) Estimate effects and identify acceptable levels	Fish response curves are shared with stakeholders to guide discussion of acceptable flow targets for each stream class that are consistent with meeting the fish IBI scores. Targets are expressed as a maximum allowable percentage reduction in August median flow by stream type.	Participating agencies review available evidence to estimate effects associated with increasing levels of hydrologic change. For some flow indicators, past studies indicate the likelihood of high effect of biological degradation under any magnitude of flow change. For others, healthy biotic communities are observed under moderate flow change and are determined to pose a lower effect if altered. This information is shared with stakeholders to further refine effects estimates and levels of flow alteration presenting unacceptable effects to stream biota. The outcome of these discussions is a set of targets expressing the maximum allowable deviation from reference conditions for each flow indicator that will protect the aquatic life use.
Follow-up and adaptive management	Participating agencies continue to collect flow and fish-community data. A plan is developed to assess flow targets every 5 years by analyzing new and historic data for evidence of their effectiveness.	Participating agencies continue to collect flow and fish-community data. A plan is developed to assess flow targets every 5 years by analyzing new and historic data for evidence of their effectiveness.

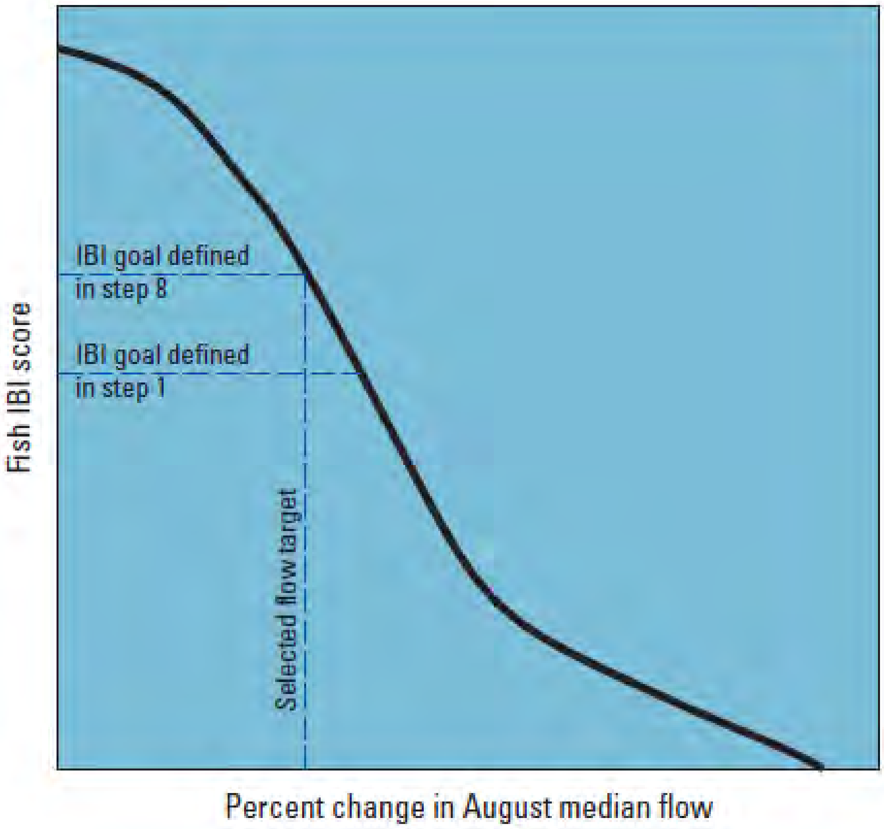

Figure 13. Example fish response curve from Scenario A generated through regression modeling.

(In this scenario, fish response curves depict the relation between altered August median flow and fish-community condition; IBI, Index of Biotic Integrity)

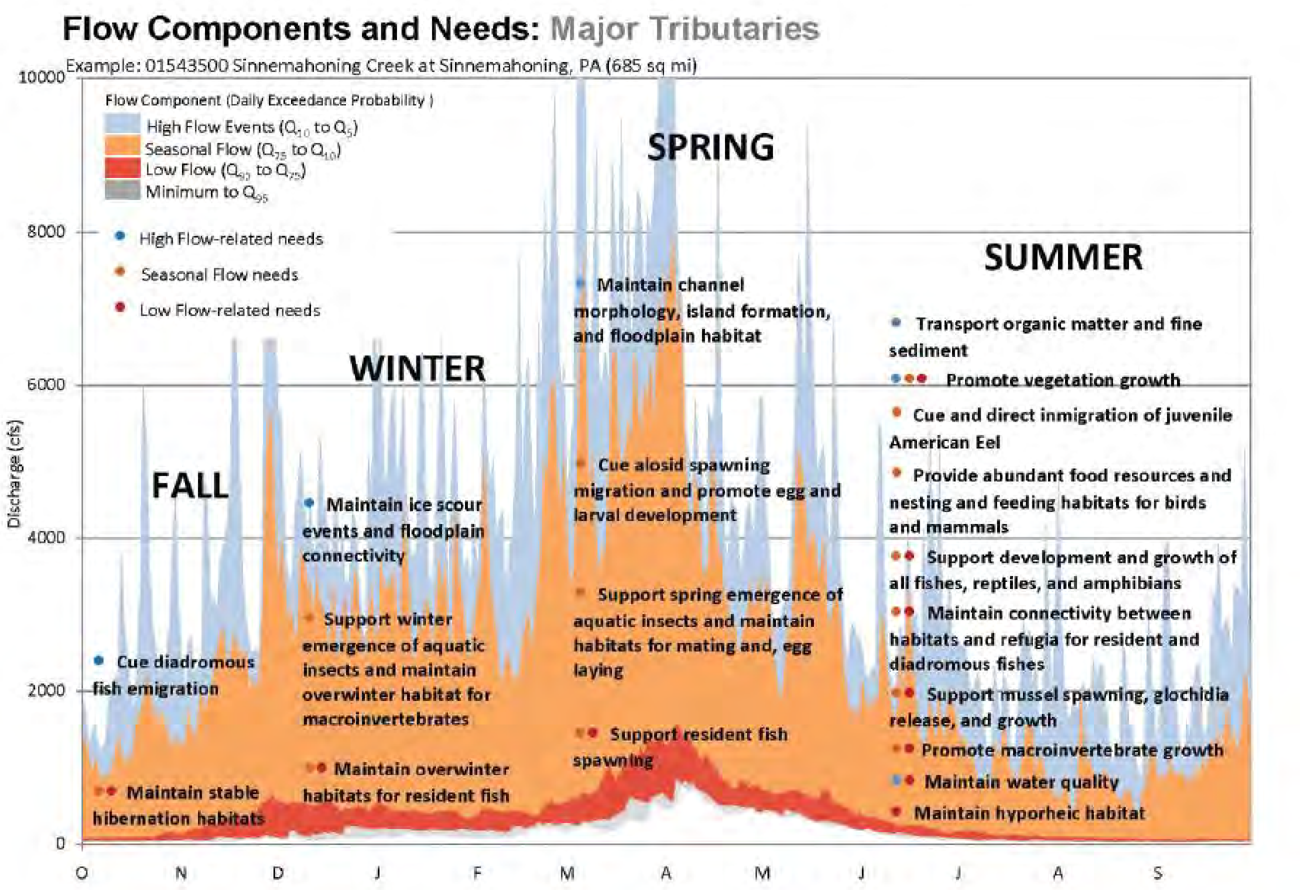

Figure 14. Conceptual diagram illustrating hypothesized flow needs of fish and other aquatic biota by season in major tributaries of the Susquehanna River Basin, northeastern United States.

(Example hydrograph shown is from U.S. Geological Survey station 01543500, Sinnemahoning Creek at Sinnemahoning, Pennsylvania [drainage basin 685 square miles]; as described in Scenario B, conceptual diagrams are used in conjunction with information on natural flow variability, flow alteration, and biological response thresholds to quantify candidate flow targets.) (From DePhilip and Moberg, 2010)

7 Conclusions

The flow regime plays a central role in supporting healthy aquatic ecosystems and the ecological services they provide to society. A stream’s natural flow regime is determined by climate and other catchment- and reach-scale properties that affect hydrologic processes such as infiltration, groundwater recharge, or channel storage. Human activities can alter the flow regime by modifying streamflow-generation processes (for example, infiltration, overland flow, etc.), altering the physical properties of stream channels (for example, channelization), or through direct manipulation of surface water and groundwater (dams or water withdrawals). Climate change effects on patterns of water and energy inputs to streams may further exacerbate these effects of flow alteration on aquatic ecosystems.

Alterations to the natural flow regime can contribute to the degradation of biological communities by reducing habitat quality, extent, and connectivity and by failing to provide cues needed for aquatic species to complete their life cycles. Flow alteration can prevent water bodies from supporting aquatic life designated uses defined by state water-quality standards. This report was cooperatively developed to serve as a source of information for states, Tribes, and territories that may want to proactively protect aquatic life from the adverse effects of flow alteration. To that end, the report provides background information on the natural flow regime and potential effects of flow alteration on aquatic life, examples of states and Tribes with narrative criteria, a flexible, nonprescriptive framework to quantify targets for flow regime components that are protective of aquatic life, and Appendix A, which provides illustrative examples of CWA tools that states and Tribes have used to protect aquatic life from altered flow.

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Appendix A. Examples where States and Tribes have applied Clean Water Act (CWA) Tools to Protect Aquatic Life from Altered Flows or that Account for Variations in the Flow Regime

A.1 Monitoring, Assessing, and Identifying Waters Impaired as a Result of Flow Alteration

States ensure Water Quality Standards (WQS) are met through implementation of technology and water quality-based controls, monitoring to assess use attainment status, reporting on use attainment and identifying impaired waters, and implementing appropriate restoration measures where waters are impaired. Waters are classified and states report on their condition to support use attainment decisions under Sections 303(d) and 305(b). States use their monitoring and assessment programs to identify and report to the public those waters that have impairments from pollution, defined under the CWA as “the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water” (Section 502(19)), including the effects of altered flow regimes or hydromodification (U.S. Environmental Protection Agency, 1997, 2003, 2005, 2016). Attainment of designated uses is evaluated through monitoring and assessment of indicators that reflect state WQS, including narrative or numeric criteria, or evaluating other data or information (U.S. Environmental Protection Agency, 1991). Accurately identifying the impairment status of these waters allows states to engage stakeholders on appropriate restoration strategies. The state of the science for restoring waters impaired by hydrologic alteration has evolved considerably, including, for instance, dam re-operation and improved methods for surface- or groundwater withdrawals.

States can record and evaluate flow information even when routine monitoring cannot occur as a result of extreme (high or low) flow conditions. This evaluation could include analytical hydrologic tools such as the USGS StreamStats (a Web application that provides users with access to stream network tools for water-resources planning purposes: http://water.usgs.gov/osw/streamstats/) or qualitative visual observations of streams. Such data or information could be used for making attainment decisions. For instance, the absence of water from a perennial stream could demonstrate that the aquatic life designated use is not being attained, and a state may conclude that the designated use is impaired. Texas provides an example: for each visit to nontidally influenced freshwater streams or rivers, the Texas Commission on Environmental Quality (TCEQ) monitoring procedures require that a “flow-severity” field (with a value of no flow, low flow, normal flow, flood flow, high flow, or dry) be recorded, even if it is not possible to quantitatively measure flow or conduct sampling during a visit (see Box E).

Box E. Procedures for Capturing Flow Information in the State of Texas

The publication “Surface water quality monitoring procedures, Volume 1: Physical and chemical monitoring methods” (Texas Commission on Environmental Quality [TCEQ], 2012) describes how Texas monitors all flow conditions and captures flow information in its State database. Parameter codes for data uploads to the U.S. Environmental Protection Agency (EPA) Storage and Retrieval Data Warehouse (STORET), a repository for water monitoring data, are provided for each type of data collected. In addition to describing methods for capturing quantitative flow information, the document describes how to capture qualitative flow information with the “flow-severity” field:

- “Record a flow-severity value for each visit to freshwater streams or rivers (nontidally influenced) and report the value to the TCEQ central office. Do not report flow severity for reservoirs, lakes, bays, or tidal streams. It should be recorded even if it was not possible to measure flow on a specific sampling visit. See the Surface water quality monitoring data management reference guide for detailed information on data reporting.“ (Texas Commission on Environmental Quality, 2013)
- “No numerical guidelines are associated with flow severity, an observational measurement that is highly dependent on the water body and the knowledge of monitoring personnel. It is a simple but useful piece of information when assessing water quality data. For example, a bacteria value of 10,000 with a flow severity of 1 would represent something entirely different than the same value with a flow severity of 5.”

Table 3.2 of Texas Commission on Environmental Quality (2012) provides photographs of each "flow-severity" category and the following descriptions, which can be found at https://www.tceq.texas.gov/assets/public/comm_exec/pubs/rg/rg415/rg-415_chapter3.pdf (accessed February 4, 2016):

- "No Flow. When a flow severity of 1 is recorded for a sampling visit, record a flow value of 0 ft^3/s (using parameter code 00061) for that sampling visit. A flow severity of 1 describes situations where the stream has water visible in isolated pools. There should be no obvious shallow subsurface flow in sand or gravel beds between isolated pools. —No flow not only applies to streams with pools, but also to long reaches of streams that have water from bank to bank but no detectable flow."
- "Low Flow. When streamflow is considered low, record a flow-severity value of 2 for the visit, along with the corresponding flow measurement (parameter code 00061). In streams too shallow for a flow measurement where water movement is detected, record a value of < 0.10 ft3/s. In general, at low flow the stream would be characterized by flows that don‘t fill the normal stream channel. Water would not reach the base of both banks. Portions of the stream channel might be dry. Flow might be confined to one side of the stream channel."
- "Normal Flow. When streamflow is considered normal, record a flow severity value of 3 for the visit, along with the corresponding flow measurement (parameter code 00061). What is normal is highly dependent on the stream. Normality is characterized by flow that stays within the confines of the normal stream channel. Water generally reaches the base of each bank."
- "Flood Flow. Flow-severity values for high and flood flows have long been established by the EPA and are not sequential. Flood flow is reported as a flow severity of 4. Flood flows are those that leave the confines of the normal stream channel and move out onto the floodplain (either side of the stream)."

- "High Flow. High flows are reported as a flow severity of 5. High flow would be characterized by flows that leave the normal stream channel but stay within the stream banks."
- "Dry. When the stream is dry, record a flow-severity value of 6 for the sampling visit. In this case the flow (parameter code 00061) is not reported, indicating that the stream is completely dry with no visible pools."

An example of a reporting option that helps clearly delineate and address waters impaired as a result of streamflow alteration is described in Box F, which illustrates the use of Category 4F in Vermont.

Box F. Vermont Addresses Hydrologically Altered Waters

Vermont first adopted narrative criteria into its water quality standards (WQS) for Clean Water Act purposes for flow or hydrologic condition in 1973 (for full text, see http://www2.epa.gov/sites/production/files/2014-12/documents/vtwqs.pdf [accessed February 4, 2016] or Vt. Code R. 12 004 052, http://www.vtwaterquality.org/wrprules/wsmd_wqs.pdf [accessed February 4, 2016]). Although hydrologic alteration is listed under integrated reporting guidance as Category 4c (impairments due to pollution not requiring a Total Maximum Daily Load), Vermont does address flow-related exceedance of the WQS through the Vermont Priority Waters List. This list includes waters assessed as “altered” using the state’s assessment methodology (Vermont Department of Environmental Conservation, 2014: http://www.vtwaterquality.org/mapp/docs/mp_assessmethod.pdf [accessed February 4, 2016]). Part F of the Priority Waters List is water bodies that do not support one or more designated uses as a result of alteration by flow regulation (primarily from hydroelectric facilities, other dam operations, or industrial, municipal, or snowmaking water withdrawals). This list includes a description of the problem, current status or control activity, and the projected year the water-body segment will come into compliance with WQS. Creating a new category for hydrologic alteration helps separate it from other causes of pollution effects that would be reported in Category 4.

A.2. Development of Total Maximum Daily Loads

A total maximum daily load (TMDL) is a calculation of the maximum amount of a pollutant that a water body can receive and still meet WQS, and an allocation of that load among the various sources of those pollutants. Quantity of flow and variation in flow regimes are important factors in the fate and transport of pollutants (for example, sediment, pathogens, and metals), and therefore flow is considered when calculating TMDLs. A common source of streamflow data is the USGS National Water Information System. Several EPA TMDL technical documents discuss the role of flow in the context of methods and models to develop loadings and load and waste-load allocations. These include the EPA document on developing TMDLs based on the load-duration curve approach (U.S. Environmental Protection Agency, 2007) and the EPA protocol for developing sediment TMDLs (U.S. Environmental Protection Agency, 1999).

A.3 Consideration of Flow Alteration in Issuing 401 Certifications

Under CWA Section 401 states and authorized Tribes have the authority to grant, condition, or deny certification for a Federal permit or license (see CWA Section 401(a)(1)) to conduct any activity that may result in any discharge into navigable waters. Before issuing a CWA Section 401 certification, a state or Tribe would ensure that any discharge to navigable waters from the activity to be permitted or licensed will be consistent with, among other things, the state's WQS and any other appropriate requirement of state law (see CWA Section 401(d)).

Box G. 401 Certifications, Sufficient Flow, and Water Quality Standards

South Carolina Board of Health and Environmental Control Negotiates New Commitments for Recertification

In 2009, South Carolina denied a 401 certification of a hydroelectric project license renewal (involving 11 dams), stating, "[t]he Board finds that the WQ Certification does not provide sufficient flow to protect classified uses, the endangered shortnose sturgeon and adequate downstream flow….to provide reasonable assurance….that WQS will be met." As a result of that action, negotiations were held that resulted in an agreement in 2014 and granting of the 401 certification. The agreement conditions committed the energy company to operating its dams to improve conditions for the sturgeon, protect flow conditions during spawning periods, and provide periodic flood-plain inundation mimicking ecologically important natural floods and recessions.

A.4 Consideration of Flow Alteration in Issuing 404 Permits

CWA Section 404 regulates[6] discharge of dredged or fill material into waters of the United States, and some proposed projects may result in loss of the conditions necessary for survival of aquatic life, including, for example, lotic species (species that depend on flowing water for survival).

Examples of projects involving discharge of dredged or fill material that affect hydrology include the construction of new water withdrawal or storage systems (for example, reservoirs); valley fills and waste disposal areas for resource extraction; expansion of existing withdrawal or storage systems; diversions and construction of projects such as drinking-water or flood-control reservoirs, impoundments for energy generation, and fishing reservoirs or amenity ponds (an impoundment developed for recreation and (or) aesthetic purposes). Impoundments alter streamflows, and operation of dams to manage releases largely determines how closely downstream flows resemble the natural hydrograph.

Activities proposed for Section 404 permits (issued by the U.S. Army Corps of Engineers) are reviewed by resource agencies (Federal and state) and are subject to Section 401 certification. Permits issued by a state that has assumed the Section 404 program (as of 2015, only Michigan and New Jersey have approved Section 404 programs), or issued by a state or Tribe implementing a programmatic general permit issued by the U.S. Army Corps of Engineers, consider the potential effects of a project on attainment of WQS, including antidegradation requirements.

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[6] The responsibility for administering and enforcing CWA Section 404 is shared by the U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency. For more information on these responsibilities, see http://www.epa.gov/cwa-404/laws-regulations-executive-orders and http://www.epa.gov/cwa-404/policy-and-guidance

A.5 Consideration of Flow Alteration in Issuing National Pollutant Discharge Elimination System (402) Permits

National Pollutant Discharge Elimination System (NPDES) permits are generally required for point-source discharges of pollutants. Many NPDES permits depend on streamflow data for pollutant discharge limit calculations. Permits issued under CWA Section 402 use critical low-flow values such as the 7Q10 (7-day, 10-year annual low-flow statistic) or regulated low flows to calculate a permittee's discharge limits so that permitted values will be protective of aquatic life under the most critical conditions. Many rivers and streams across the United States have experienced trends in low flows since the 1940s–with increases generally in the Northeast and Midwest, and decreases (streams carrying less water) in the Southeast and the Pacific Northwest (Figure 7). Permit writers use the most up-to-date critical low-flow information for the receiving water and, where historical flow data are no longer representative, use current low-flow data to calculate effluent permit limits to protect for the new critical low flow (see the EPA Water Quality Standards Handbook [U.S. Environmental Protection Agency, 1994, Chapter 5.2]).

Box H. Stormwater and West Virginia Department of Environmental Protection Municipal Separate Storm Sewer Systems (MS4) Permit Language

The West Virginia Department of Environmental Protection issued a small MS4 permit including the language below for new and redevelopment projects to reduce effects from stormwater runoff at permitted sites:

"Performance Standards. The permittee must implement and enforce via ordinance and/or other enforceable mechanism(s) the following requirements for new and redevelopment: [....]"

"Site design standards for all new and redevelopment that require, in combination or alone, management measures that keep and manage on site the first one inch of rainfall from a 24-hour storm preceded by 48 hours of no measurable precipitation. Runoff volume reduction is achieved by canopy interception, soil amendments, evaporation, rainfall harvesting, engineered infiltration, extended filtration, and/or evapotranspiration and any combination of the aforementioned practices. This first one inch of rainfall must be 100% managed with no discharge to surface waters."

For a full compendium of this and other examples, see U.S. Environmental Protection Agency (2014c).

For additional examples of stormwater-related permits and their analysis, see U.S. Environmental Protection Agency (2012b).

A.6 Further Considerations

The discussion above is not meant to be a comprehensive assessment of all CWA tools that may address flow and the protection of aquatic life uses. In addition to the approaches mentioned above, other non-CWA mechanisms exist that may protect aquatic ecosystems from alteration of flow. Although many of these programs may provide a method to specifically address these altered-flow effects, others may lack specified frameworks and (or) established methods to quantify targets to address the impacts of flow on aquatic life uses, allowing room for supplemental considerations or the application of methods considered the "best available science."

Appendix B. Climate-Change Vulnerability and the Flow Regime

Climate change is one category of stressors among many (see Section 4.3) that increase the vulnerability of rivers and streams to flow alteration and affect the ecosystem services they provide. Changes in global temperature and shifts in precipitation are superimposed on local stressors such as water contamination, habitat degradation, exotic species, and flow modification (Dudgeon and others, 2006). Given the challenges posed by climate change, many natural-resource management agencies likely will find protecting and restoring the health of aquatic ecosystems increasingly challenging. For example, projected changes in temperature and precipitation due to climate change are expected to increase the departures from historic conditions. This means that using the past envelope of variability as a guide for the future is no longer a reliable assumption in water-resources management (Milly and others, 2008). Observed streamflow trends since about 1940 indicate regional changes in low flows, high flows, and timing of winter/spring runoff (U.S. Environmental Protection Agency, 2014b). However, there is much uncertainty about the future effect of climatically driven changes on streamflow. Even though knowledge of national and regional climate-change effects are useful at a coarse scale, water scientists need to move from generalizations of climate-change effects to more regional and (or) place-based effects to develop approaches relevant to the scale of management (Palmer and others, 2009). Global, national, and regional effects are described comprehensively elsewhere (Intergovernmental Panel on Climate Change, 2007; Field and others, 2014; Georgakakos and others, 2014; Karl and others, 2009).

Resilience is the ability of a system to recover after disturbance and the capacity of that system to maintain its functions in spite of the disturbance (Turner and others, 2003; Walker and others, 2004). Restoring or maintaining a natural flow regime can increase system resilience to climate-change effects and help avoid or reduce intensification of historical stresses (Beechie and others, 2013; Palmer and others, 2008, 2009; Pittock and Finlayson, 2011; Poff and others, 2012). Therefore, defining and protecting environmental flows is not only a way to protect and restore rivers and streams from anthropogenic stressors, but it may also be a means of adapting to climate-change.

Not all rivers and streams are equally vulnerable to the effects of climate change. An assessment of climate-change vulnerability can help identify locations and hydrologic and ecological attributes that are most vulnerable to altered climate conditions. A climate-change vulnerability assessment, at a minimum, will supply specific information on the type of climate change expected across the assessed area. Depending on the scope of the effort, a climate-change vulnerability assessment may also translate projected changes in climate into effects on flow and (or) aquatic biota. This information is valuable for planning and implementation of Clean Water Act program strategies to support the resilience of aquatic life to a changing climate. Furthermore, flow and biological projections are incorporated into efforts to quantify flow targets that are protective of aquatic life under both historic and projected future climate conditions.

Approaches for assessing climate-change vulnerability are evolving and becoming more robust (Dawson and others, 2011). This appendix describes the components of vulnerability (Box I) and presents two examples from studies in California (Box J) and the Pacific Northwest (Box K) that illustrate the ways in which regional climate-change effects are being incorporated into vulnerability studies of the flow regime and the potential resulting effects on aquatic life (Box J).

Box I. Components of Climate-Change Vulnerability

The paragraphs that follow briefly describe the primary components of climate-change vulnerability that may be included in climate vulnerability assessments: exposure, sensitivity, and adaptive capacity. An in-depth discussion of these components is available in Glick and others (2011) and Poff and others (2012). Generalized case examples available in Glick and others (2011) demonstrate assessment approaches for climate vulnerability assessments across various ecosystems and species, both aquatic and terrestrial. Examples that focus on watershed vulnerability and aquatic resources are included in Furniss and others (2013). An additional resource (U.S. Environmental Protection Agency, 2014a) is a workbook for organizations managing environmental resources that provides a two-part process to carry out vulnerability assessments and develop effects-based adaptation plans for strategic climate-change plans.

Exposure: Exposure generally refers to the character, magnitude, and rate of climatic changes (Glick and others, 2011). Results of climate model simulations such as regional climate projections or downscaled climate projections, though accompanied by uncertainty, can help to estimate the range and location of potential climate change. Identifying sources of increased past variability may also be helpful (for example, paleoclimate records of tree-rings). Those changes that are ecologically significant (for example, those that affect an assessment endpoint) are considered as exposure metrics (for example, snowpack vulnerability, winter water temperature, aridity index, monthly precipitation, winter peak flows, freeze and thaw days, etc.) Additional examples of exposure metrics used in case studies are given in Furniss and others (2013).

Sensitivity: Climate sensitivity is the degree to which a system, habitat, or species is (or is likely to be) altered by or responsive to a given amount of climate change (in this case, climate-induced hydrologic changes in particular) (Glick and others, 2011). Sensitivity factors can include intrinsic attributes of a watershed, aquatic ecosystem, or organism, as well as the existing condition owing to anthropogenic factors. For example, the hydrology in a snowmelt-dominated watershed (and the ecosystem that is adapted to this hydrologic regime) may be more sensitive to climate changes that reduce the proportion of precipitation from snow than that in a rainfall-dominated watershed (see the Beechie and others [2013] example in Box K). Many of the intrinsic attributes at the landscape level (for example, geology, soil, topography) affect the sensitivity of the aquatic ecosystem to any stressor. For example, the rate at which shifts in stream temperature can occur is driven by variables such as stream slope and interannual variability—so the rate at which temperature gradients shift are variable, even within a given basin, and statistically significant signals may not be detected for decades (Isaak and Reiman, 2013). The intrinsic factors that affect sensitivity at the population scale may include environmental tolerance range (for example, thermal tolerances), mobility, genetic adaptation, and range or population size.

Adaptive Capacity: Adaptive capacity is the ability of a species or system to cope with or adjust to climate-change effects with minimal disruption (Glick and others, 2011). It is also a subset of system resilience and can help managers assess vulnerability for use in decision making. Ecosystems and aquatic organisms can cope with climate change in different ways; for example, they may migrate, shift to more suitable microhabitats, or persist in place (for example, phenotypic plasticity) (Dawson and others, 2011). On a landscape scale, some vulnerability assessment approaches include landscape/river connectivity under this component. Many adaptive capacity factors may be those pre-existing conditions that future management conditions can address (for example, reducing fragmentation of a water body, thereby preventing mobility to more suitable conditions, such as cooler temperatures) (Glick and others, 2011). The Pacific Northwest salmon restoration case study (Box K) provides some examples of restoration practices Beechie and others (2013) identified as adaptive activities that may ameliorate some of the expected climate changes and increase habitat diversity and salmon population resilience.

Box J. California's Climate-Change Vulnerability Index

The goal of the California Integrated Assessment of Watershed Health (U.S. Environmental Protection Agency, 2013b) was to identify and better protect healthy watersheds by integrating data and making them available to planning agencies for improved coordination of monitoring and prioritization of protection efforts. The primary partners included the U.S. Environmental Protection Agency (EPA) and the Healthy Streams Partnership (HSP), an interagency workgroup of the California Water Monitoring Council. The assessment partners identified and integrated 23 indicators of watershed health, stream condition, and watershed vulnerability to characterize relative watershed health and vulnerability across California. The indicators used in this assessment reflect the reality that multiple ecological attributes and anthropogenic effects play a role in watershed and stream health, and need to be considered together.

The integrated watershed vulnerability index used in the assessment of watershed health is a composite of four vulnerability indices that may change from 2010 to 2050 (land cover, wildfire severity, water use, and climate change). The composite climate-change vulnerability index, in turn, is composed of seven component metrics of estimated climate-change parameters using projections from Cal-Adapt, a collaboration of several institutions that modeled downscaled hydrologic response across California by using temperature and precipitation projections produced from global general circulation models (GCMs). The interagency partners used the modeled outputs to evaluate the relative response of watersheds in California to future climate change, but the models did not explicitly simulate effects on ecosystem health or watershed processes (although they are certainly related to the modeled inputs), nor was the sensitivity of those watersheds to such changes a focus of this screening-level assessment. Rather, the vulnerability index is meant to be assessed with the composite indices of stream health and watershed condition to help prioritize protection opportunities.

The HSP used annual precipitation, mean base flow, mean surface runoff, and snowpack (as snow water equivalent) as the hydrologic responses to projected climate change because they were identified as the primary indicators affecting stream hydrology. It also identified annual temperature maximum, minimum, and mean as climate variables that may affect future watershed vulnerability. The interagency partners calculated the percent difference between projected values of these indicators (that is, component metrics of exposure) from 2050 and 2010.

The composite results of the vulnerability assessment (Figure B-1) illustrate the climate exposure primarily in terms of its effects on temperature and hydrology-related parameters in this example. Overall, the climate vulnerability component of this assessment identified the greatest vulnerability for northern California as a result of a combination of expected temperature increases and changes in snowpack, surface runoff, and base flow.

This screening-level assessment is an instructive example that may help inform the protection of healthy watersheds based on climate-change vulnerability. However, the assessment combined other vulnerability indices—land cover, water use, and fire-regime class (which can affect surface erosion, sediment deposition, and stream temperature)—with climate change as characteristics that could modify (exacerbate or ameliorate) overall vulnerability. Additionally, this assessment not only sought to develop priorities based on ecosystem vulnerability, but also a comprehensive understanding of the overall status of the aquatic ecosystem. For the entire assessment, stream condition, watershed health, and vulnerability were considered.

For more information, see U.S. Environmental Protection Agency (2013b) (http://www.epa.gov/sites/production/files/2015-11/documents/ca_hw_report_111213_0.pdf).

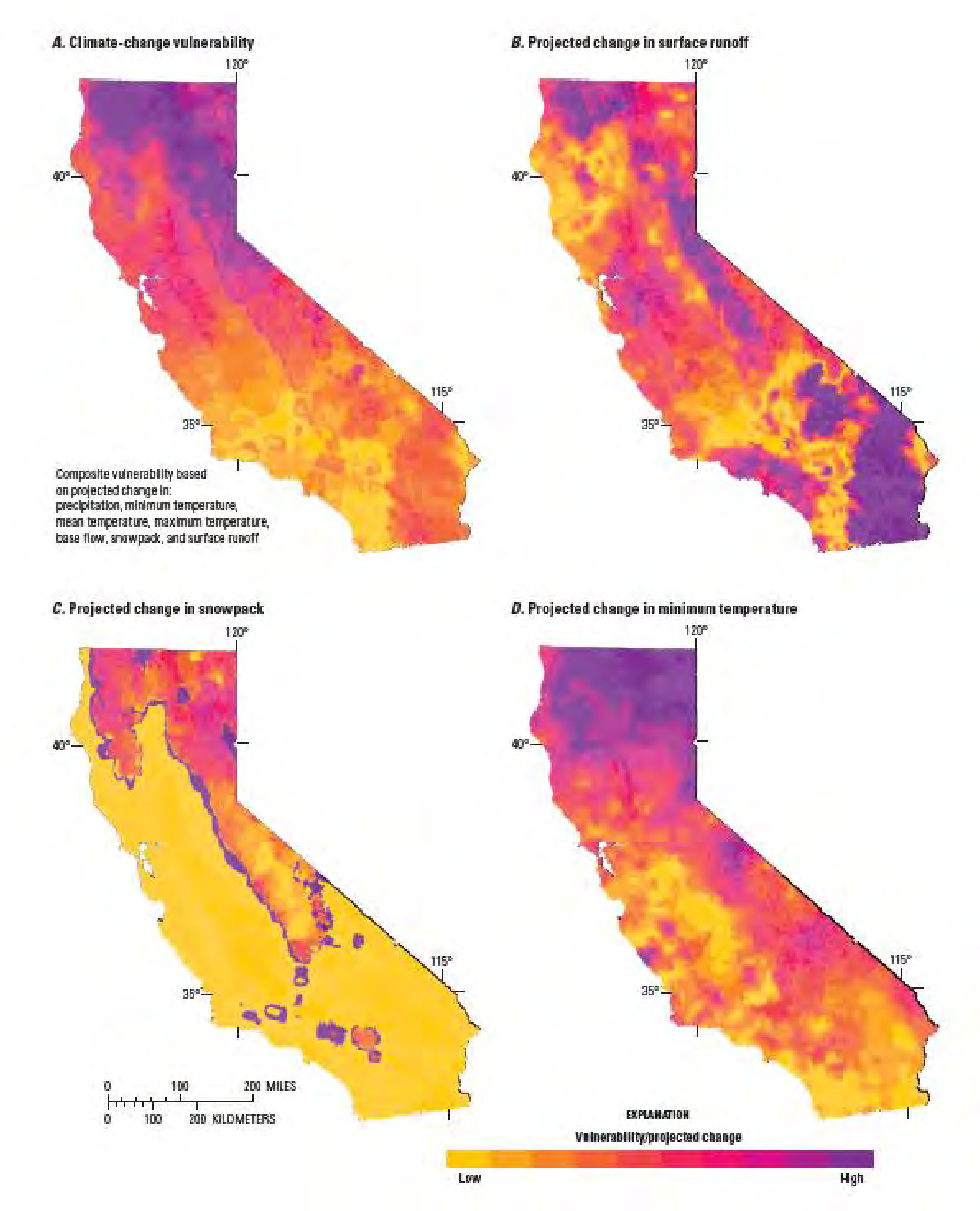


Figure B-1. (a) Composite results of the vulnerability assessment illustrating the combined changes in the seven component metrics of projected climate-change parameters, three of which are shown: (b) surface runoff, (c) minimum temperature, and (d) snowpack. (Additional component metrics including projected change in precipitation, mean temperature, maximum temperature, and base flow are shown in U.S. Environmental Protection Agency [2013b], available at http://water.epa.gov/polwaste/nps/watershed/integrative_assessments.cfm.)

Box K. Addressing Regional Climate-Change Effects on Salmon Habitat in the Pacific Northwest: Examples for Prioritizing Restoration Activities

Salmon habitat restoration is a prominent issue in the Pacific Northwest; however, a need exists to better understand whether current restoration activities and priorities will be effective under future climate conditions. Beechie and others (2013) sought to address this issue by providing insight into ways in which a restoration plan might be altered under various climate-change scenarios.

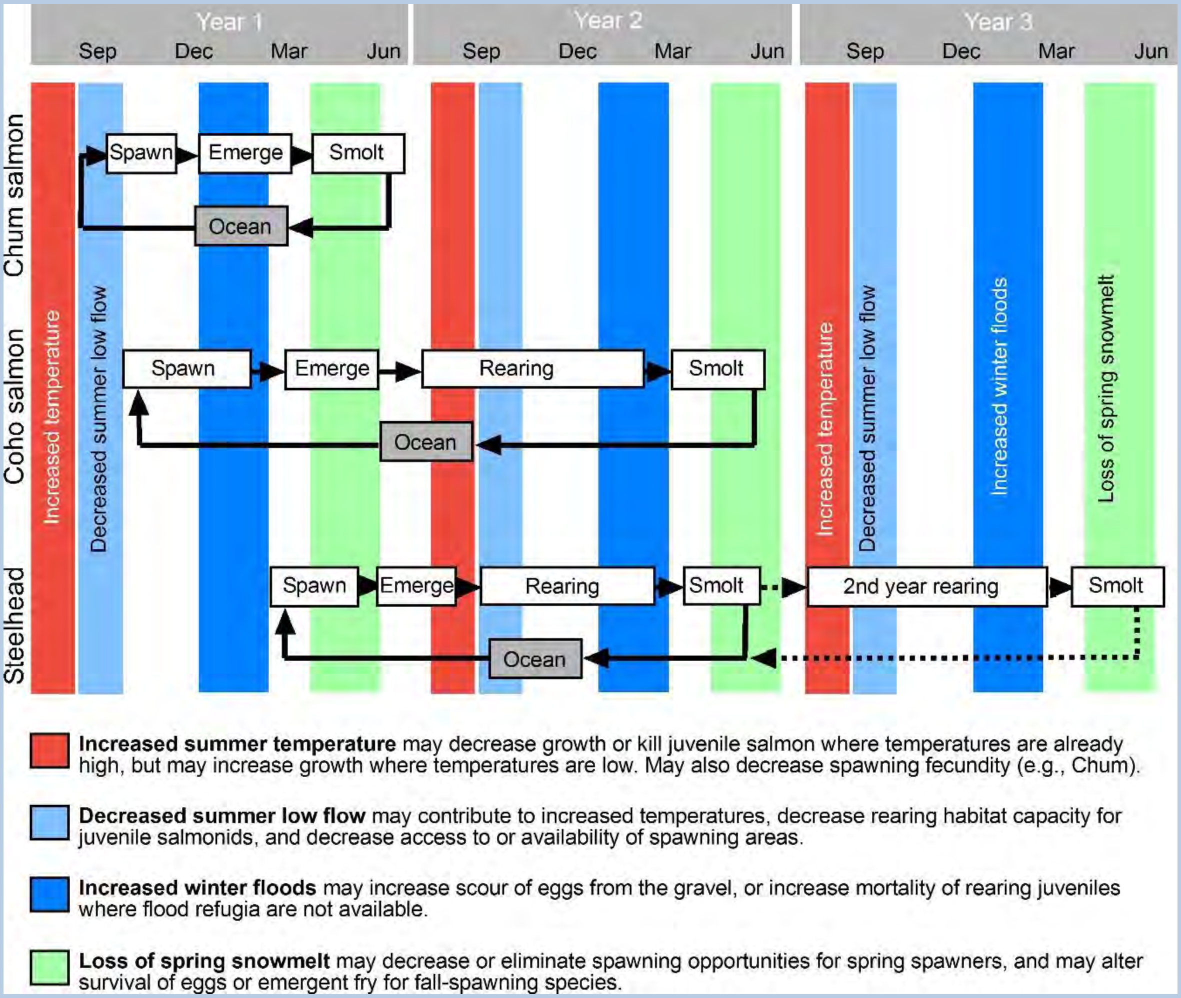
The authors developed a decision support system to adapt salmon recovery plans to address climate-mediated stream temperature and flow changes in order to both ameliorate climate effects and increase salmon resilience. To guide the effort, the researchers mapped scenarios of future stream temperature and flow and performed a literature review of current restoration practices.

The authors modeled stream temperature and flow from a multimodel average of daily gridded precipitation and air temperature. By using the variable infiltration capacity (VIC) model, the inputs were used to predict daily runoff, runoff routing, and stream temperature and flow. (Additional information on the specifics of the development of these parameters is found in Beechie and others [2013].) The scenario mapping exercise compared historical baseline (1970–99) water temperature and flow conditions to those projected for the periods 2000–29, 2030–69, and 2070–99. The researchers modeled mean monthly flows, calculating the change in magnitude and timing of maximum monthly flows between the future period and the historical baseline for each stream cell. They modeled and mapped stream temperature directly. The results indicated lower summer flows (35–75 percent lower), higher monthly maximum flows (10–60 percent higher), and higher air and stream temperatures (maximum weekly mean temperature 2–6 ºC [degrees Celsius] higher). Snowmelt-dominated hydrologic regimes across the region almost entirely disappeared by the 2070–99 time period, and transitional (rain-snow mix) hydrologic regimes contracted substantially as well. By the final 2070–

99 time period, most of the region was characterized by a rainfall-dominated hydrologic regime. The authors compared the projected stream-temperature changes to the known thermal thresholds and seasonal flows needed during different salmonid life stages (Figure B-2).

Beechie and others (2013) carried out a literature review to identify restoration practices that could ameliorate expected changes in streamflow (base-flow decrease and peak-flow increase) and stream temperature, and increase habitat diversity and population resilience. The primary activities most likely to do so include restoring flood-plain connectivity, restoring streamflow regimes, and reaggrading incised stream channels.

This Pacific Northwest salmonid restoration example combines projected climate-exposure information and known ecological sensitivities of salmonid species to improve understanding of potential vulnerability to climate change. This knowledge can help inform management plans to prioritize restoration practices that are more likely to be effective under projected climate scenarios.



🟥 **Increased summer temperature** may decrease growth or kill juvenile salmon where temperatures are already high, but may increase growth where temperatures are low. May also decrease spawning fecundity (e.g., Chum).

🟦 **Decreased summer low flow** may contribute to increased temperatures, decrease rearing habitat capacity for juvenile salmonids, and decrease access to or availability of spawning areas.

🟦 **Increased winter floods** may increase scour of eggs from the gravel, or increase mortality of rearing juveniles where flood refugia are not available.

🟩 **Loss of spring snowmelt** may decrease or eliminate spawning opportunities for spring spawners, and may alter survival of eggs or emergent fry for fall-spawning species.

Figure B- 2. Diagram showing effect of climate change on life stages of salmonids through time, by season. (Modified from Beechie and others, 2013; white rectangles represent the freshwater life-history stage of salmonids, gray boxes represent the ocean stage, and stippled lines indicate an alternate life-history)

The science of incorporating climate change into environmental flow assessments is young and complex. Considerations for incorporating climate change into the framework for developing flow targets to protect aquatic life discussed in Section 6 and illustrated in Figure 10 are presented above. This information can help identify which ecologically significant flow indicators may be most affected by climate change (as determined from the observed trends and projections). These examples can help elucidate relative climate effects (that is, vulnerability) related to flow targets and the aquatic life uses they are designed to protect. States and Tribes can more effectively prioritize limited resources and identify new management actions more strategically to increase aquatic-ecosystem resilience. This framework is meant to be a qualitative assessment to rank relative effects, which may help in identifying and ranking adaptive management actions in later steps. In a resource-constrained environment, managers also need to evaluate the importance of projected climate change on key hydrologic variables compared to that of hydrologic alteration from other anthropogenic sources. The ranking of effects below can assist in this process to optimize management of limited resources.

Table B1. Incorporating climate-change considerations into the framework for quantifying flow targets.

Framework component	Potential climate-change considerations
(1) Formally link narrative criteria to biological goals	May not be applicable to Step 1 unless climate changes affect biological expectations.
(2) Identify target streams	Consider which elements, if any, in the classification of target streams are climate dependent.
(3) Conduct literature review	Consider all potential climate-change-related effects that could eventually threaten the target streams. Identify available climate-change reports relevant to the region or state water resources. Identify potential changes in ecologically relevant flow components from both observed trends and projected changes. It may be helpful to create broad categories of effects and list specific stressors by type for consideration in conceptual model development.
(4) Develop conceptual models	Include climate change in development of conceptual models. Consider how climate-related stressors can affect biological goals from various pathways, building on the findings obtained from the literature review. The level of detail should be commensurate with the level of detail for planning or screening.
(5) Inventory data	Identify which of the available observed hydrologic, climatic, and biological data may be affected by climate-related stress identified in preceding steps. Consider observed data/projected information to identify the already or potentially affected biological indicators and (or) flow indicators/flow-regime components. Rate them considering the following qualitative categories: **consequences (low, medium, high); likelihood (low, medium, high); spatial extent (site, watershed, region); time until problem begins (decades, within next 15 to 30 years, already occurring/likely occurring**). Consider sensitivity: Do some characteristics of the catchment increase or decrease sensitivity to these climate stressors (for example, north-facing aspect or high elevations may reduce sensitivity of snowmelt or water temperature to increased air temperature, whereas south-facing aspect or low elevations may increase sensitivity).

Framework component	Potential climate-change considerations
(6) Identify biological and flow indicators	Identify which biological and flow indicators may be most affected by climate change. Rate them by considering the qualitative categories previously mentioned (consequence, likelihood, spatial extent, time until problem begins).
(7) Develop qualitative or quantitative flow-ecology models	Climate change considerations may not be applicable to Step 7.
(8) Identify acceptable biological condition goals/effects levels	Compare range of potential likely climate changes to the potential flow targets.
(9) Select candidate flow targets	Compare range of potential likely changes to the actual selected flow target. Identify management adaptation actions and determine which of them are most appropriate given the likely effect to flow targets/biological goals.
(10) Monitor, evaluate, and periodically refine flow targets	Assess observed climate and hydrologic data for any emerging climate-change related trends in variability of magnitude, frequency, duration, timing, and rate of change of flow. Identify and assess new or updated climate-change projections. Are the updated projections consistent with observed trends and (or) other existing projected information? How are the updated projections ecologically significant? Do the updated climate change projections merit reassessment of acceptable effects levels and the ability to meet environmental flow targets under current management practices?

As discussed in this appendix, climate change may challenge the management of aquatic resources because past variability is no longer a reliable assumption for the future. However, protection of environmental flows can serve as an adaptation tool, increasing resilience so that a system is more likely to recover from the effects of climate change. Climate-change vulnerability assessments can help managers strategically address water-resource protection in spite of uncertainty. Climate-change vulnerability assessment approaches are highly diverse; the two presented here illustrate only two of the many possible approaches. The California example (Box J) describes a screening-level assessment in which climate-change exposure is the focus, whereas the Pacific Northwest example (Box K) additionally accounts for potential effects of climate exposure on assessment endpoints, in large part on the basis of the sensitivity of the biota and their life stages. The information developed during a climate-change vulnerability assessment can help managers identify differential effects to aquatic resources and understand the reasons that their resources are at risk so they can set priorities and develop appropriate management responses.

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2019-10-29.TNC.Conowingo_FERC_CWA_with_attachments.PDF....................1

Attachment 6

UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

Exelon Generation Company, LLC	)	P-405-106
Conowingo Hydroelectric Project	)	P-405-121

THE NATURE CONSERVANCY'S ANSWER TO JOINT MOTION FOR A RULING ON JOINT OFFER OF SETTLEMENT AND ISSUANCE OF LICENSE

Pursuant to Rule 213 of the Federal Energy Regulatory Commission's ("Commission") Rules of Practice and Procedure, 18 C.F.R. § 385.213, The Nature Conservancy ("the Conservancy" or "TNC") hereby responds to the "Joint Motion of the Maryland Department of the Environment and Exelon Generation Company, LLC for a Ruling on the Joint Offer of Settlement and Issuance of License" ("Motion"), eLibrary no. 20210223-5070 (Feb. 23, 2021). This answer supplements the Conservancy's comments on the Joint Offer of Settlement ("Settlement Offer"), *see* eLibrary no. 20200117-5199. The concerns and questions we raised in the comments have not been resolved. Rather than restate those comments below, we provide them as Attachment 1 and focus herein on further actions the Commission and its Staff must take prior to rendering a decision on the Settlement Offer and new license.

I.
ANSWER

A. The Commission Must Find that the New License, Even If Based on a Settlement Agreement, Is Best Adapted to a Comprehensive Plan of Development Based on a Complete Record.

Exelon and Maryland Department of the Environment ("MDE") ask the Commission "to either issue a new license for the Conowingo Hydroelectric Project ("Project") *or advise the parties what further action is required to issue the license*."[1] They claim the Settlement Offer "allows the Commission to finalize the license, eliminate a significant dispute between MDE and Exelon, and provide immediate benefits to the waterways affected by the Project."[2]

The Conservancy shares Exelon and MDE's concern regarding schedule; the existing license conditions are largely based on outdated science and standards and it is past time to update project operations and facilities. That said, we disagree that MDE and Exelon have shown the Settlement Offer presents the Commission with a basis for issuing a new license that will satisfy the Commission's obligations under Federal Power Act ("FPA") section 10(a), 16 U.S.C. § 803(a).

It is the Commission's policy to favor multi-lateral settlements in licensing proceedings:

> When parties are able to reach settlements, it can save time and money, avoid the need for protracted litigation, promote the development of positive relationships among entities who may be working together during the course of a license term, and give the Commission, as it acts on license and exemption applications, a clear sense as to the parties' views on the issues presented in each settled case.[3]

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[1] Motion, p. 1 (emphasis added).

[2] *Id.* at 2.

[3] FERC, "Policy Statement on Hydropower Licensing Settlements" (Sept. 21, 2006) ("FERC Settlement Policy"), ¶ 2.

However, even under this policy, the Commission has emphasized its duty to independently review and confirm that any offer of settlement satisfies the FPA:

> At the same time, the Commission cannot automatically accept all settlements, or all provisions of settlements. Section 10(a)(1) of the FPA requires that the Commission determine that any licensed project is
>
> > best adapted to a comprehensive plan for improving or developing a waterway or waterways for the use or benefit of interstate or foreign commerce, for the improvement and utilization of waterpower development, for the adequate protection, mitigation, and enhancement of fish and wildlife (including related spawning grounds and habitat), and for other beneficial public uses, including irrigation, flood control, water supply, and recreational and other purposes referred to in section 4(e).
>
> Consequently, in reviewing settlements, the Commission looks not only to the wishes of the settling parties, but also at the greater public interest, and whether settlement proposals meet the comprehensive development/equal consideration standard.[4]

Thus, the Commission is charged with issuing a new license that it finds will be best adapted to a comprehensive plan of development for the Susquehanna River for the next 30 to 50 years, not just one that potentially resolves disputes between only two of the licensing parties.[5] A partial settlement by definition means there are opposing parties; the Commission's policy of deferring to the wishes of the settling parties does not apply to a partial settlement in the same way it does to comprehensive, multi-lateral licensing settlement agreements.

Further, under both the FPA and the National Environmental Quality Act ("NEPA"), the Commission must ensure that it has a complete record adequate to support its licensing

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[4] *Id.* at ¶¶ 3-4.

[5] We note that many of the measures proposed to address the Project's contribution to nutrient and sediment loading to the Lower Susquehanna River and Chesapeake Bay are proposed to be off-license. As such, they cannot be considered by the Commission in its comprehensive planning determination under FPA section 10(a). *See* FERC Settlement Policy, p. 3 ("the Commission has no jurisdiction over such [off-license] agreements and their existence will carry no weight in the Commission's consideration of a license application under the FPA."). The Conservancy restates its "concern that these off-license commitments are inadequate substitutes for clearly defined measures that are enforceable by the Commission. Attachment 1, p. 6.

decision.[6] As stated in the Conservancy's comments on the Settlement Offer and as discussed below, further action is necessary to complete the record for that purpose.

B. **The Commission Must Supplement the FEIS to Consider New Information Prior to Rendering a License Decision.**

The Motion urges that "the time for the Commission to act on the Offer of Settlement is now, as the results and benefits to be realized by the implementation of the Offer of Settlement are slipping away."[7] Again, while we share the Exelon and MDE's concern regarding passage of time, we disagree the Commission has the information it needs to act on the Settlement Offer consistent with its duties under NEPA and the FPA.

Before the Commission can render a decision on the Settlement Offer or new license, it must first undertake environmental analysis of the Settlement Offer and new information that has been developed since Office of Energy Projects ("OEP") Staff published the Final Environmental Impact Statement ("FEIS") in March 2015 (*see* eLibrary no. 20150311-4005).

Under the Council for Environmental Quality's ("CEQ") regulations for implementing the National Environmental Policy Act (NEPA), federal agencies have a continuing responsibility to supplement their environmental analyses if circumstances or information change before the agencies take final action:

> Agencies:
>
> (1) Shall prepare supplements to either draft or final environmental impact statements if a major Federal action remains to occur, and:
>
>> (i) The agency makes substantial changes to the proposed action that are relevant to environmental concerns; or

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[6] *Scenic Hudson Preservation Conference v. Fed. Power Comm'n*, 354 F.2d 608, 621 (2d Cir. 1965) ("*Scenic Hudson*").

[7] Motion, p. 3.

> (ii) There are significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts.[8]

An agency must take a "'hard look' at the new information to assess whether supplementation might be necessary."[9] An agency also has broad discretion under the regulations to "prepare supplements when [it] determines that the purposes of the Act will be furthered by doing so."[10]

Here, the Commission must issue a supplement to the FEIS that provides comparative analysis of the flow regime and water quality mitigation measures proposed in the Settlement Offer to those considered in the FEIS. OEP Staff must also reconsider its alternatives analysis and findings in the FEIS, based on information the following three documents previously entered into the record:

- Maryland's Final 2018 Integrated Report (listing the Lower Susquehanna Mainstem as impaired in meeting the designated use of aquatic life and wildlife caused by flow alteration from Conowingo dam operations);
- U.S. Environmental Protection Agency's (EPA) April 9, 2019 approval letter for the Final 2018 Integrated Report; and
- Final EPA-U.S. Geological Survey (USGS) Technical Report: Protecting Aquatic Life from Effects of Hydrologic Alteration, EPA Report 822-R-16-007/USGS Scientific Investigations Report 2016-5164 (USGS & EPA (2016)).[11]

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[8] 40 C.F.R. § 1502.9(d)(1).

[9] *Norton v. S. Utah Wilderness All.*, 542 U.S. 55, 72–73 (2004) (quoting *Marsh v. Oregon Natural Resources Council,* 490 U.S. 360, 385 (1989)). In Norton, the Court declined to require supplementation because there was "no ongoing 'major Federal action' that could require supplementation." *Id.* Here, by contrast, the Commission has yet to take final action. Even where an agency declines to prepare a supplement, it is required to document it.

[10] 40 C.F.R. § 1502.9(d)(2).

[11] Letter from The Nature Conservancy to Secretary Kimberly D. Bose, eLibrary no. 20191029-5163 (Oct. 29, 2019) ("TNC Additional Information Filing").

In addition, OEP Staff must consider the following documents, which report that climate change has already resulted in increased rainfall, flow, and nutrient and sediment loads to the Chesapeake Bay in a manner that may affect the significance of the cumulative effects of the Project on downstream water quality:

- Chesapeake Bay Program, "Hot, Wet, and Crowded: Phase 6 Climate Change Model Findings" (Apr. 20, 2020) (Attachment 2).
- Chesapeake Bay Program, "Draft Actions/Decisions," (Dec. 17, 2020) (Attachment 3).

OEP Staff's reconsideration of its previous environmental analysis and findings is necessary because these documents show the Conowingo Dam and continued project operation will likely continue to impair the designated use of supporting aquatic life and wildlife on the Lower Susquehanna River mainstem and in the Chesapeake Bay in a manner not disclosed or addressed in the FEIS.[12]

1. OEP Staff Must Issue a Supplement that Compares the Flow Regime Proposed in the Settlement Offer to Those Considered in the FEIS.

The Motion (p. 4) notes that the Settlement Offer proposes a different flow regime for incorporation into the new license than those considered in the FEIS. In previous comments, Exelon has claimed this flow regime "more appropriately balances developmental and non-developmental considerations."[13]

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[12] *See id.*

[13] Exelon, "Reply to Comments on Joint Offer of Settlement," eLibrary no. 20200131-5251 (Jan. 31, 2020) ("Exelon Reply Comments"), p. 45.

OEP Staff has not yet supplemented its previous analysis of the alternative flow schedules to permit the Commission and public to evaluate the comparative merits of the flow regime proposed in the Settlement Offer. Such supplementation is required under NEPA.

NEPA requires a detailed statement of "alternatives to the proposed action."[14] Under the statute, an EIS must:

> present the alternatives to the proposed action. This discussion-of-alternatives requirement is intended to provide evidence that those charged with making the decision have actually considered other methods of attaining the desired goal, and to permit those removed from the decisionmaking process to evaluate and balance the factors on their own. A thorough consideration of all appropriate methods of accomplishing the aim of the proposed action is expected.[15]

This duty under NEPA to study alternatives prior to making a licensing decision parallels the Commission's substantive duty under Section 10(a)(1) duty to undertake a thorough study of alternatives to the proposed license that is based on a complete record.[16] FPA section 10(a)(1) is a "broad public interest standard, requiring consideration of all factors affecting the public interest."[17]

In its reply to the Conservancy's comments on the Settlement Offer, Exelon argued that the proposed flow regime would provide comparable ecological benefits to the NGO-Agency flow regime: "While the Joint Offer of Settlement does not mirror the TNC proposal in all ways, it adopts the same framework and provides many of the same ecological benefits. As important,

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[14] 42 U.S.S. § 4332(2)(C)(iii).

[15] *Sierra Club v. Morton*, 510 F.2d 813, 825 (5th Cir. 1975) (internal citations and notes omitted). *See also Sierra Club v. Watkins,* 808 F.Supp. 852, 874, fn. 40 (D.C. Cir. 1991) ("[E]ven if a project is found to be environmentally beneficial, an agency must still consider alternatives.").

[16] *See Scenic Hudson*, 354 F.2d at 612; *Green Island Power Authority v. FERC*, 577 F.3d 148, 168 (2d Cir. 2009) ("*Green Island*").

[17] *Green Island*, 577 F.3d at 166.

the Joint Offer of Settlement more appropriately balances the developmental and non-developmental considerations than does the TNC proposal."[18] However, Exelon did not provide specific, scientific evidence to support these claims, which appear both unfounded and inaccurate.

To date, Exelon and MDE have not disclosed the ecological benefits of the Settlement Offer's flow regime, despite their access to readily available models and scientific methods to do so. For example, using publicly available data to estimate the value of the Settlement Offer's flow regime for diadromous fish reproduction (striped bass, American shad), TNC estimates that Exelon's proposal will support, in most months, less than 1/3 of maximum available persistent habitat and in many cases less than 10% for important life stages including spawning and egg and larval development.[19] In sum, the evidence does not support Exelon and MDE's claim that the Settlement Offer's proposed flow regime appropriately mitigates project impacts.

2. OEP Staff Must Issue a Supplement that Considers Maryland's Final 2018 Integrated Report and Related Documents.

In 2019, the Conservancy filed Maryland's 2018 Final Integrated Report[20] as an additional information source for OEP Staff's consideration in its alternatives analysis and findings in the FEIS. Section "F.6 Category 4c Waters," of the report lists the Lower Susquehanna River mainstem below Conowingo dam as an impaired waterbody under the Clean Water Act due to non-attainment of the designated use of supporting aquatic life and wildlife.

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[18] Exelon Reply Comments, p. 44.

[19] Attachment 1, p. 24.

[20] Available at https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Documents/Integrated_Report_Section_PDFs/IR_2018/2018IR_Part_F.6_Final.pdf (last accessed Mar. 10, 2021).

The cause of impairment was listed as flow alteration and changes to stream hydraulics, and the pollution source was listed as dam or impoundment. We stated that the impairment listing was supported by the best evidence in the record.[21] We summarized the effects of project operations, particularly the alternation between minimum and peaking operations, including:

- Between a 75% and 95% loss in migration and spawning habitat for diadromous fish including striped bass and American shad;
- Alteration of the resident fish community from riverine species toward habitat generalists (e.g. gizzard shad) and estimated loss of 50 to 80% of persistent spawning habitat;
- Loss of freshwater mussel recruitment below the dam;
- 'Hydrologically impaired' macroinvertebrate community;
- Fish stranding and mortality due to ramping and resulting dewatering, thermal stress and predation;
- Loss of state and federally endangered species habitat for reproductive growth and hibernation;
- Sediment-starved lower river and flats; and
- Absence or reduction of Submerged Aquatic Vegetation (SAV) communities below the dam.[22]

The Conservancy asked that OEP Staff reconsider the evidence in the record that showed the flow regime proposed in the Staff Alternative would not be adequate to address project impacts documented in the impaired listing. In support, we summarized deficiencies in the analysis in the FEIS as follows:

- The Staff Alternative recommends minimum flow releases that are lower than historic minimum flows for much of the year and rates of change from hydropeaking that would result in daily fluctuations in river stage of up to 7 feet;

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[21] TNC Additional Information Filing, p. 3.

[22] *Id.* at 3-4 (internal citations omitted).

> - This approach for developing an operational recommendation below a hydropeaking facility focuses on a measure of instantaneous habitat (Maximum Weighted Usable Area) and is characteristic of scientific understanding 50 years ago. However, contemporary scientific methods to compare and develop operational recommendations below a hydro-peaking facility require the use of persistent habitat measures and time-series analysis to track the availability of habitat throughout daily and weekly hydro-peaking cycles; and
>
> - The documentation in the EIS does not demonstrate that the comparison of alternatives is based on a valid scientific method.[23]

OEP Staff has not responded to the Conservancy's request to date. Exelon summarily responded that the flow regime proposed in the Settlement Offer was adequate to address the impairment.[24] However, as we commented on the Settlement Offer:

> The Explanatory Statement does not explain whether the proposed operational flow regime will address the Conowingo Project as the source of flow alteration and changes to stream hydraulics, specifically daily changes in depth and velocity, that have caused non-attainment of the designated use of supporting aquatic life and wildlife on the Lower Susquehanna River.[25]

Before the Commission acts on the Settlement Offer or new license, OEP Staff must evaluate how the flow regime proposed in the Settlement Offer, as compared to the other flow regime alternatives, will address the Conowingo Project as the source of impairment of the designated use of supporting aquatic life and wildlife.

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[23] *Id.* at 4 (internal citations omitted).

[24] "Answer of Exelon Generation Company, LLC," eLibrary no. 20191108-5053 (Nov. 8, 2019), p. 2.

[25] Attachment 1, p. 5; *see also id.* at 9-29.

3. OEP Must Issue a Supplement that Considers New Information regarding Potential Project Impacts on Nutrient and Sediment Loading in the Lower Susquehanna River and Chesapeake Bay over the Term of the New License and Measures to Mitigate those Impacts.

The Motion states that climate change may affect release of sediment trapped by Conowingo Dam: "… Conowingo Dam has trapped significant amounts of the nutrients and sediment present in the Susquehanna River. This in-fill material can be impacted by storm events, which likely will increase in intensity as a result of climate change."[26]

The Conservancy agrees that climate change will likely worsen storm-related releases of nutrients and sediment into the Chesapeake Bay, but disagrees that Exelon and MDE have shown the Settlement Offer provides adequate measures to mitigate the Project's contribution to this significant threat to the Chesapeake Bay. In our comments on the Settlement Offer, we stated, "[t]he Conservancy is very concerned by the Settlement Offer's omission of an adaptive management program and additional restrictions on reopener given our improved understanding of how climate change is likely to affect the Susquehanna River Basin over the term of any new license."[27] There is new information that reinforces this concern.

New scientific information[28] estimates that effects from climate change have already resulted in increased rainfall, flow, and nutrient and sediment loads to the Chesapeake Bay, and those impacts will accelerate in coming decades. The Principal Staff Committee of the Chesapeake Bay Program Partnership confirmed in December 2020[29] that "estimates for the

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[26] Motion, p. 4.

[27] Attachment 1, p. 35.

[28] Attachment 2, slide 4.

[29] Attachment 3, p. 1.

climate impact through 2035 indicate a doubling of the 2025 load effect. The effect of climate change on our ability to meet the Bay's water quality standards is a significant and increasing concern."

Notably, nearly a century of observations indicates there is an increasing volume of precipitation being delivered every year, and that this increased volume is delivered through higher intensity events. Some of the largest increases in rainfall volume in the Chesapeake Bay watershed are predicted to occur in the Susquehanna River basin.[30]

This new information magnifies the Conservancy's concern that the record does not show that measures proposed in the Settlement Offer for inclusion in the new license can or will be adapted to address the documented changing conditions in the Susquehanna River. Information regarding the efficacy of proposed mitigation is required by NEPA.

Under NEPA, an EIS must include "a detailed discussion of possible mitigation measures" to show that the agency carefully considered the significant environmental impacts of a project, including whether there are measures that would avoid, minimize, or mitigate those impacts.[31]

> An essential component of a reasonably complete mitigation discussion is an assessment of whether the proposed mitigation measures can be effective. *Compare Neighbors of Cuddy Mountain v. U.S. Forest Service,* 137 F.3d 1372, 1381 (9th Cir.1998) (disapproving an EIS that lacked such an assessment) *with Okanogan Highlands Alliance v. Williams,* 236 F.3d 468, 477 (9th Cir.2000) (upholding an EIS where "[e]ach mitigating process was evaluated separately and given an effectiveness rating"). The Supreme Court has required a mitigation discussion precisely for the purpose of evaluating whether anticipated environmental impacts can be avoided. *Methow Valley,* 490 U.S. at 351–52, 109 S. Ct. 1835 (citing 42 U.S.C. § 4332(C)(ii)). A mitigation

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[30] Attachment 2, slide 6.

[31] *Westlands Water Dist. v. U.S. Dep't of Interior*, 376 F.3d 853, 872–73 (9th Cir. 2004) (citing *Robertson v. Methow Valley Citizens Council*, 490 U.S. 332, 349 (1989).

> discussion without at least *some* evaluation of effectiveness is useless in making that determination.[32]

Indeed, "omission of a reasonably complete discussion of possible mitigation measures would undermine the "action-forcing" function of NEPA. Without such a discussion, neither the agency nor other interested groups and individuals can properly evaluate the severity of the adverse effects."[33]

Here, there is strong evidence that climate change is and will continue to change how the river flows and, since the Project alters the form and timing of pollutants moving through the river, the new license must address how these additional impacts will be effectively mitigated over the license term.

4. OEP Staff Should Supplement the FEIS to Consider New Information regarding Battery Storage.

As stated above, the Project has been identified as the source of impairment of the designated use of supporting aquatic life and wildlife in the Lower Susquehanna River, largely due to its operations to generate power for peak demand. Prior to the publication of the impairment listing, OEP Staff rejected the NGO-Agency flow regime, which would provide greater protection to aquatic life and wildlife, because "[o]peration under the TNC Flow Regime would be restrained and would eliminate many of the [Project's] peaking and ancillary services benefits ….[34]

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[32] *S. Fork Band Council Of W. Shoshone Of Nevada v. U.S. Dep't of Interior*, 588 F.3d 718, 727 (9th Cir. 2009); *see also Pac. Coast Fed'n of Fishermen's Associations v. Blank*, 693 F.3d 1084, 1103 (9th Cir. 2012).

[33] *Robertson v. Methow Valley Citizens Council*, 490 U.S. 332, 352 (1989).

[34] FEIS, p. 429.

There is new information since the FEIS was published that integration of battery storage at the Project could reduce the impacts of peaking generation at the Project for the benefit of aquatic species without restraining operations in a manner that would harm the energy market. Research by the U.S. Energy Information Administration shows "[l]arge-scale battery storage systems are increasingly being used across the power grid in the United States," as technology costs decrease and regulatory hurdles are addressed.[35] Despite these developments, the Settlement Offer does not propose options for technology integration, like utility scale battery storage, over the term of the license.

The Director of OEP recently approved a "Battery Storage Feasibility Study to Retain Full Peaking Capabilities While Mitigating Hydropeaking Impacts" as part of the relicensing of the R.L. Harris Project (P-2628) located in Alabama. According to the Study Plan Determination:

> The goal of the study is to determine whether a battery energy storage system (BESS) could be economically integrated at Harris to mitigate the impacts of peaking, while retaining full system peaking capabilities. Under such a scenario, the BESS would be used to provide power during peak demand periods, which would decrease the need for peak generation flow releases and reduce flow fluctuations downstream of the project. The objectives of the study are to evaluate battery type and size configurations, costs, and ownership options, as well as technical barriers to implementing BESS. The study would also assess how much operational flexibility could be provided by BESS and allow for more control of discharges downstream of the dam.[36]

In approving the study OEP Staff noted, "[t]he cost of batteries … is rapidly decreasing," adding, "[t]he National Energy Research Laboratory reports that since 2018, battery costs have been reduced by about 15 percent, with further decreases expected."

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[35] *See* U.S. Energy Information Administration Battery Storage in the United States; An Update on Market Trends" (July 2020) (Attachment 4).

[36] Letter from Terry L. Turpin to Angie Anderegg re: Determination on Requests for Study Modifications for the R.L. Harris Hydroelectric Project, eLibrary no. 20200810-3007 (Aug. 10, 2020), App. B, pp. B-9 – B-10.

OEP Staff should supplement its analysis here to evaluate measures to potentially integrate battery storage at the Project over the term of the license in order to mitigate the impacts of project operations on downstream water quality, including designated uses, while preserving the Project's ability to provide peak and ancillary services.

C. <u>OEP Staff Should Convene a Technical Conference.</u>

The Conservancy reiterates its request that OEP Staff convene a technical conference pursuant to Rule of Practice and Procedure 601, 18 C.F.R. § 385.601, to address the disputed or otherwise unresolved issues identified above and in Section III of the Conservancy's comments on the Settlement Offer. We previously explained the need for a technical conference:

> the explanation provided in the Settlement Offer does not show that the proposed terms will mitigate the Project's impacts on ecological resources in the Lower Susquehanna River and Chesapeake Bay, and there remain disputes regarding which measures *will* mitigate project impacts consistent with the Commission's comprehensive planning responsibility under FPA section 10(a). These disputes remain even though the relicensing has been pending for over a decade, and are more likely to carry over into litigation if OEP Staff do not provide an opportunity for a technical conference or other dispute resolution procedures prior to license issuance.[37]

The Conservancy remains committed to participating in such a conference and specifically working with OEP Staff and other interested parties to identify ways to increase the effectiveness of the Project's operational flow regime and other proposed mitigation measures in a manner that preserves the Project's value as a generation asset.

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[37] Attachment 1, p. 36.

CONCLUSION

We thank the Commission for considering this Answer in response to Exelon and MDE's Motion.

Dated: March 10, 2021

Respectfully submitted,

Julie Gantenbein

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DECLARATION OF SERVICE

Exelon Generation Company, LLC's Conowingo Hydroelectric Project (P-405)

I, Emma Roos-Collins, declare that I today served the attached "The Nature Conservancy's Answer to Joint Motion for a Ruling on Joint Offer of Settlement and Issuance of License for the Conowingo Hydroelectric Project (P-405)," by electronic mail, or by first-class mail if no e-mail address is provided, to each person on the official service list compiled by the Secretary in this proceeding.

Dated: March 10, 2021

By: Emma Roos Collins

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Attachment 1

UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

	)	
Exelon Generation Company, LLC	)	
Conowingo Hydroelectric Project	)	P-405-106
	)	
	)	

THE NATURE CONSERVANCY'S COMMENTS ON OFFER OF SETTLEMENT

Pursuant to the Federal Energy Regulatory Commission's (Commission) Rules of Practice and Procedure, *see* 18 C.F.R. § 385.602(f), The Nature Conservancy (TNC or the Conservancy) provides these comments to the "Joint Offer of Settlement and Explanatory Statement of Exelon Generation Company, LLC and the Maryland Department of the Environment," eLibrary no. 20191029-5119 (October 29, 2010) (Settlement Offer).

As stated in its Motion to Intervene,[1] the Conservancy has significant interests in the restoration and long-term protection of the lower Susquehanna River and Chesapeake Bay. It has participated actively in the relicensing proceeding to develop the scientific record regarding the Conowingo project's impacts on water quality and aquatic resources in the lower Susquehanna and Chesapeake Bay and measures to avoid, minimize, or mitigate those impacts.[2] For example, it worked collaboratively with other relicensing participants to develop an alternative operational

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[1] TNC, "Motion to Intervene, Recommended Alternatives for Environmental Analysis, and Preliminary Terms and Conditions," eLibrary no. 20140131-5199 (Jan. 31, 2014) (TNC MOI), pp. 1-2.

[2] *See, e.g, id.*; TNC, "Comments on Draft Multi-Project Environmental Impact Statement For Hydropower Licenses, Susquehanna River Hydroelectric Projects," eLibrary no. 20140929-5354 (Sept. 29, 2014);TNC, "Supplemental Comments on Draft Multi-Project Environmental Impact Statement For Hydropower Licenses, Susquehanna River Hydroelectric Projects," eLibrary no. 20150206-5219 (Feb. 6, 2015); TNC, "Letter re: Exelon Generation Company, LLC's Conowingo and Muddy Run Projects (P-405, P-2355), and York Haven Power Company, LLC's York Haven Project (P-1888)," eLibrary no. 20150304-5131 (Mar. 4, 2015); TNC, "Comments on Final Multi-Project Environmental Impact Statement For Hydropower Licenses, Susquehanna River Hydroelectric Projects," eLibrary no. 20150416-5198 (Apr. 16, 2015) (TNC FEIS Comments); TNC, "Letter re: Conowingo Hydroelectric Project (P-405-106)," eLibrary no. 20191029-5163 (Oct. 29, 2019).

flow regime (NGO-Agency Flow Alternative) that could meet biological objectives for migratory and residence fish, freshwater mussels, macroinvertebrates, aquatic turtles, and submerged aquatic vegetation (SAV), while limiting costs to 1% of annual revenue.[3] As a science-based organization, the Conservancy recognizes that the Susquehanna River and Chesapeake Bay are complex ecosystems with multiple sources of ecological impacts, upstream and downstream. In that context our focus in these proceedings has been on defining and mitigating the *incremental* impact of Conowingo dam on these systems over the term of the requested license. Consistent with this focus, the Conservancy has advocated, before the Commission and the Maryland Department of the Environment (MDE),[4] for a new license that strikes an appropriate balance between the power and non-power benefits of the project based on this and other scientific data in the record.

The Conservancy is concerned that the Settlement Offer will not be protective of the already degraded aquatic ecosystems that will continue to be heavily impacted by the presence and operation of the Conowingo Project for the next 30 to 50 years. The Explanatory Statement accompanying the Settlement Offer, which is short on science-based analysis and evidence, does not allay this concern. More specifically, the Explanatory Statement does not resolve two key issues that are critical to the Commission's comprehensive development analysis under Federal Power Act (FPA) section 10(a)(1), 16 U.S.C. § 803(a)(1), and ultimate licensing decision:

- Whether the proposed operational flows will comply with water quality standards and address the Project's contribution to hydrologic impairment in the Lower Susquehanna River; and

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[3] TNC, "Letter re: Conowingo Hydroelectric Project (P-405-106)," eLibrary no. 20191029-5163 (Oct. 29, 2019).

[4] *See* letter from Allison Vogt to Elder Ghigiarelli, Jr. (Jan. 16, 2018) (Enclosure 1).

- Whether off-license measures are adequate to mitigate the Project's incremental impacts on water quality (including sediment and nutrients) in the Lower Susquehanna River and Chesapeake Bay.

These comments are organized as follows: Section I provides general comments on the adequacy of the Explanatory Statement; Section II provides comments regarding the enforceability of settlement terms; Section III provides comments regarding whether the Settlement Offer shows the proposed measures will effectively address project impacts over the term of the new license; Section IV requests the Commission's Office of Energy Projects (OEP) Staff convene a technical conference; and Section V concludes the comments. Section III includes specific questions for the Settling Parties and/or OEP Staff that seek to clarify the basis for certain proposed settlement terms, including claims that such terms will adequately mitigate the project impacts over the proposed 50-year license term. We request that the Settling Parties respond in writing to these questions prior to OEP Staff convening a technical conference to address remaining technical disputes, as requested in Section IV.

I.

The Settlement Offer Does Not Include an Adequate Explanatory Statement.

Under the Commission's rules, "[a]n offer of settlement must include: (i) The settlement offer; (ii) A separate explanatory statement; (iii) Copies of, or references to, any document, testimony, or exhibit, including record citations if there is a record, and any other matters that the offeror considers relevant to the offer of settlement …."[5]

The Commission's "Policy Statement on Hydropower Licensing Settlements" (Sept. 21, 2006) (Settlement Policy) further states that settling parties should: "[p]repare an explanation of the settlement that will enable the Commission to understand the parties' intent *and what in the*

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[5] 18 C.F.R. § 385.602(c)(1).

record they believe supports their proposals."[6] Such explanation and citation to the record is important because:

> The Commission must also ensure that its decisions on settlements, like all decisions under the FPA, are supported by substantial evidence. To support a proposed license condition, then, it is necessary for the parties to develop a factual record that provides substantial evidence to support the proposed condition, and demonstrates how the condition is related to project purposes or to project effects. The settling parties should provide the Commission with record support showing a nexus between the proposal and the impacts of the project, as well as to project purposes, and also explain how the proposal will accomplish its stated purpose.[7]

The Settlement Offer broadly claims, "the Proposed License Articles are fully supported by the record in the proceeding, including the Final Environmental Impact Study (the "EIS") and the relicensing studies undertaken by Exelon in consultation with resource agencies and other stakeholders."[8] However, as discussed in more detail in Section III, the Explanatory Statement does not show this to be the case.

For example, with regard to flow, the Explanatory Statement includes multiple citations to the record regarding the potential impacts of project operations on downstream resources.[9] However, it does not provide science-based analysis or evidence in support of its claim that the proposed flow regime will mitigate those impacts. It states that it is incorporating two discrete flow-related recommendations made by OEP Staff in the EIS – e.g., eliminating periods of zero minimum flow in the winter and increasing minimum flows in early June – but does not show that its flow proposal with these changes will be protective of water quality and aquatic resources. It states that the flow regime "will provide additional benefits and protection," but

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[6] Settlement Policy (emphasis added), p. 4.

[7] *Id.* at 3.

[8] Settlement Offer, p. 2.

[9] *Id.* at 10.

does not attempt to quantify the "benefits," describe them in biologically meaningful terms, or cite to any record evidence in support.[10] It does not respond to the evidence submitted by the Conservancy, Susquehanna River Basin Commission (SRBC), and U.S. Department of the Interior's Fish and Wildlife Service (FWS), that Exelon's previous flow proposal, which is substantially similar to the one proposed in the Settlement Offer, with the exception of Mid-March through May, will continue, not mitigate, ongoing degradation of ecological resources and impairment of water quality.[11] The Explanatory Statement does not explain whether the proposed operational flow regime will address the Conowingo Project as the source of flow alteration and changes to stream hydraulics, specifically daily changes to depth and velocity, that have caused non-attainment of the designated use of supporting aquatic life and wildlife on the Lower Susquehanna River,[12] even though the Settlement Offer effectively waives Maryland's authority to address that impairment further. *See* Section IV, *infra*.

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[10] Settlement Offer, p. 11.

[11] *See* Enclosure 1, *see also* Susquehanna River Basin Commission, "Comments Regarding Final Environmental Impact Statement for the Susquehanna River Hydroelectric Projects (York Haven Project-FERC Project No. 1888-030; Muddy Run Project-FERC Project No. 2355-018; Conowingo Project-FERC Project No. 405-106)," eLibrary no. 20150420-5208 (Apr. 20, 2015), pp. 3-5; U.S. Department of the Interior, "Review of Notice of Application Ready for Environmental Analysis, Conowingo Hydroelectric Project, Federal Energy Regulatory Commission (FERC No. 405-106): Comments, Recommendations, Preliminary Terms and Conditions, and Preliminary Prescriptions," eLibrary no. 20140131-5194 (Jan. 31, 2014), pp. 15-16.

[12] TNC, "Letter re: Conowingo Hydroelectric Project (P-405-106)," eLibrary no. 20191029-5163 (Oct. 29, 2019); *see also* Maryland's 2018 Final Integrated Report - Category 4c Waters (April 9, 2019), *available at* https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Documents/Integrated_Report_Section_PDFs/IR_2018/2018IR_Part_F.6_Final.pdf (last accessed Jan. 17, 2020); letter from Catherine A. Libertz to Lee Currey (Apr. 9, 2019), *available at* https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Documents/Integrated_Report_Section_PDFs/IR_2018/2018_EPA_Approval_Letter.pdf (last accessed Jan. 17, 2020).

II.
The Settlement Offer Includes Several Terms that Would Be Unenforceable by the Commission.

A. The Settlement Offer Relies Too Heavily on Off-License Measures.

The Settlement Offer includes several measures that would not be included in the new license. Many of the measures commit Exelon to fund MDE and/or the Maryland Department of Natural Resources (MDNR) initiatives. The Conservancy is concerned that these off-license commitments are inadequate substitutes for clearly defined measures that are enforceable by the Commission.

According to the Commission's Settlement Policy, parties may include off-license commitments in a settlement offer, but the Commission cannot consider such agreements in evaluating whether a settlement offer complies with the FPA and is in the public interest:

> Settling parties are free to enter into "off-license" or "side" agreements with respect to matters that will not be included in a license. However, the Commission has no jurisdiction over such agreements and *their existence will carry no weight in the Commission's consideration of a license application under the FPA*.[13]

The off-license measures in the Settlement Offer appear intended to address a wide-range of project-related impacts, including restoration of the mussel populations, improved eel passage, improved water quality, study of removal and disposal, tailrace gaging, etc. However, because these measures are off-license, the Commission cannot consider them. The record does not show that the Settlement Offer as a whole is adequate to mitigate project impacts on affected resources. The extent of unmitigated impacts under the Settlement Offer is even greater if the Commission cannot consider the off-license agreements. In short, the Settling Parties have not shown that a new license based on the proposed license articles will comply with the

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[13] Settlement Policy, p. 3 (emphasis added).

Commission's duty under FPA section 10(a)(1) to ensure the licensed project is best adapted to a comprehensive plan of development for the Susquehanna River.

In addition to the Commission's inability to consider off-license measures in its comprehensive development analysis, it is contrary to the public interest to have measures intended to comply with legal requirements for environmental protection enforceable only by the licensee and MDE as a matter of contract. This interferes with the Commission's statutory oversight and enforcement authorities. It also denies the public a venue to seek enforcement of such measures.

B. The Proposed License Articles Are Not Sufficiently Enforceable.

The Settlement Offer includes a number of proposed license articles.[14] Leaving aside disputes regarding the substance of the proposed articles, a number of them are drafted in a way that are not sufficiently enforceable by the Commission.

According to the Commission's Settlement Policy: "proposed license conditions must be enforceable.… [C]onditions that do not clearly outline the licensee's responsibilities and establish the parameters governing required actions may be difficult or impossible to enforce."[15]

For example, the Settlement Offer includes a proposed license article for "Trash and Debris." However, the proposed license article does not include any provisions for notifying the Commission of complaints relating to accumulated trash and debris, reporting compliance with proposed cleanup requirements, or other measures for monitoring whether proposed measures are adequate in terms of public safety, environmental resources, and project facilities.[16]

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[14] Settlement Offer, Attachment A.

[15] Settlement Policy, p. 3.

[16] Settlement Offer, Attachment A, p. 8.

As another example, the proposed license article, "Monitoring Stream Flows in the Tailrace," states: "licensee shall perform and submit to the Maryland Department of the Environment a study regarding the feasibility of redesigning, installing, and maintaining best available real-time flow telemetry at the stream gage in the Project tailrace …." If the study found it would be feasible, Exelon's obligation to prepare and implement a Tailrace Gage Plan is dependent on the outcome of the study. As such, the Commission should have oversight for the feasibility study itself, including the criteria that will be applied to determine feasibility.

III.

The Settlement Offer Does Not Show the Proposed Terms Will Address the Project's Significant Environmental Impacts on Ecological Resources of the Lower Susquehanna River over the License Term.

As the proponents of the Settlement Offer, Exelon and MDE have the burden of showing that their proposal would protect the public interest and meeting the Commission's comprehensive development/equal consideration standard.[17] Again, it is the Settling Parties' responsibility "to develop a factual record that provide substantial evidence to support the proposed condition, and demonstrates how the condition is related to project purposes or to project effects."[18] It is also their responsibility to "explain how the proposal will accomplish its stated purposes."[19]

Based on our review, the settling parties have not met this burden with respect to certain conditions discussed below.

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[17] Settlement Policy, p. 2.

[18] *Id.* at 2-3.

[19] *Id.* at 3.

A. The Settlement Offer Does Not Show the Proposed Flow Regime Will Protect Fish and Other Aquatic Resources in the Lower Susquehanna River.

As MDE found in issuing the water quality certification, operation of the Conowingo Project has significant and presently unmitigated impacts on the availability of habitat for fish and wildlife in the Lower Susquehanna River ecosystem.[20] These impacts are linked to (1) the operation of Conowingo dam, as part of an open-looped pumped storage system with daily peaking and (2) the trapping of coarse substrate (sand, gravel and cobble) behind the dam that is critical for maintaining habitat for the growth and propagation of fish, wildlife and aquatic vegetation in the Lower Susquehanna River and provides additional benefits to the Chesapeake Bay.[21]

The Settlement Offer provides (p. 10), "[t]o mitigate any potential impacts, Exelon has agreed to a two-phased operational flow regime." Within three years of license issuance, the Settlement Offer proposes to adjust operational flows from current operations (*see* Attachment A, p. 1, "Operational Flow Regime"). The Explanatory Statement (p. 17) states the proposed, "operational flow regime of the Conowingo Project will, within three years of license issuance, significantly increase minimum flow releases at the project." It also claims the flow regime will provide ecological benefits: "[t]hese increased flow will provide additional aquatic habitat downstream of Conowingo Dam. Additionally, the limitations on ramping will reduce the potential for fish stranding, improve conditions for fish migrating upstream, and reduce impacts to spawning." *Id.*

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[20] *See* MDE, "Clean Water Act Section 401 Certification for the Conowingo Hydroelectric Project FERC Project No. P-405/MDE WSA Application No. 17-WQC-02 (Apr. 27, 2018) (401 Certification), Section 6 (Summary of Findings); *see also* Enclosure 1.

[21] *See* Enclosure 1.

The Conservancy disagrees that the Settling Parties have shown their proposed operational flow regime will mitigate the impacts of project operations, particularly peaking operations, on habitat and ecological health in the Lower Susquehanna River for four main reasons: (1) under the existing license conditions, operations cause impairment of the aquatic life and wildlife designated use on the Lower River, (2) proposed minimum flows would be very similar to or lower than the existing license for most of the year (3) the magnitude of daily peaking will continue to severely limit habitat availability for fish, wildlife and aquatic vegetation and (4) proposed down ramping conditions do not adequately consider the evidence of stranding impacts. We address each of these reasons in more detail below.

1. Conowingo Dam operations cause impairment of the aquatic life and wildlife designated use on the Lower Susquehanna River mainstem.

The Conservancy previously requested that OEP Staff consider Maryland's 2018 Final Integrated Report (April 9, 2019), Section "F.6 Category 4c Waters," which lists the Lower Susquehanna River mainstem below Conowingo dam as an impaired waterbody under the Clean Water Act (CWA) for non-attainment of the designated use of supporting *aquatic life and wildlife*.[22] Conowingo Dam is identified as the source of the flow alteration and changes to stream hydraulics (depth and velocity) that cause non-attainment of the designated use. The report states that assessment of the flow regime and measured biological impacts were used to demonstrate the "Conowingo Dam operations cause impairment of the aquatic life and wildlife designated use."[23] The Environmental Protection Agency approved Maryland's listing on April 9, 2019.

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[22] TNC, "Letter re: Conowingo Hydroelectric Project (P-405-106)," eLibrary no. 20191029-5163 (Oct. 29, 2019).

[23] *Id.*

As supported by the record and summarized in the Conservancy's previous filings, operational impacts to aquatic life and wildlife include:

- 75 to 95% loss in available spawning, egg and larval habitat for diadromous fish including American shad, river herring, striped bass and Atlantic and shortnose sturgeon and little to no evidence of successful larval development within reach. (*see* TNC MOI, p. 14, Attachment 1, Table 4 and Figures 6-12, 23-30, 32-41);
- Altered migration cues and lengthen migratory times for diadromous fish (TNC MOI, Attachment 1, Table 4);
- Alteration of the resident fish community toward habitat generalists and an estimated loss of 50 to 80% of persistent spawning habitat (*see* TNC MOI, Attachment 1, Table 4 and Figures 17, 26, 41-43);
- Fish stranding and mortality due to peaking, downramping and dewatering, thermal stress and predation (*see* TNC MOI).
- Loss of freshwater mussel recruitment below the dam (*see* TNC MOI, pp. 14-15, Attachment 1, Table 4 and Figure 13; *see also* RSP 3.19,[1] pp. ii.);
- An impaired macroinvertebrate community, dominated by highly tolerant species (*see* TNC MOI, p. 15, *see also* RSP 3.18,[1] pp. 16-17);
- Loss of state and federally endangered species habitat, including reptiles, for reproductive growth and hibernation (*see* TNC MOI, p. 15, Attachment 1, Table 4, Figures 18, 22 (map turtles), Figures 11, 16, 25, 29, 35-37 (Shortnose sturgeon);
- Sediment-starved lower river and flats (*see id.* at 15-16);
- Loss of Submerged Aquatic Vegetation (SAV) communities below the dam (*see* TNC MOI, TNC NREA Comments, p. 15); and
- Loss of stable shallow feeding habitats for wading birds below the dam (egrets, great blue heron).

2. Proposed minimum flows are very similar to, or lower than, the existing license for most of the year and are below typical drought conditions for most of the year.

We agree with the Settlement Offer's claim that, in the spring months, proposed minimum flow releases will be substantially increased, relative to minimum flows under the existing license approved in 1980. However, this would not be the case for the summer, fall and winter months. Rather, the proposed minimum flows in summer, fall and winter months – that is for three-quarters of the year – would be very similar to or below the minimum flows in the existing license (*see* Figure 1). As acknowledged in RSP 3.16,[24] successful propagation and growth requires suitable habitat conditions across all life stages. The seasonal periodicity of several fish, macroinvertebrate and freshwater mussel species in the Lower River is illustrated in Table 1, including dependences on summer, winter and fall months.

Further, in all months, the proposed minimum flow releases are below typical drought conditions (monthly Q95) for most of the year, below the historic daily flows in December, January, February, and April, and orders of magnitude below median conditions, year-round (*see* Figure 2). As stated in our Motion to Intervene, the Conservancy in partnership with the SRBC and the U.S. Army Corps of Engineers, developed ecosystem flow recommendations to support the species and ecological functions of the Susquehanna River mainstem (DePhilip and Moberg 2010). The study provides clear evidence that the proposed minimum flow releases below the monthly Q95 are inadequate to mitigate Project impacts and is supported by the USGS & EPA

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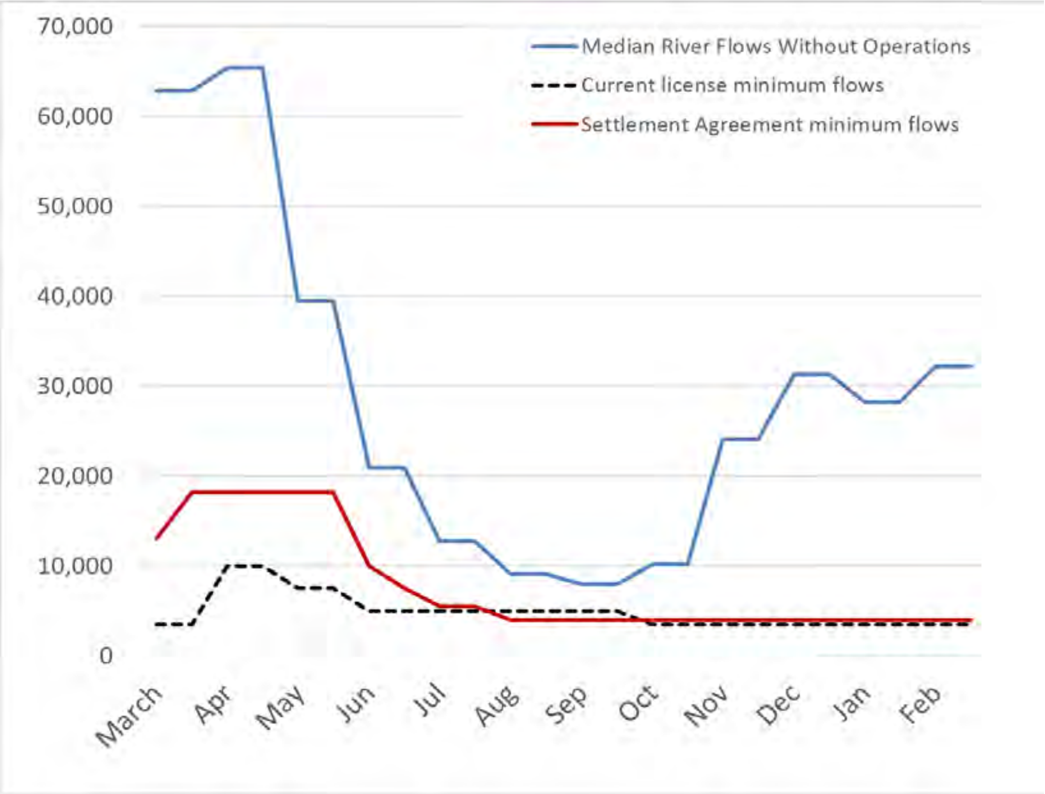
[24] Exelon, "Final Study Report: Instream Flow Habitat Assessment Below Conowingo Dam: RSP 3.16" (Aug. 2012), *available at* https://mde.maryland.gov/programs/Water/WetlandsandWaterways/Documents/ExelonMD/WQCApplication0517_pp1202-1476.pdf (last accessed Jan. 17, 2020).

(2016) technical guidance for developing flow standards to support Clean Water Act water quality standards and their beneficial uses (pp. 41-51).[25]

Figure 1. A Comparison of median river flows without operations (blue), current minimum flows requirements (dashed black) and minimum flows in the Proposed License Articles (red).



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[25] *See* TNC, "Letter re: Conowingo Hydroelectric Project (P-405-106)," eLibrary no. 20191029-5163 (Oct. 29, 2019).

Table 1. Under the Settlement Offer, **minimum flows will remain the same or lower than the existing condition through the summer, fall and winter**. **As illustrated by RSP 3.16, most species have life stages that require suitable habitat during summer, winter and fall.**

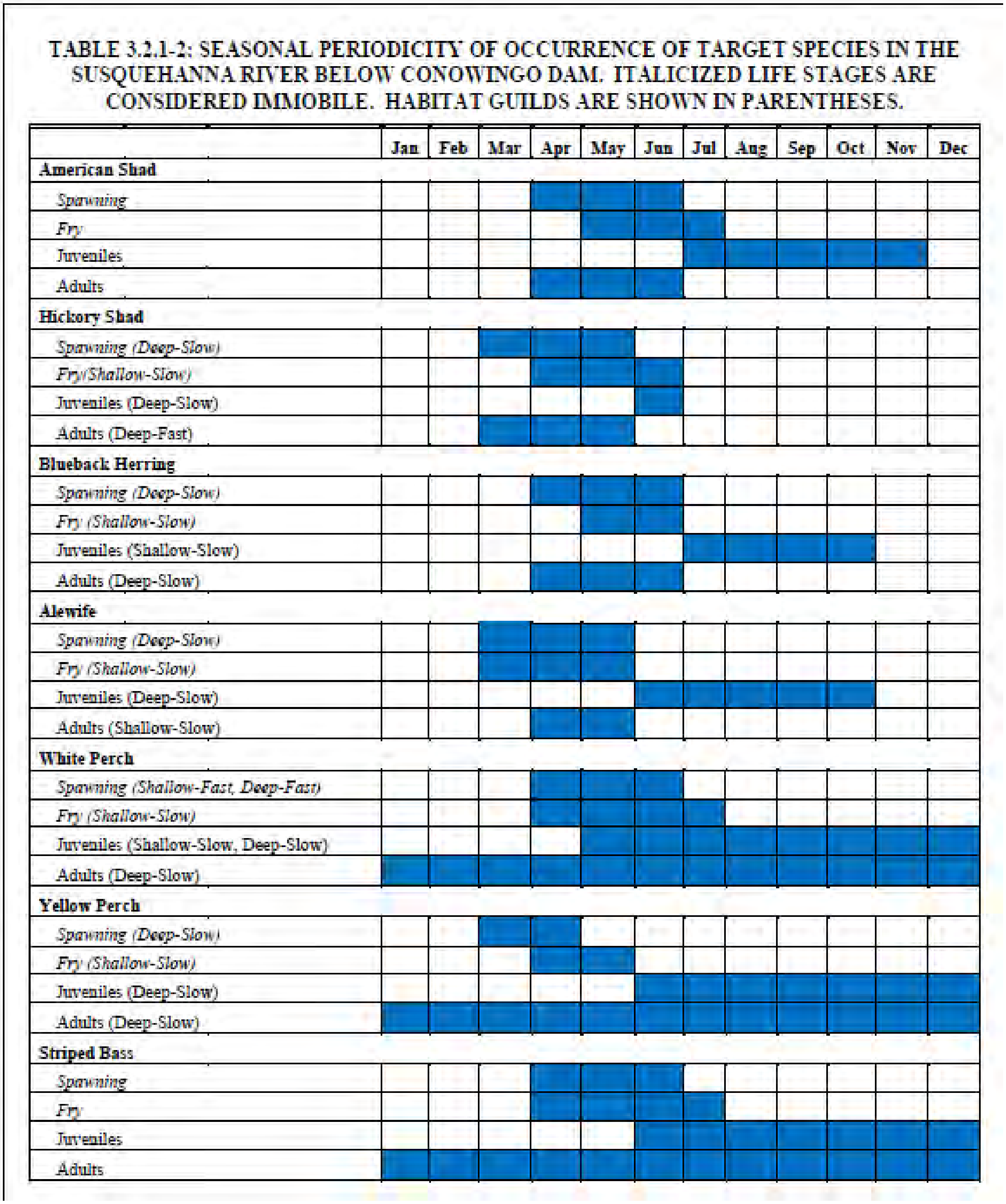


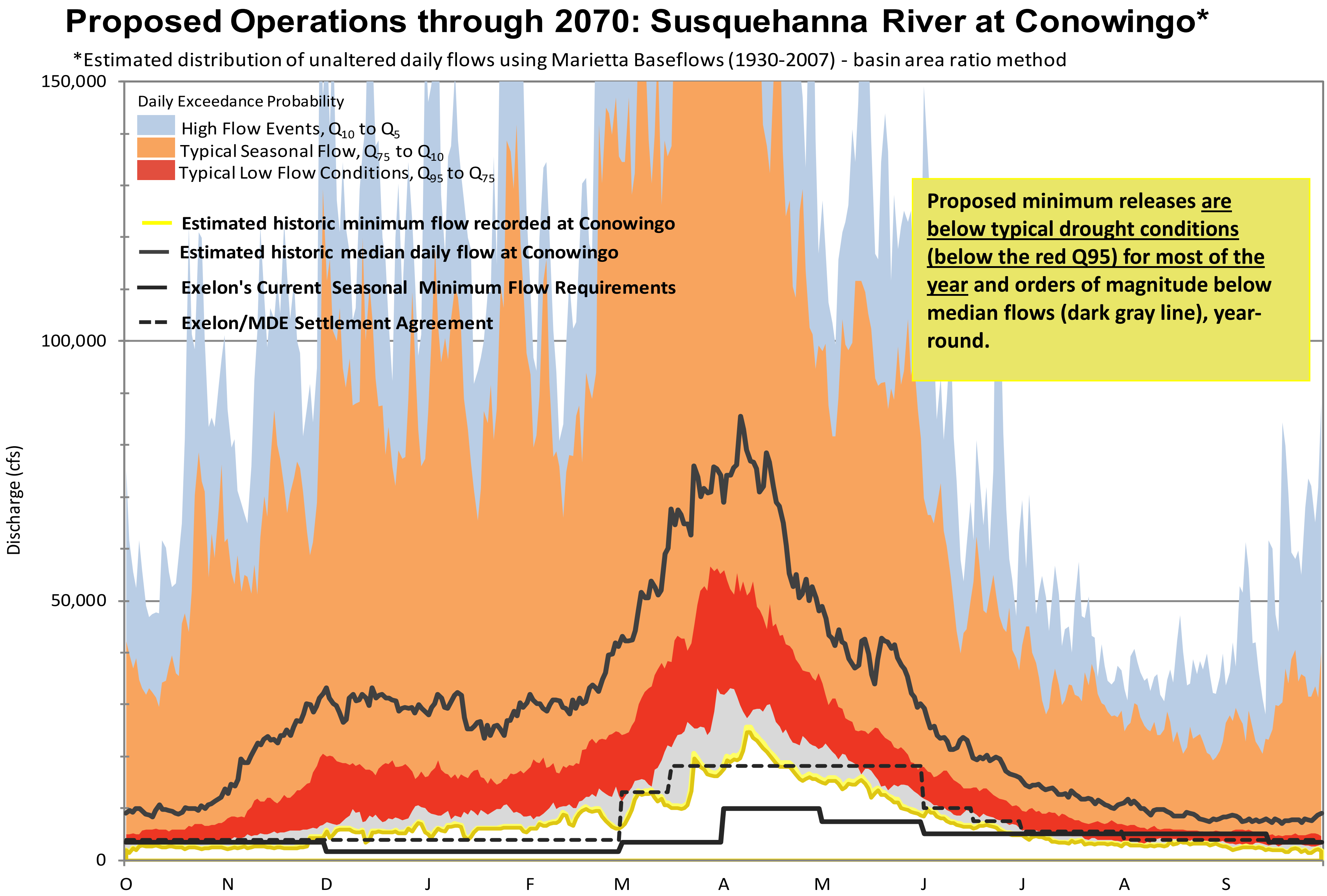
TABLE 3.2.1-2: SEASONAL PERIODICITY OF OCCURRENCE OF TARGET SPECIES IN THE SUSQUEHANNA RIVER BELOW CONOWINGO DAM. ITALICIZED LIFE STAGES ARE CONSIDERED IMMOBILE. HABITAT GUILDS ARE SHOWN IN PARENTHESES.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
American Shad												
Spawning				■	■	■						
Fry					■	■	■					
Juveniles							■	■	■	■	■	
Adults				■	■	■						
Hickory Shad												
Spawning (Deep-Slow)			■	■	■							
Fry(Shallow-Slow)				■	■	■						
Juveniles (Deep-Slow)						■						
Adults (Deep-Fast)			■	■	■							
Blueback Herring												
Spawning (Deep-Slow)				■	■	■						
Fry (Shallow-Slow)					■	■						
Juveniles (Shallow-Slow)							■	■	■	■		
Adults (Deep-Slow)				■	■	■						
Alewife												
Spawning (Deep-Slow)			■	■	■							
Fry (Shallow-Slow)			■	■	■							
Juveniles (Deep-Slow)						■	■	■	■	■		
Adults (Shallow-Slow)				■	■							
White Perch												
Spawning (Shallow-Fast, Deep-Fast)				■	■	■						
Fry (Shallow-Slow)				■	■	■	■					
Juveniles (Shallow-Slow, Deep-Slow)					■	■	■	■	■	■	■	■
Adults (Deep-Slow)	■	■	■	■	■	■	■	■	■	■	■	■
Yellow Perch												
Spawning (Deep-Slow)			■	■								
Fry (Shallow-Slow)				■	■							
Juveniles (Deep-Slow)						■	■	■	■	■	■	■
Adults (Deep-Slow)	■	■	■	■	■	■	■	■	■	■	■	■
Striped Bass												
Spawning				■	■	■						
Fry				■	■	■	■					
Juveniles						■	■	■	■	■	■	■
Adults	■	■	■	■	■	■	■	■	■	■	■	■

Table 1 continued.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Largemouth Bass												
Spawning (Shallow-Slow, Deep-Slow)					🟦	🟦						
Fry (Shallow-Slow, Deep-Slow)						🟦	🟦					
Juveniles (Shallow-Slow, Deep-Slow)								🟦	🟦	🟦	🟦	🟦
Adults (Deep-Slow)	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Smallmouth Bass												
Spawning					🟦	🟦						
Fry						🟦	🟦					
Juveniles								🟦	🟦	🟦	🟦	🟦
Adults	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Walleye												
Spawning (Deep-Fast)			🟦	🟦								
Fry (Deep-Slow)				🟦	🟦	🟦						
Juveniles (Deep-Slow)						🟦	🟦	🟦	🟦	🟦	🟦	🟦
Adults (Deep-Slow)	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Shortnose sturgeon												
Spawning				🟦	🟦							
Fry					🟦	🟦	🟦					
Juveniles/Adults	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Atlantic sturgeon												
Spawning (Deep-Fast)				🟦	🟦							
Fry (Deep-Slow, Deep-Fast)					🟦	🟦	🟦					
Juveniles/Adults (Deep-Slow, Deep-Fast)	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
American eel												
Elver (Shallow-Slow, Deep-Slow, Deep-Fast)				🟦	🟦	🟦	🟦	🟦	🟦	🟦		
Yellow (Shallow-Slow,Deep-Slow,Deep-Fast)	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Silver (Deep-Slow)									🟦	🟦	🟦	🟦
Alewife floater												
Adults/juveniles	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Spawning										🟦	🟦	🟦
Larvae			🟦	🟦	🟦							
Eastern elliptio												
Adults/juveniles	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Spawning	🟦	🟦	🟦									
Larvae				🟦	🟦	🟦	🟦	🟦				
Fingernail clams												
Adults	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Spawning/larvae	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Ephemeroptera-Plecoptera-Trichoptera												
all life stages	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

Figure 2. A comparison of interannual variability and minimum flows proposed in the Settlement Agreement Operational Flow Regime (dashed black line).



Proposed minimum releases <u>are below typical drought conditions (below the red Q95) for most of the year</u> and orders of magnitude below median flows (dark gray line), year-round.

3. The frequency and magnitude of peaking operations (combination of minimum and maximum flows) will continue to impair the availability of suitable habitat to support the propagation of fish, wildlife and aquatic vegetation.

The Settlement Offer does not propose a frequency for peaking operations, therefore we expect that the licensee will continue to operate as part of an open-loop pumped storage project and continue to peak with a frequency similar to past operations, so long as energy markets are favorable. Specifically, this means that the project would continue daily peaking operations, in some cases twice per day, with some gaps between days during extreme low flow conditions. Table 2 outlines proposed minimum and maximum peaking flows by month. Illustrations of daily changes in hydraulic habitat conditions (depth and velocity) between minimum flows and maximum generation flows are included in Enclosure 2.

Table 2. Daily minimum and maximum peaking flows and differences in stages as estimated at USGS Gage 01578310 SUSQUEHANNA RIVER AT CONOWINGO, MD

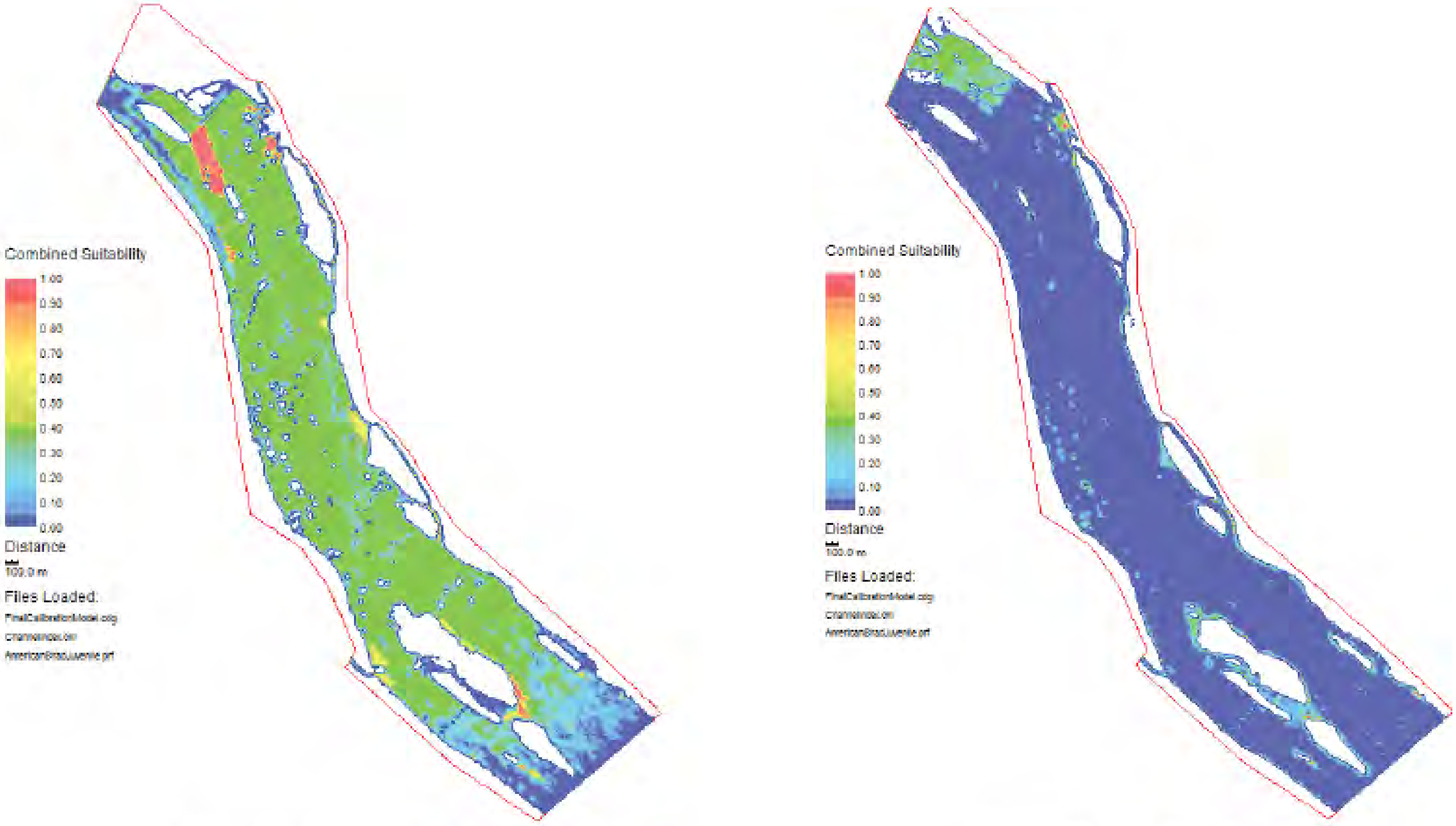
Month	Minimum flow releases (cfs)	Maximum flow releases (cfs)	Daily difference in stage from minimum to maximum (feet)
Jan	4,000	86,000	7
Feb	4,000	86,000	7
Mar	13,100 18,200	86,000	6 5
Apr	18,200	86,000	5
May	18,200	75,000	4
June	10,000 7,500	75,000	6
July	5,500	79,000	6
Aug	4,000	79,000	7
Sept	4,000	79,000	7
Oct	4,000	86,000	7

Nov	4,000	86,000	7
Dec	4,000	86,000	7

With these operations, the distribution of suitable depths and velocities within the river will continue to vary significantly on a daily basis, with those swings being most dramatic in the months with the greatest difference between minimum and maximum flows. In most cases, what is suitable habitat under daily minimum flow releases, is not suitable habitat under daily high flow releases. Using juvenile shad as an example, Figures 3a and b illustrate how habitat suitability changes significantly between daily minimum flow releases and maximum generation flows. Figure 3a illustrates habitat suitability on the lower river under the proposed flow regime for minimum flows of 5,000 cfs, with light green, yellow, orange and red areas having habitat above the suitability threshold and light and dark blue areas having habitat below the suitability thresholds. In Figure 3a, we see a significant portion of the study area has suitable habitat – and know that this is translated to an estimate of 92% of maximum weighted usable area (RSP 3.16 Table 5.1-2). However, in Figure 3b, under maximum generation flows of 80,000 cfs, we see that suitability changes significantly. What was suitable habitat under minimum flow releases is not suitable habitat (has transitioned to light and dark blue) under maximum generation flows. Further, under maximum generation flows, the majority of the suitable habitat for juvenile shad now exists in the tailrace. The tailrace is dewatered under minimum flows (Figure 3a).

This example illustrates that with a daily peaking operation, minimum flows alone, cannot be used to estimate habitat availability. Rather, we must look at the habitat available under minimum *and* maximum flows to understand whether or not a flow proposal will result in functional habitat improvements that would be expected to result in biologically meaningful outcomes.

Figure 3a and b. Example of the change in daily habitat suitability for juvenile shad from minimum flows of 5,000 cfs to maximum generation flows of 80,000 cfs. **Light blue and dark blue areas are unsuitable (source RSP 3.16).** These figures are the best publicly available representation of July proposed flows of a minimum of 5,500 cfs and a maximum of 79,000 cfs.



American Shad Juvenile – 5,000 cfs

American Shad Juvenile – 80,000 cfs

As discussed in detail in our comments on the final EIS (*see* Enclosure 1, Exhibit A, Attachment 4), and written testimony by Dr. Claire Stalnaker (*see* Enclosure 1, Exhibit A, Attachment 3), given Conowingo dam's hydroelectric peaking operations, a habitat time series analysis is necessary to compare habitat persistence across species and life stages. Absent this analysis, we use data provided in RSP 3.16 to provide a best estimate of habitat suitability, including percent of maximum weighted usable area (mobile life stages) and persistent habitat (immobile life stages) to summarize habitat availability across species and life stages based on the proposed minimum flows and maximum daily generation flows (Table 3a). We compare this to estimated habitat availability under unregulated median monthly flow conditions (Table 3b).

Upstream migration. Under the proposed operational flow regime, we estimate that improved flow conditions during diadromous fish migration during March, April and May, would provide more than 70% maximum weighted usable area (WUA) for adult fish. Relative to existing conditions, this could improve the far field attraction flows for American shad and the probability of entering the fish lift, resulting in a functional benefit relative to existing conditions (Table 3a).

Diadromous fish spawning, egg and larval and juvenile development. The Lower Susquehanna was once the most productive spawning ground for striped bass on the east coast (Dovel and Edmunds 1971)[26] and similarly supported robust shad, river herring and sturgeon recruitment (Enclosure 1, Attachment 2). As documented in RSP 3.18, under existing conditions, there is little evidence of successful egg and larval development for diadromous fish. For the proposed operational flow regime, it is estimated that 8 to 30% of suitable habitat would be available during American shad spawning and egg development, 46 to 51% during sturgeon

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[26] *Available at* https://www.jstor.org/stable/1350500?seq=1 (last accessed Jan. 17, 2020).

spawning and 5 to 52% during striped bass spawning (Table 3a). This is an incremental improvement from existing conditions which support 2 to 40% spawning habitat across those species (Enclosure 1, Table 5). Habitat conditions during fry development are also marginally improved relative to existing conditions, however, relative to maximum available habitat, they are still extremely restricted, with 3 to 23% of available habitat supported in June and only 1 to 14% supported in July (Table 3a). Under unregulated flow conditions, 70 to 99% of habitat would be available for fry development (Table 3b). During late fall and winter less than 70% MWUA would be supported for overwintering of juvenile and adult fish.

While the proposed operational flow regime will marginally increase spawning habitat during the spring months, re-establishing successful recruitment of diadromous fish below Conowingo dam, will require a flow regime that supports all life stages. As proposed, habitat conditions would provide minimal suitability from July through February. Further, the Settlement Offer makes no proposal to restore or mitigate the impact of the loss of coarse sediments (sand and gravel) on spawning habitat loss in the Lower River. As proposed, habitat conditions supported under the Settlement Offer would not be expected to result in restored recruitment of diadromous fish below the dam over the license term.

Macroinvertebrates. Changes to the operating regime in 1980 were focused on addressing impairments to the macroinvertebrate community. Under existing conditions, the macroinvertebrate community continues to be dominated by tolerant taxa (RSP 3.18) and is characterized as impaired (RSP 3.18). Under the proposed operating flow regime, an estimated 12 to 19% of habitat would be supported in spring months and an estimated 6 to 8 % of available habitat would be supported in summer, fall and winter months (Table 3a). Restricted habitat conditions under the proposed operating flow regime would be similar to existing conditions and would not be expected to restore the impaired macroinvertebrate community.

Table 3a. – Periodicity of species and life stages with estimated percent (%) of habitat availability under the proposed Operational Flow Regime using weighted usable area (mobile life stages) and persistent habitat (*immobile life stages*) for maximum and minimum daily flows. For habitat conditions providing > 70% habitat availability, cells are shaded in green, 25 to 70% in light red and < 25% in dark red. For mobile life stages, the limiting flow condition (minimum generation/maximum generation) is indicated in **bold**.

		Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Proposed operational flow regime	Minimum flow (cfs)	13,000/ 18,200	18,200	18,200	10,000/ 7,500	5,500	4,000	4,000	4,000	4,000	4,000	4,000	4,000
	Max generation (cfs)	86,000	86,000	75,000	75,000	75,000	75,000	75,000	86,000	86,000	86,000	86,000	86,000
American shad	*Spawning & Inc*		26%	30%	8%								
	Fry			29%	23/17%	14%							
	Juvenile					96/**49%**	90/**49%**	90/**49%**	90/**46%**	90/**46%**			
	Adult		**78%**/79	**78%**/86	**59/51**%/ 86								
Shortnose sturgeon	*Spawning & Inc*		46%	51%									
	Fry			27%	19/14%	3%							
	Juvenile	85/92/**76%**	92/**76%**	94/**80%**	82/**80%**	**69%**/80	**59%**/80	**59%**/80	**59%**/76	**59%**/76	**59%**/76	**59%**/76	**59%**/76
	Adult	85/92/**76%**	92/**76%**	94/**80%**	82/**80%**	**69%**/80	**59%**/80	**59%**/80	**59**/%76	**59%**/76	**59%**/76	**59%**/76	**59%**/76
Striped bass	*Spawning & Inc*		44%	52%	14/5%								
	Fry		35%	41%	9/3%	1%							
	Juvenile				75/**71%**	**62%**/71	**54%**/80	**54%**/80	**54%**/71	**54%**/71	**54%**/71		
	Adult	**50/85%**/99	**85%**/99	**85%**/99	**44/35%**/ 99	**30%**/99	**21%**/99	**21%**/99	**21%**/99	**21**/%99	**21%**/99	**21%**/99	**21%**/99
Smallmouth bass	*Spawning & Inc*			8%	3%								
	Fry				6%	5%							
	Juvenile						99/**13%**	99/**13%**	99/**11%**	99/**11%**	99/**11%**		
	Adult	99/**43%**	97/**43%**	97/**48%**	98/**48%**	82/**48%**	75/**49%**	75/**49%**	75/**43%**	75/**43%**	75/**43%**	75/**43%**	75/**43%**
Macroinvertebrates	*Trichop*	14/12%	14%	19%	14/12%	11%	8%	8%	6%	6%	6%	6%	6%

Table 3b. – Periodicity of species and life stages with estimated percent (%) of habitat availability under median monthly unregulated flow using weighted usable area (mobile life stages) and persistent habitat (*immobile life stages*) for minimum and maximum daily flows. For habitat conditions providing > 70% habitat availability, cells are shaded in green, 25 to 70% in light red and < 25% in dark red (note there are no months with <25% habitat availability).

		Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Median monthly unregulated flow		61,744	63,752	38,768	20,661	13,045	9,201	7,995	9,845	22,927	30,672	27,732	32,617
American shad	*Spawning & Inc*		97%	98%	68%								
	Fry			99%	80%	70%							
	Juvenile					99%	99%	98%	99%	97%			
	Adult		95%	99%	83%								
Shortnose sturgeon	*Spawning & Inc*		99%	92%									
	Fry			82%	96%	86%							
	Juvenile	87%	87%	97%	97%	86%	80%	79%	82%	96%	96%	96%	96%
	Adult	87%	87%	97%	97%	86%	80%	79%	82%	96%	96%	96%	96%
Striped bass	*Spawning & Inc*		97%	99%	81%								
	Fry		98%	99%	70%	43%							
	Juvenile				89%	78%	75%	70%	75%	89%	95%		
	Adult	98%	99%	91%	68%	48%	45%	36%	44%	68%	80%	80%	82%
Smallmouth bass	*Spawning & Inc*			35%	44%								
	Fry				52%	63%							
	Juvenile						92%	96%	91%	64%	40%		
	Adult	58%	56%	73%	95%	99%	95%	93%	98%	95%	80%	83%	80%
Macroinvertebrates	*Trichop*	52%	52%	70%	92%	96%	95%	92%	96%	96%	81%	81%	81%

Freshwater mussel diversity and recruitment. As detailed in our filings, the combination of minimum flows, generation flows and loss of coarse sediment transport has impaired the freshwater mussel diversity and recruitment below Conowingo dam (Enclosure 1, pp. 6, 17). Specifically, generation flows create unsuitable scour conditions inhibiting spawning and larval development and the lack of persistent habitat for host-fish further limits successful larval development. The Settlement Offer does not provide evidence that the operational flow regime will address these Project impacts to habitat for Eastern Elliptio, Alewife floater, Eastern Floater, Tidewater Mucket and Eastern Lampmussl, nor does it connect these impacts with proposed off-license mitigation measures.

Comparison to NGO-Stakeholder Alternative. Lastly, the Settlement Offer does not provide any comparative analysis of the proposed operational flow regime and alternatives in the record. Given the unmitigated impacts under the proposed operational flow regime, we expect OEP Staff to undertake such analysis or direct the Settling Parties to do so prior to making a decision on the Settlement Offer. In particular, the proposed operational flow regime should be compared to the NGO-Agency alternative flow regime using an appropriate scientific method for peaking operations.[27] As described above, the Conservancy, in consultation with resource agencies and other stakeholders developed ecological performance goals and used best available data, including habitat models and literature, to identify an alternative operational flow regime that would support the continued generation of economically viable, low carbon energy, while restoring the ecological and ecosystem service values of the river. The NGO-Agency alternative flow regime relies on information learned from the operational scenario analysis to identify the combination of scenarios that is most likely to meet both objectives. It is based on a detailed

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[27] Dr. Stalanaker previously described appropriate methods. *See* Enclosure 1, Exhibit, Attachment 3.

analysis of hydrology, operations and habitat availability. In addition, this alternative takes into account settlement discussions between the agencies/stakeholders and Exelon. To be clear, it is a negotiated proposal that reflects significant compromise.

Consistent with the findings of our scenario analysis and relevant literature review, the NGO-Agency alternative flow regime includes three components (a) a two-tiered monthly minimum flow requirement to meet biological objectives at those times of greater water availability (streamflows are above normal) and lower cost to the licensee; (b) a maximum flow customized to habitat suitability spawning and rearing season for fish, mussels, macroinvertebrates, reptiles and amphibians and SAV to support persistent habitat and restore recruitment; and (c) up- and down-ramping rates to improve the availability of aquatic habitat and reduce stranding during peaking events.[28]

4. The proposed operational flow regime does not include downramping rates to mitigate fish stranding from daily peaking flows generation flows > 30,000 cfs.

The Settlement Offer proposes downramping measures to reduce the potential for fish stranding at flows below 30,000 cfs. More specifically, the Settlement Offer proposes (Attachment A, Table (b)) to implement a ramping rate of up to 12,000 cfs/hour when flows are less than 30,000 cfs. It does not propose ramping rates when flows are between 86,000 cfs and 30,000 cfs. The Settlement Offer does not show this proposal will mitigate fish stranding under the full range of project operations.

Evidence in the record demonstrates that fish stranding and mortality occur in a portion of the channel that is dewatered at flows above 30,000 cfs,[29] and that this impact is significant

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[28] *See* Enclosure 1.

[29] Final Study Report. Downstream Flow Ramping and Stranding, RSP 3.8.

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(Figures 1a &b, 2a&b). Extrapolating from the discrete stranding study days to seasonal peaking events, it is estimated that more than 420,000 fish may have been stranded over the course of the year. Mortality from stranding was highest in the spring and summer months and is expected to be an underestimate, as significant avian predation was observed but not incorporated into estimates of mortality. These impacts are significant. For example, it is estimated that more than 1,400 American shad were stranded (Figure 1a) during the 2011 spawning and migration season, which was about 7% of the American shad that passed that year.[30]

The Settlement Offer does not propose any measures to mitigate stranding mortality as flows drop from 86,000 cfs to 30,000 cfs despite record evidence that the impact to shad is significant. Accordingly, the Settlement Offer does not show the proposed downramping measure will "*mitigate any potential impacts*" (Settlement Offer, p. 10) or "*provide additional benefits and protection by reducing the potential for fish stranding"* (*id.* at 11).

In order to better understand the relationship between mitigation proposed in the Settlement Offer and impacts, we request that the settling parties provide written responses to the questions below*:*

Q.1. Under existing conditions, effective spawning and rearing of diadromous fish, including American shad, herring, striped bass and sturgeon is not currently supported in the Lower River. How will the Settling Parties ensure that investments in the operational flow regime will mitigate the impacts of project operations on spawning and rearing?

Q.2. How will the Settling Parties ensure that investments in the operational flow regime will mitigate the impacts of project operations on the impaired macroinvertebrate community?

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[30] TNC MOI, Attachment 1, Table 4-Column III; *see also* Pennsylvania Fish and Boat Commission, "Suquehanna River American Shad: YTD Passages," *available at* https://www.fishandboat.com/Fish/PennsylvaniaFishes/Pages/SusquehannaShad.aspx (last accessed Jan. 17, 2020).

Q.3. What is the basis for Settling Parties' claim that the operational flow regime will provide suitable habitat to restore freshwater mussel recruitment below the dam, including Eastern Elliptio, Alewife floater, Eastern floater, Tidewater Mucket and Eastern Lampmussel?

Q.4. What benefits will the Settlement Offer provide to state and Federally threatened and endangered species, including the map turtle?

Q.5. SAV depends on the availability of relatively stable shallow habitats during the growing season. How will the proposed flow fluctuations of several feet per day during the growing season affect efforts to restore SAV in the project area?

Q.6. The Lower Susquehanna River was recently listed as an impaired waterbody for flow alteration by the State of Maryland. What evidence can the Settling Parties provide that the proposed operational flow regime will address the Project as a source for this impairment and achieve attainment of the relevant water quality standards?

Q.7. What quantitative benefits will the proposed operational flow regime have for stranded fish, particularly for downramping flows between 86k and 30k?

Q.8. What is the basis for the Settling Parties recommendation to defer implementation of the second phase of the flow regime for three (3) years after license issuance? What are the ecological impacts of not implementing phase 2 for the three years? Does the Settlement Offer consider and/or include mitigation for impacts associated with this delay?

Figure 1 a & b. As documented in RSP 3.8 Figure 4.1-2-2, during the Spring, fish stranding and mortality was documented (a) in a portion of the channel that is dewatered during downramping between 86,000 cfs and 30,000 cfs (b). Downramping rates below 30,000 cfs would not be expected to mitigate these stranding and mortality impacts.

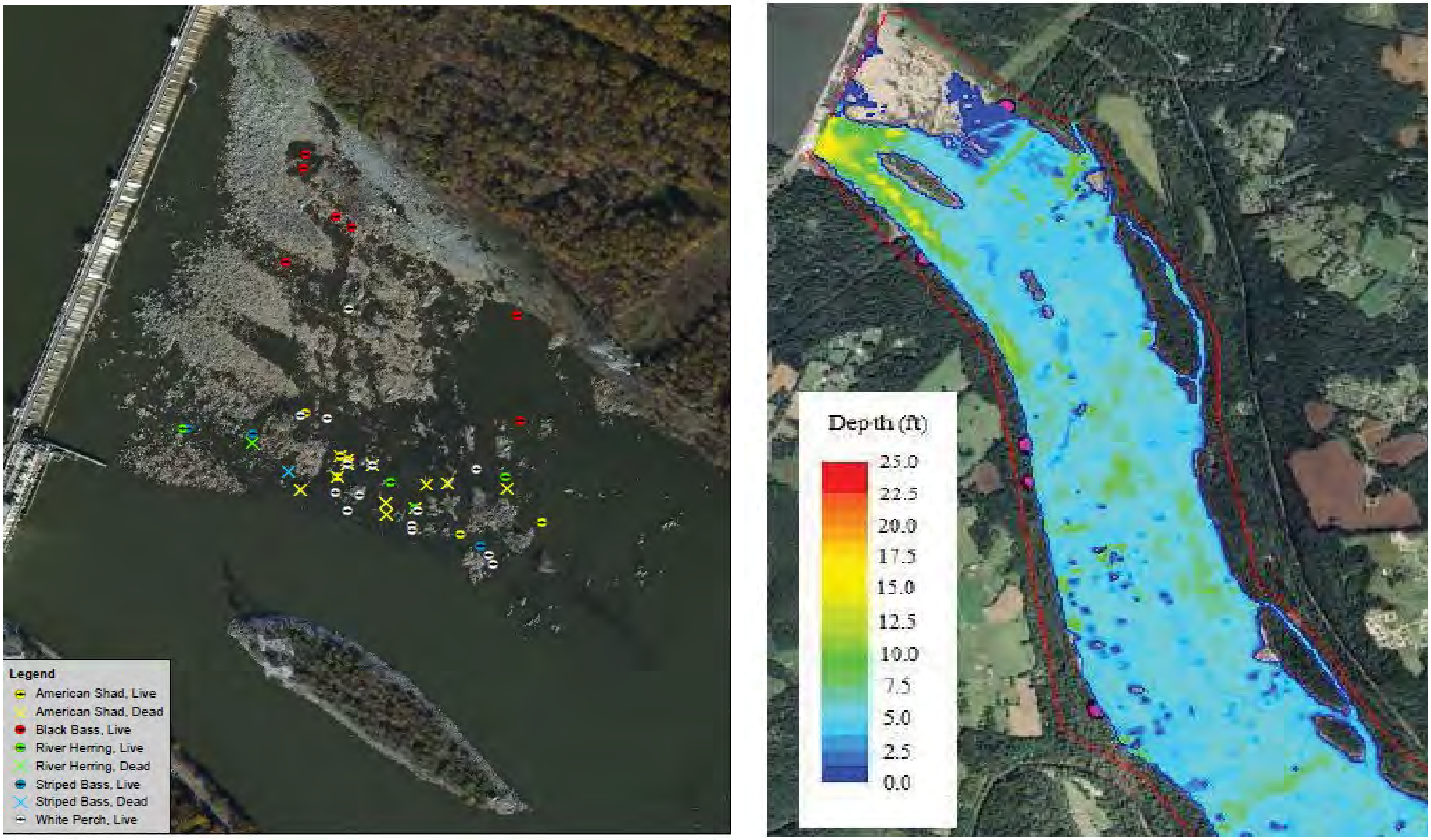
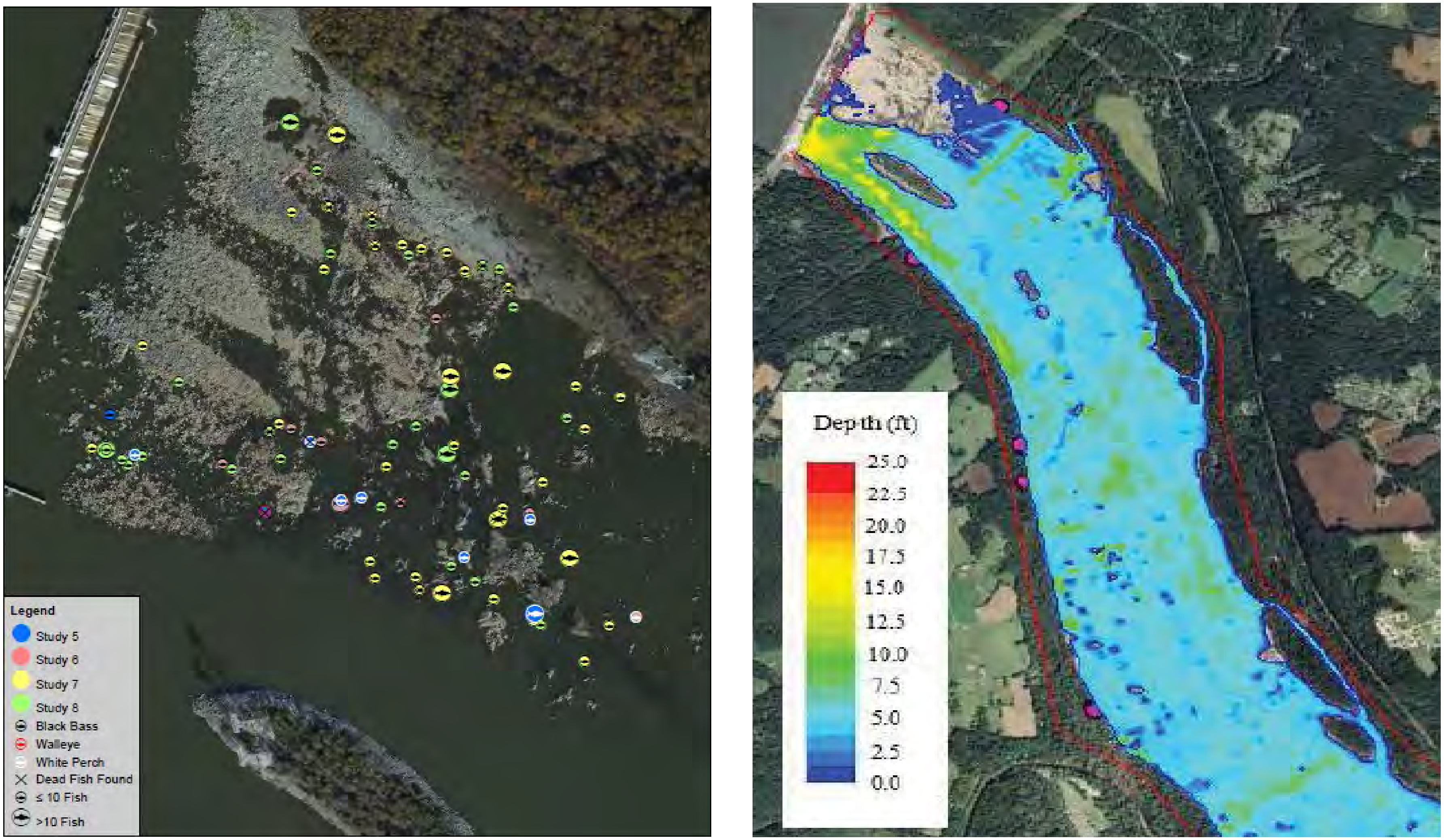


Figure 2 a & b. As documented in RSP 3.8 Figure 4.2-2-2, during the Summer, fish stranding and mortality was documented (a) in a portion of the channel that is dewatered between 86,000 cfs and 30,000 cfs (b). Downramping rates below 30,000 cfs would not be expected to mitigate these stranding and mortality impacts.



B. The Settlement Offer Does Not Show It Will Protect Water Quality in the Lower Susquehanna River and Chesapeake Bay.

The Settlement Offer does not propose license terms to address the Project's impacts on water quality in the lower Susquehanna River and Chesapeake Bay. Rather, the Settlement Offer proposes only off-license terms related to water quality impacts. These terms include making payments intended for mussel restoration (Settlement Offer, p. 6), resiliency projects (such as SAV restoration, aquaculture, clam and oyster restoration and living shoreline creation) (*id.* at 7), mitigation of impacts of high-flow scour events (*id.*), and other projects that will have benefits to water quality (including agricultural practices such as cover crops and forest buffers) (*id.* at 7-8).

The Explanatory Statement states the following in support of these terms:

- "The eastern elliptio mussel provides important ecosystem services, including filtration and transformation of sediment and nutrient pollution. A significant mussel restoration initiative is needed to re-establish the eastern elliptio population in the lower River. Exelon has agreed to support MDE's efforts to undertake such an initiative…" (Explanatory Statement, p. 19).

- "Exelon has agreed to provide MDE with financial support for projects to make the River and the Bay more resilient to severe weather events… MDE intends to use these funds for projects such as submerged aquatic vegetation restoration, oyster restoration, clam restoration, aquaculture, and living shoreline creation (*id.*).

- "Exelon has agreed to provide MDE with financial support for other water quality improvement projects, including forest buffers and agricultural projects such as cover crops." (*id.* at 20).

The Settling Parties have not provided adequate information to show that the above measures will mitigate the project's water quality impacts, namely because the terms do not specify quantifiable biological or ecological objectives or outcomes.

Evidence has been presented in the record that provides a clear basis for the quantification of the Conowingo Project's incremental impact on water quality and corresponding mitigation needs.[31] This evidence documents that project operations alter the form and timing of pollutant delivery, and that significant mitigation is needed to reduce these pollutants. Because the proposed non-license terms described in the Settlement Offer and Explanatory Statement are simply payments into a Fund, there is no basis to estimate how much the proposed mitigation would achieve towards addressing the water quality impacts traceable to the project.

In order to better understand the relationship between mitigation proposed in the Settlement Offer and the project impacts, we request that the Settling Parties provide written responses to the questions below.

Q.9. What quantitative benefits, specifically annual amounts of "filtration and transformation of sediment and nutrient pollution," could be reasonably expected to result from investments in the construction and operation of a mussel hatchery?

Q.10. What plans have the Settling Parties made to compensate for this expected mitigation should the hatchery fail, and/or if plantings of hatchery-bred mussels are unsuccessful? In particular, the Explanatory Statement indicates that a "significant mussel restoration initiative is needed to re-establish the eastern elliptio population ***in the lower River"*** *(emphasis added). What evidence exists that transplanted mussels could persist in the lower River under the proposed flow regime and current habitat conditions?*

Q.11. How many acres of resiliency projects could be reasonably expected to result from the proposed investments? What are the quantitative water quality and/or resilience benefits anticipated from these projects?

Q.12. Section 2.3 (b) of the Settlement Offer states that Exelon will make annual payments of $250,000 to MDE's Clean Water Fund which will be used to "mitigate the impact of high-flow events that may result in scour of sediment impounded by the Dam…". What is the Settling Parties estimate of the magnitude of the impact of these high-flow events, and what do the Parties estimate this annual payment will accomplish with regards to that impact?

Q.13. Hydrologic conditions are predicted to change significantly over the next 50 years, with equally significant implications for sediment dynamics in the Conowingo reservoir. How are the Settling Parties planning to evaluate changes to these conditions, estimate their impacts on high-flow scour events, and adjust the needed mitigation from those impacts?

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[31] *See* letter from Alison Prost to Elder Ghigiarelli, Jr. (Jan. 16, 2018) (CBF's WQC Comments), pp. 1-3.

Q.14. What process will MDE follow to ensure that water quality and resilience projects selected and implemented from Clean Water Fund payments will maximize desired benefits over the course of the license?

C. The Settlement Offer Does Not Show the Proposed Adaptive Management Provision Will Improve Ecological Outcomes over the Proposed 50-year License Term.

The Settlement Offer includes a provision for "Adaptive Management," which allows MDE to seek to modify the new license to comply with more stringent regulatory requirements that may be enacted over the term of the new license:

> MDE may seek to modify the New License to achieve compliance with any applicable effluent limitation, other limitations, or water quality standards or requirements issued or approved under Sections 301, 302, 303, 306, and 307 of the CWA or applicable State Law if the limitation, standard, or requirement so issued or approved contains different conditions or is otherwise more stringent that any requirements of the Incorporated License Articles.

Settlement Offer, p. 12. However, there are several restrictions on MDE's right to seek modification. Under the Settlement Offer, MDE is prevented from seeking to:

- modify Flow Regime if it would have "detrimental economic impact,"[32]
- impose fish passage measures that are additive to, or different from, the requirements of the Fish Passage Prescription;
- impose additional nutrient or sediment-related measures or nutrient or sediment funding requirements associated with nutrients or sediment originating from sources outside the Project; or
- impose any additional requirements related to PCBs or chlorophyll-a associated with pollution originating from sources outside of the Project.

The "Adaptive Management" provision could be better characterized as MDE's right to seek reopener of the new license before the Commission in limited circumstances where it is

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[32] Settlement Offer, § 3.6(d). We understand "detrimental economic impact" to be based primarily on a projected decrease in combined energy revenues at the Conowingo and Muddy Run Projects from what Exelon would expect to receive absent a modification. *See id.*

necessary to comply with a more stringent water quality requirement enacted post-license and it would not adversely affect anticipated project revenues.

Whether MDE can prospectively waive its authority to regulate the Conowingo Project under Sections 301,302,303, 306, and 307 of the CWA as a matter of contract is outside the scope of the Commission's authority to resolve, and so we reserve those comments for another venue. The Conservancy previously responded in opposition to Exelon's arguments that the Commission should find that MDE has inadvertently waived its authority under CWA section 401.[33]

The provisions limiting MDE's right to seek modification to the operational flow regime appear designed to prevent actions to adaptively manage mitigation investments in order to optimize restoration objectives, and contrary to standard adaptive management guidance.[34] The Conservancy is very concerned by the Settlement Offer's omission of an adaptive management program and additional restrictions on reopener given our improved understanding of how climate change is likely to affect the Susquehanna River Basin over the term of any new license. Hydrologic conditions are already changing in the Susquehanna River watershed, with predictions indicating the next 30 years will bring even more intense and frequent storms leading.[35] The inability of the proposed settlement terms to adapt to these changes, particularly since the Project alters the form and timing of pollutants moving through the river, indicates additional, unmitigated impacts to natural resources are likely during the term of the new license.

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[33] TNC, "Motion to Intervene and Opposition to Exelon Generation Company, LLC's Petition for Declaratory Order," eLibrary no. 20190328-5189 (Mar. 28, 2019).

[34] U.S. Department of Interior, "Technical Guide to Adaptive Management" (2009), *available at* https://www.doi.gov/sites/doi.gov/files/migrated/ppa/upload/TechGuide.pdf (last accessed Jan. 17, 2020).

[35] Chesapeake Bay Program, "Climate Change," *available at* https://www.chesapeakebay.net/state/climate_change (last accessed Jan. 17, 2020).

IV.
Request for Settlement Technical Conference

The Conservancy requests that OEP Staff convene a technical conference pursuant to Rule of Practice and Procedure 601, 18 C.F.R. § 385.601, to address the disputed or otherwise unresolved issues identified in Section III. As stated above, the explanation provided in the Settlement Offer does not show that the proposed terms will mitigate the Project's impacts on ecological resources in the Lower Susquehanna River and Chesapeake Bay, and there remain disputes regarding which measures *will* mitigate project impacts consistent with the Commission's comprehensive planning responsibility under FPA section 10(a). These disputes remain even though the relicensing has been pending for over a decade, and are more likely to carry over into litigation if OEP Staff do not provide an opportunity for a technical conference or other dispute resolution procedures prior to license issuance.

V.
Conclusion

The Conservancy thanks OEP Staff for considering these comments. We request that OEP Staff order additional procedures, including directing the settling parties to provide written responses to the questions herein and convene a technical conference, prior to taking final action on the Settlement Offer.

Respectfully submitted,

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Attorneys for THE NATURE
CONSERVANCY

DECLARATION OF SERVICE

Exelon Generation Company, LLC's Conowingo (P-405)

I, Tiffany Poovaiah, declare that I today served the attached "The Nature Conservancy's Comments on Offer of Settlement," by electronic mail, or by first-class mail if no e-mail address is provided, to each person on the official service list compiled by the Secretary in this proceeding.

Dated: January 17, 2020

By: Tiffany Poovaiah

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Document Content(s)

2020-01-17 final TNC comments re Settlement Offer.PDF 1

Attachment 2

Hot, Wet, and Crowded: Phase 6 Climate Change Model Findings

Climate Resiliency Workgroup
April 20, 2020

Lew Linker, EPA; Gary Shenk, USGS; Gopal Bhatt, Penn State;
Richard Tian, UMCES; and the CBP Modeling Team
llinker@chesapeakebay.net

Chesapeake Bay Program
Science, Restoration, Partnership

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Key Points in Assessment of 2025 Climate Change Risk

- The new 2019 climate change assessment confirms the December 2017 climate change findings with a better model, providing better understanding of underlying processes, more specific findings on nutrient speciation, CSOs, wet deposition of nitrogen, etc.
- Consistent assessment of violation CB4MH Deep Channel and Deep Water nonattainment from December 2017 PSC meeting to today of about 1.4% and 1.0%, respectively, even though we’ve expanded our assessment to look at EVERYTHING in the CC analysis.

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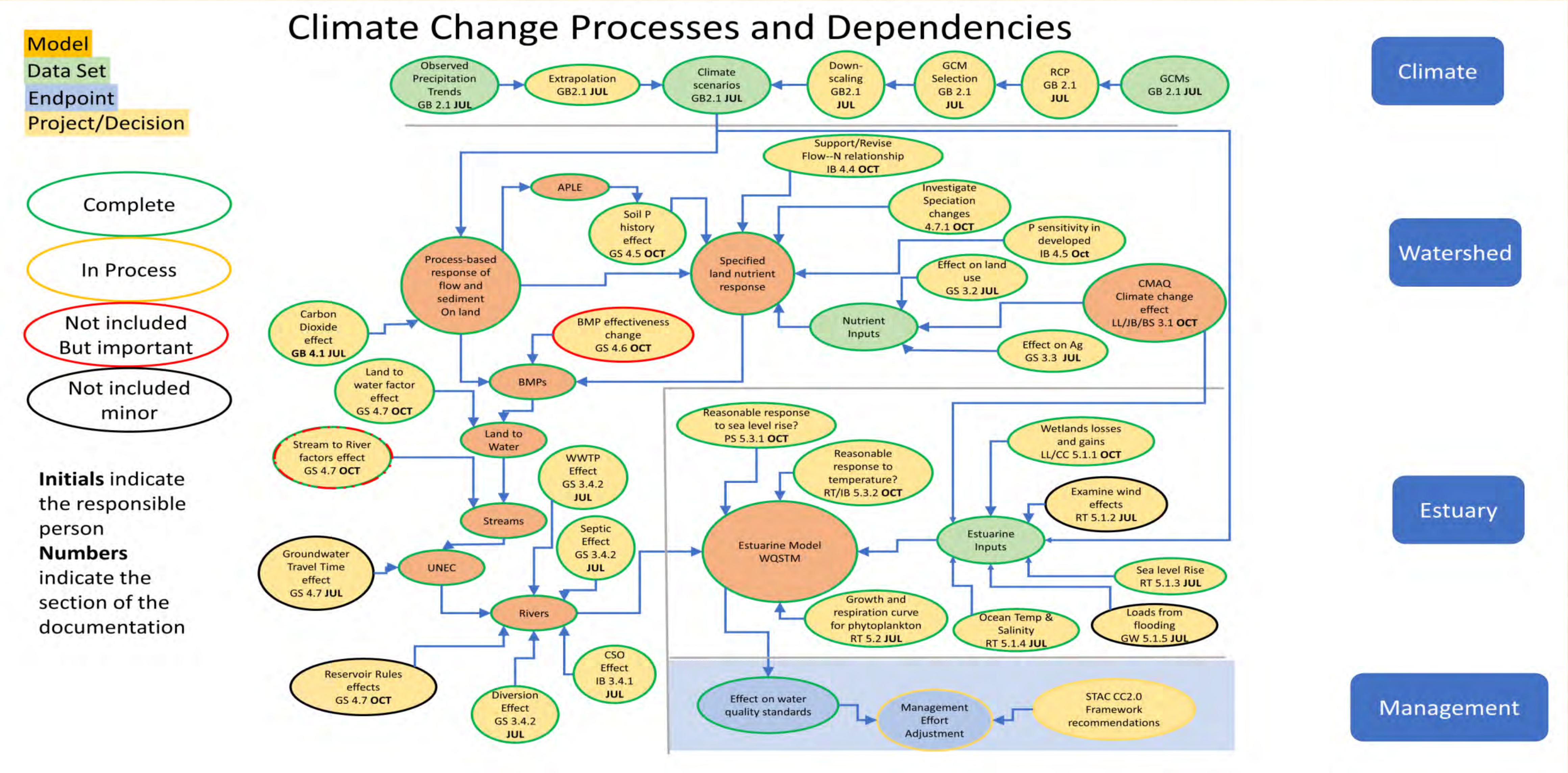
Elements of Chesapeake Water Quality Climate Risk Assessment



Climate Change Processes and Dependencies

Model
Data Set
Endpoint
Project/Decision

Complete
In Process
Not included But important
Not included minor

Initials indicate the responsible person
Numbers indicate the section of the documentation

Climate
Watershed
Estuary
Management

Observed Precipitation Trends GB 2.1 **JUL**
Extrapolation GB2.1 **JUL**
Climate scenarios GB2.1 **JUL**
Down-scaling GB2.1 **JUL**
GCM Selection GB 2.1 **JUL**
RCP GB 2.1 **JUL**
GCMs GB 2.1 **JUL**

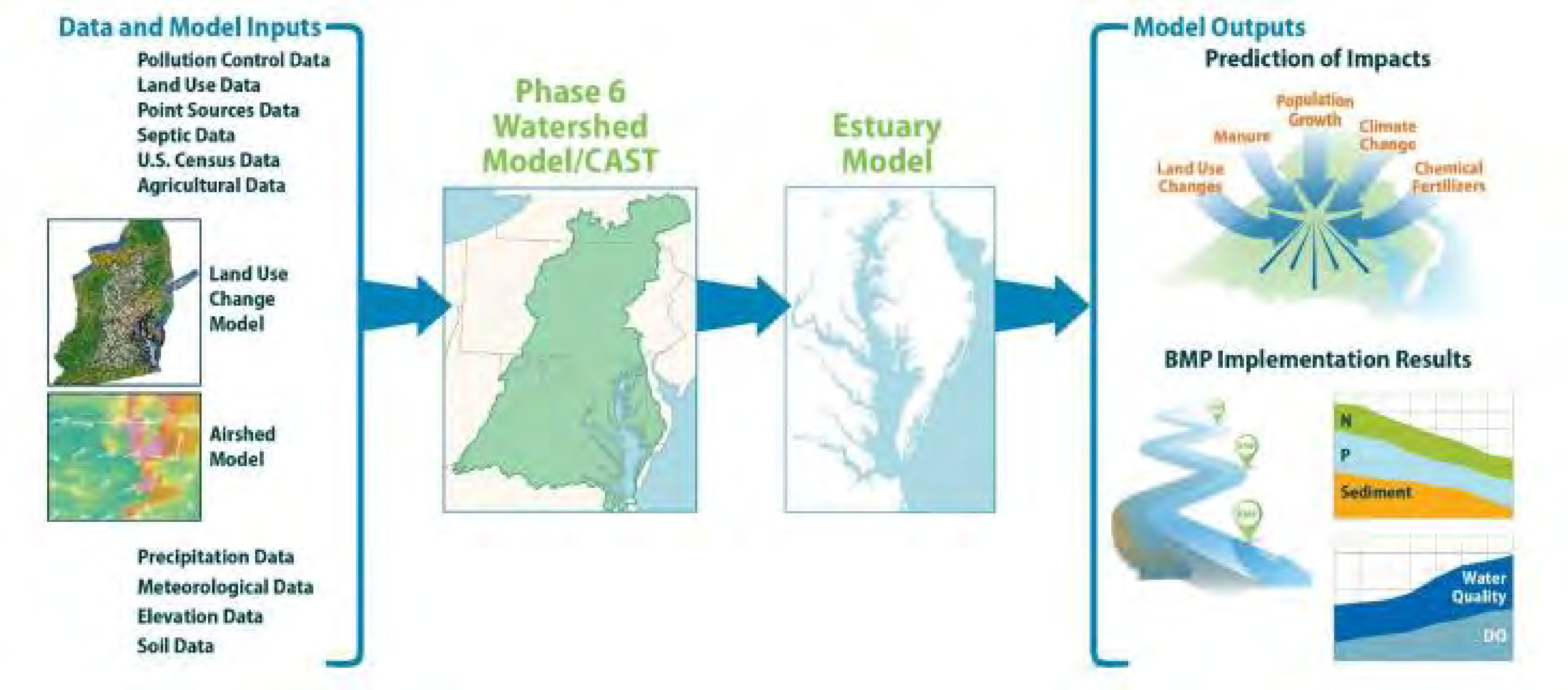
Support/Revise Flow--N relationship IB 4.4 **OCT**
APLE
Soil P history effect GS 4.5 **OCT**
Investigate Speciation changes 4.7.1 **OCT**
P sensitivity in developed IB 4.5 **Oct**
Process-based response of flow and sediment On land
Specified land nutrient response
Effect on land use GS 3.2 **JUL**
CMAQ Climate change effect LL/JB/BS 3.1 **OCT**
Carbon Dioxide effect **GB 4.1 JUL**
BMP effectiveness change GS 4.6 **OCT**
Nutrient Inputs
Effect on Ag GS 3.3 **JUL**
Land to water factor effect GS 4.7 **OCT**
BMPs
Land to Water
Stream to River factors effect GS 4.7 **OCT**
WWTP Effect GS 3.4.2 **JUL**
Streams
Septic Effect GS 3.4.2 **JUL**
Groundwater Travel Time effect GS 4.7 **JUL**
UNEC
Rivers
Reservoir Rules effects GS 4.7 **OCT**
Diversion Effect GS 3.4.2 **JUL**
CSO Effect IB 3.4.1 **JUL**

Reasonable response to sea level rise? PS 5.3.1 **OCT**
Reasonable response to temperature? RT/IB 5.3.2 **OCT**
Wetlands losses and gains LL/CC 5.1.1 **OCT**
Examine wind effects RT 5.1.2 **JUL**
Estuarine Model WQSTM
Estuarine Inputs
Sea level Rise RT 5.1.3 **JUL**
Growth and respiration curve for phytoplankton RT 5.2 **JUL**
Ocean Temp & Salinity RT 5.1.4 **JUL**
Loads from flooding GW 5.1.5 **JUL**

Effect on water quality standards
Management Effort Adjustment
STAC CC2.0 Framework recommendations

Assessment of 2025 Climate Change in the Airshed

Airshed Key Finding: Increased wet deposition N loads under increased precipitation.



Data and Model Inputs

- Pollution Control Data
- Land Use Data
- Point Sources Data
- Septic Data
- U.S. Census Data
- Agricultural Data
- Land Use Change Model
- Airshed Model
- Precipitation Data
- Meteorological Data
- Elevation Data
- Soil Data

Phase 6 Watershed Model/CAST

Estuary Model

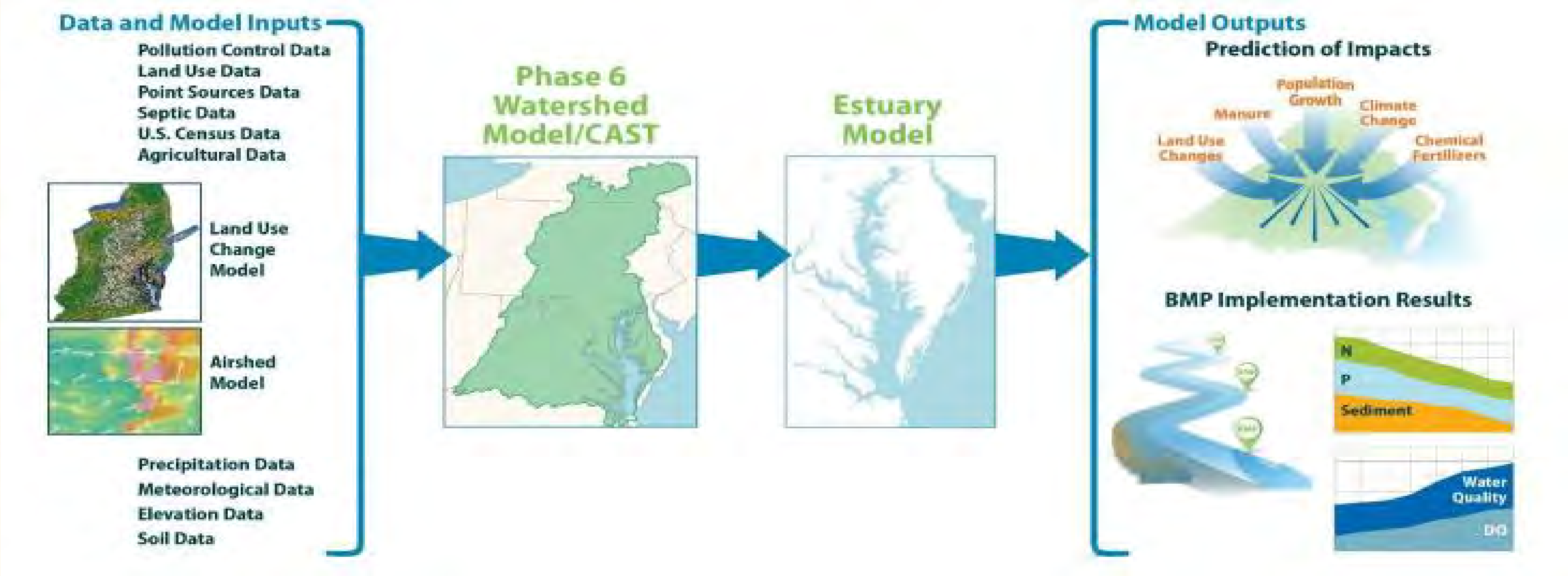
Model Outputs

Prediction of Impacts

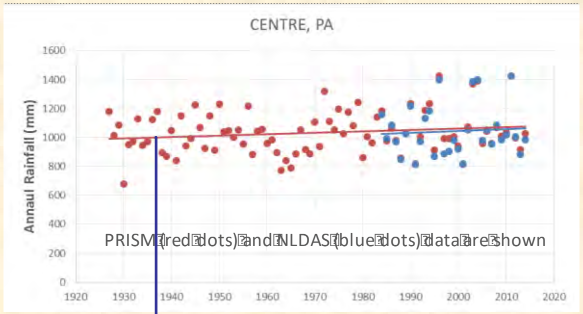
BMP Implementation Results

Assessment of 2025 Climate Change in the Watershed

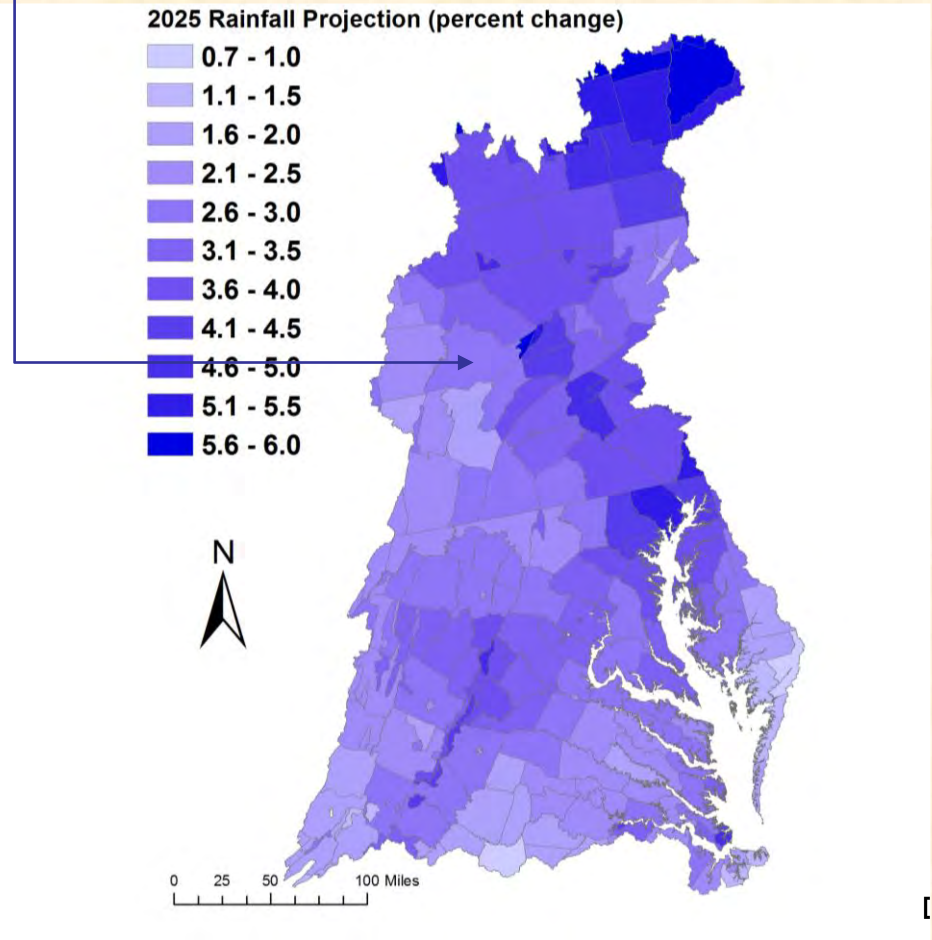
<u>Watershed Key Findings</u>: Increased precipitation volume, precipitation intensity, and evapotranspiration are major determinates of changes in loads due to climate change. (Land use change beyond 2025 also increases nutrient and sediment loads.)



Precipitation Volume Increasing



Projections of rainfall increase using trend in 88-years of annual PRISM[1] data



Change in Rainfall Volume 2021-2030 vs. 1991-2000

Major Basins	PRISM Trend
Youghiogheny River	2.1%
Patuxent River Basin	3.3%
Western Shore	4.1%
Rappahannock River Basin	3.2%
York River Basin	2.6%
Eastern Shore	2.5%
James River Basin	2.2%
Potomac River Basin	2.8%
Susquehanna River Basin	3.7%
Chesapeake Bay Watershed	**3.1%**

The 1991 – 2000 period of hydrology & nutrient loads is the basis of decisions in the Chesapeake TMDL.

There are 30 years between 1995 and 2025.

Long term mean precipitation increased 3.1% and temperature by 1° C.

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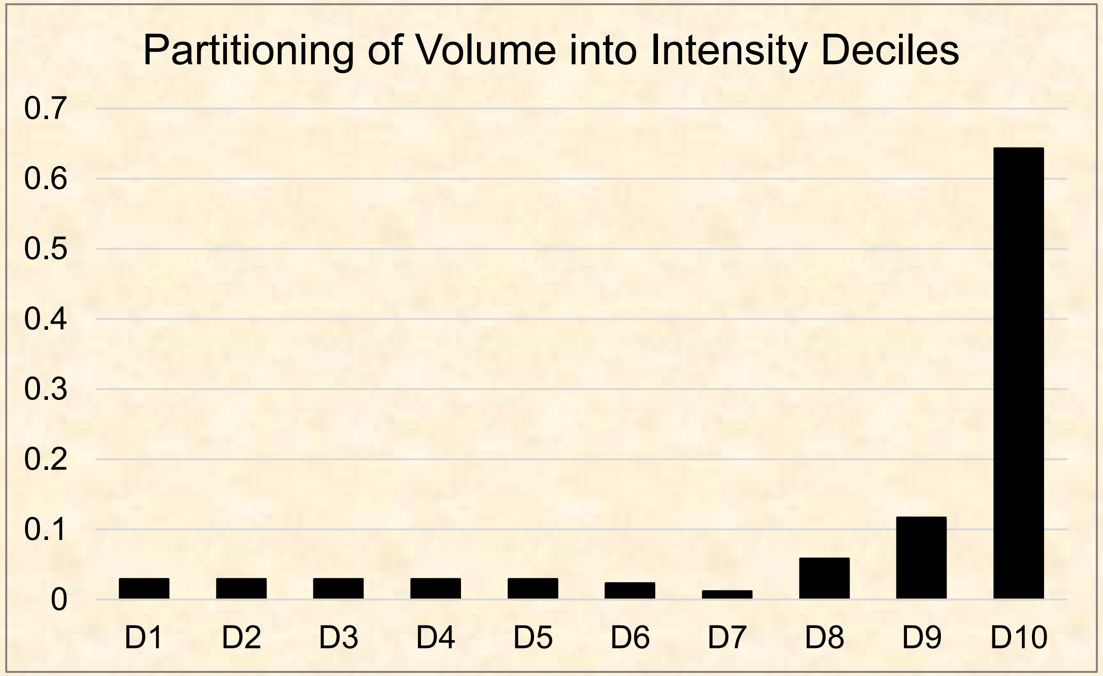
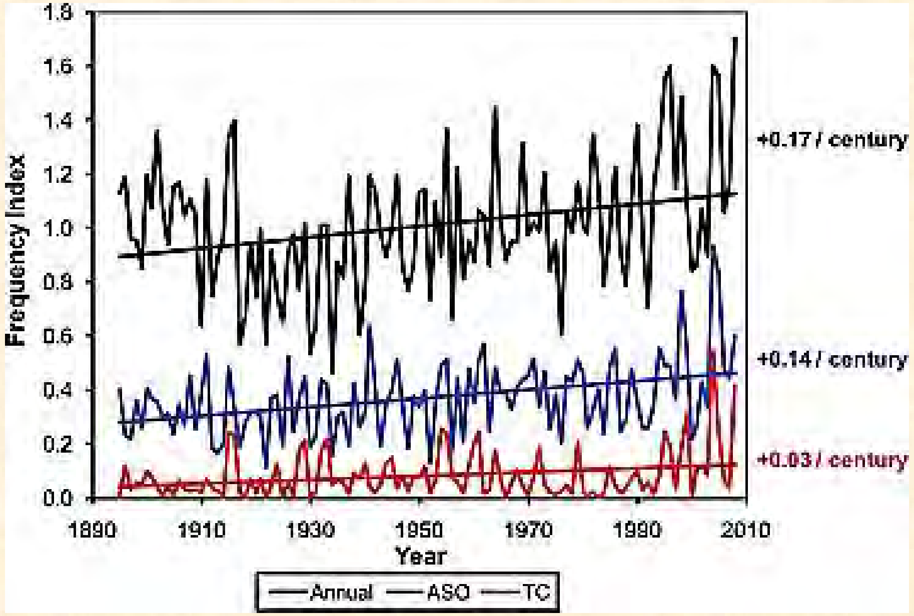
[1] Parameter-elevation Relationships on Independent Slopes Model

Rainfall Intensity Increasing

Observed trend of more precipitation volume in higher intensity events based on a century of observations.



Source: Groisman et al., 2004



National average heavy precipitation event index (HPEI) for the entire year (annual, black), for August through October (ASO, blue), and for heavy events associated with tropical cyclones (TC, red). [Kunkel et al., 2010]

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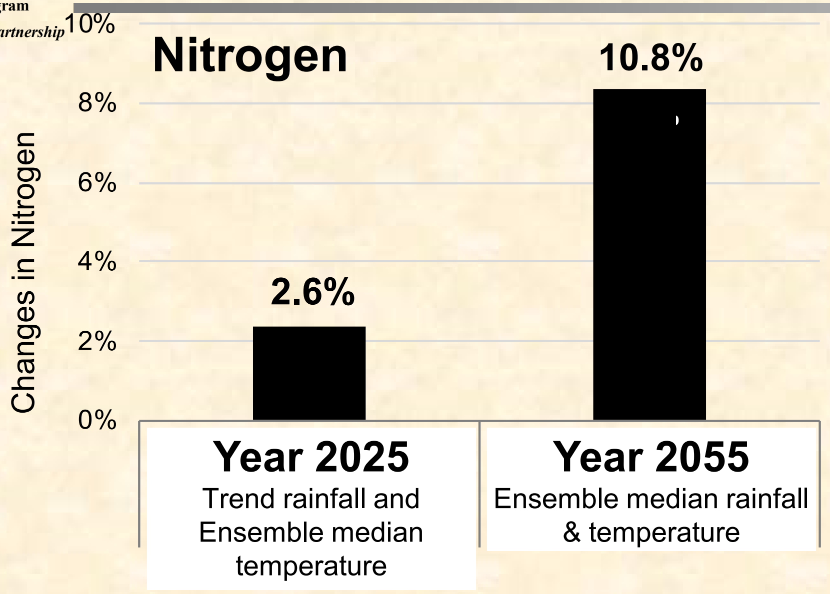
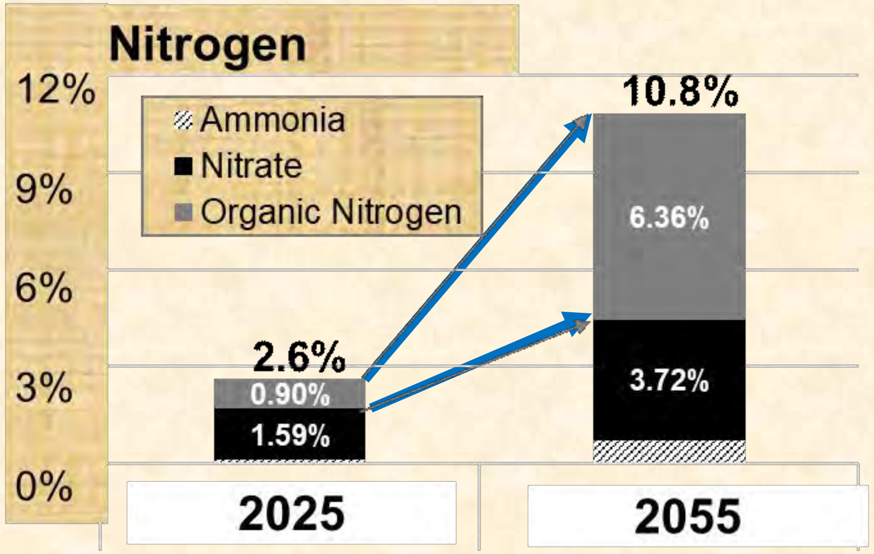
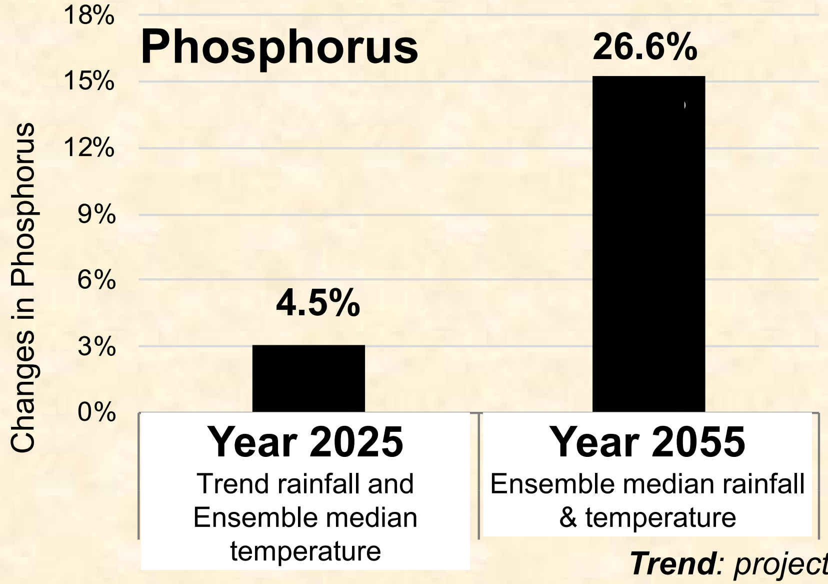
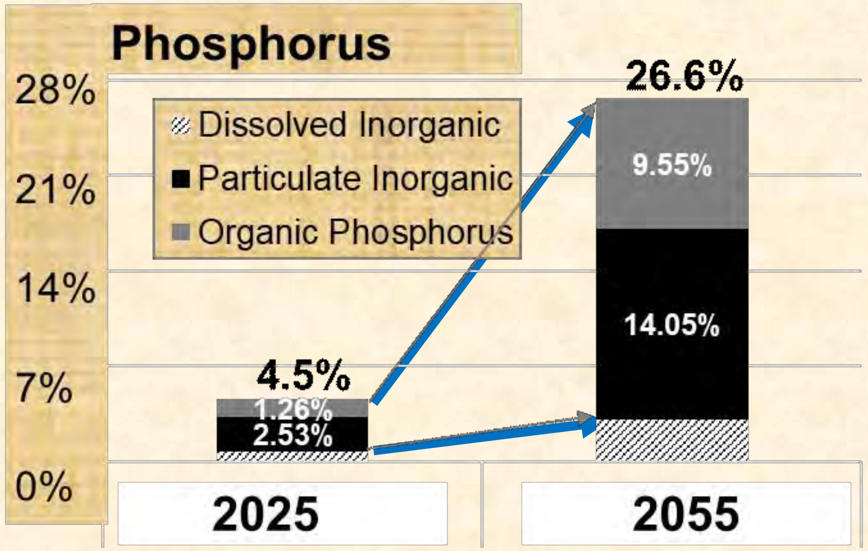
Summary of Changes in Nutrient Species Delivery





Arrows show relatively more increase in organic N & P or PIP compared to DIN or DIP.





The TN & TP loads are steadily increasing from 2025 to 2055 under climate change but there is a greater proportion of refractory N and P in the total N & P going forward.

***Trend**: projection of extrapolation of long-term trends*
***Ensemble**: 31-member ensemble of RCP4.5 GCMs*

Estimates of Climate Only and Climate and Land Use

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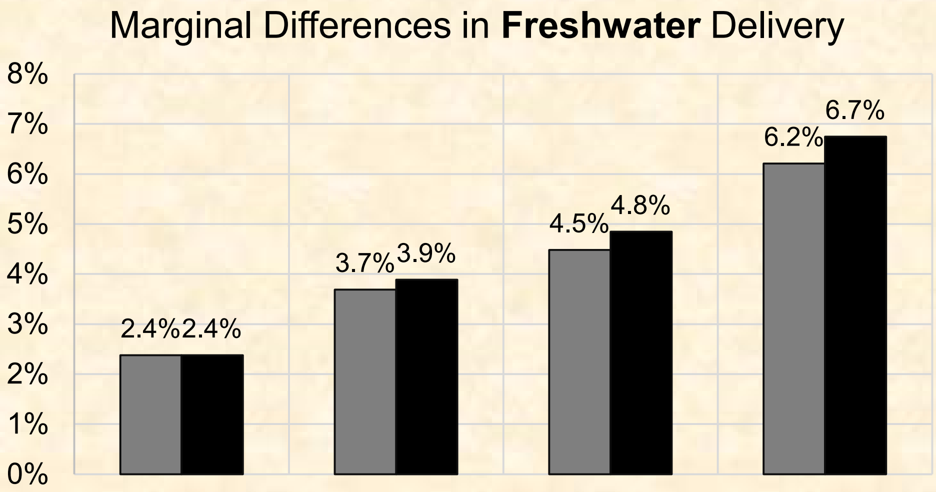
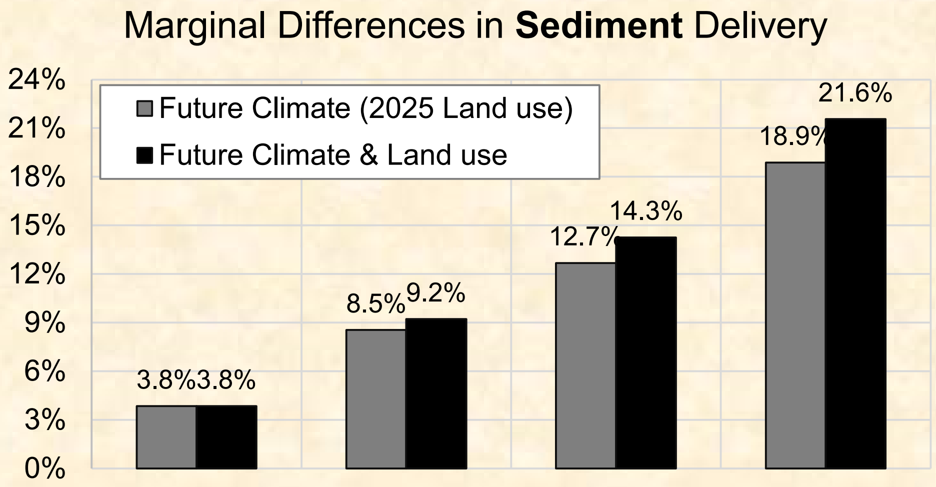
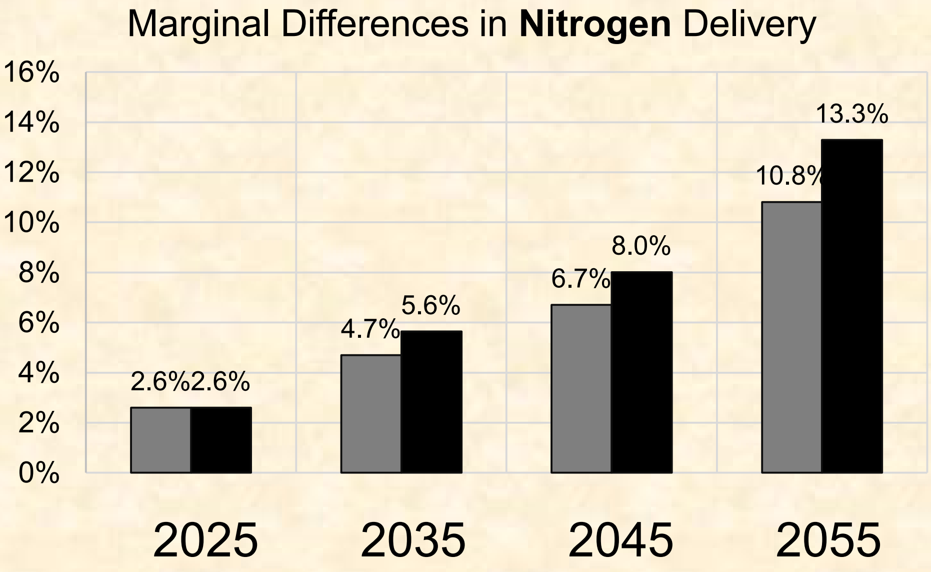
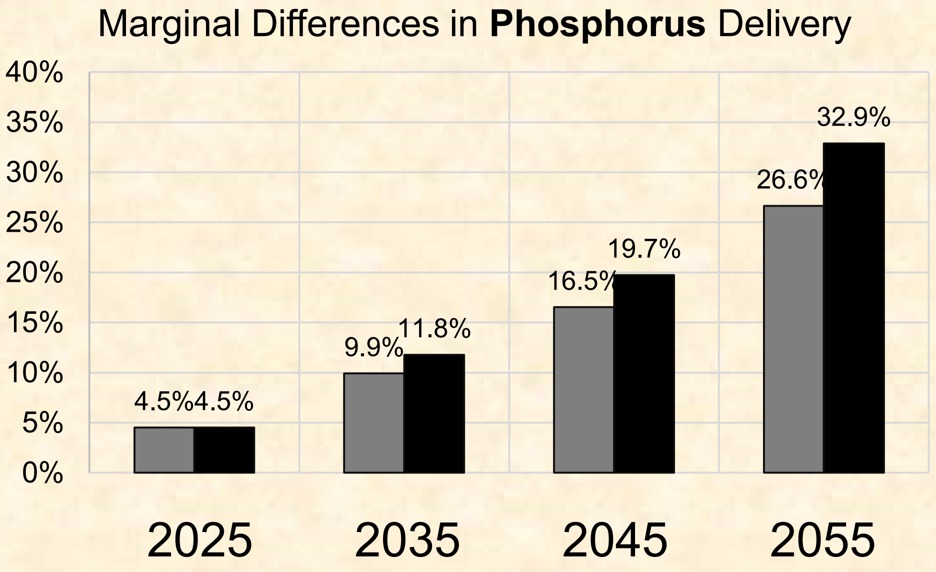

Marginal Differences in **Freshwater** Delivery


Marginal Differences in **Sediment** Delivery


Marginal Differences in **Nitrogen** Delivery


Marginal Differences in **Phosphorus** Delivery

Grey bar = climate only   Black bar = Climate and Land Use

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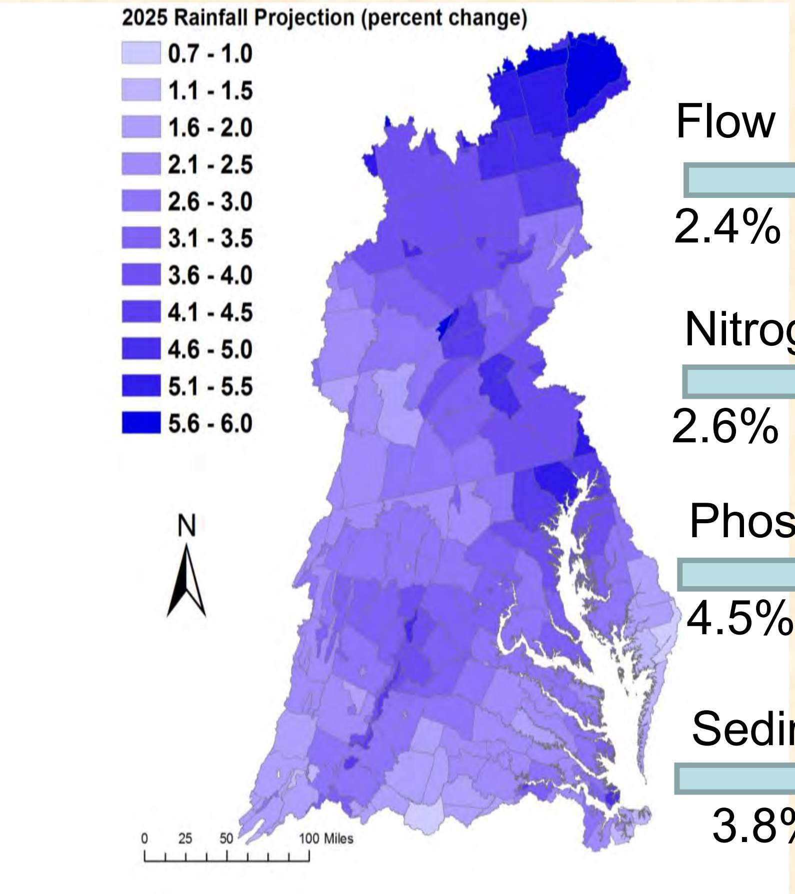
Elements of 2025 Climate Change in the Estuary



Phase 6 Watershed Model

Flow

2.4% Increase

Nitrogen Load

2.6% Increase

Phosphorus Load

4.5% Increase

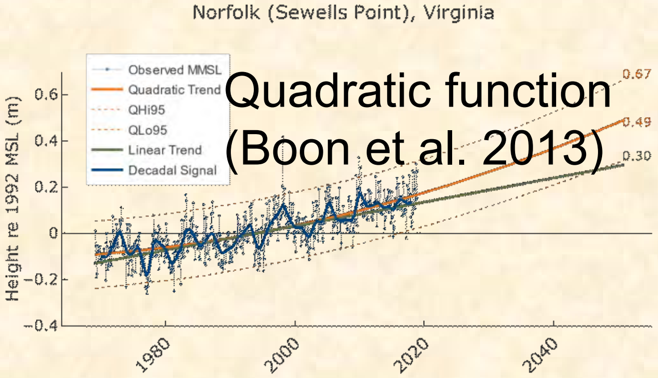
Sediment Load

3.8% Increase

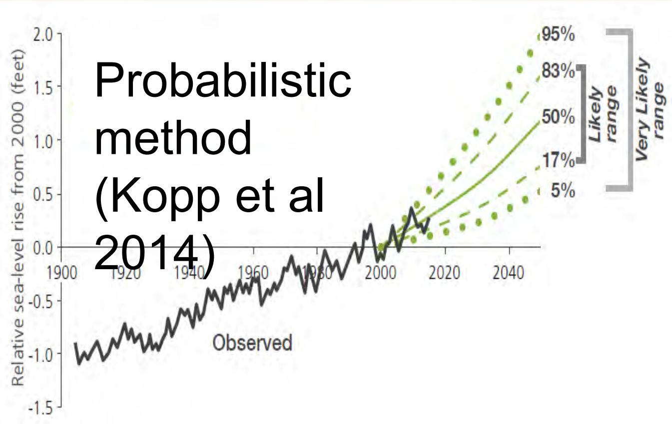
Air-temperature increase: 1.06 °C

Model: CH3D-ICM
400m-1km Resolution

2025 Sea Level Rise: 0.22m



Quadratic function (Boon et al. 2013)



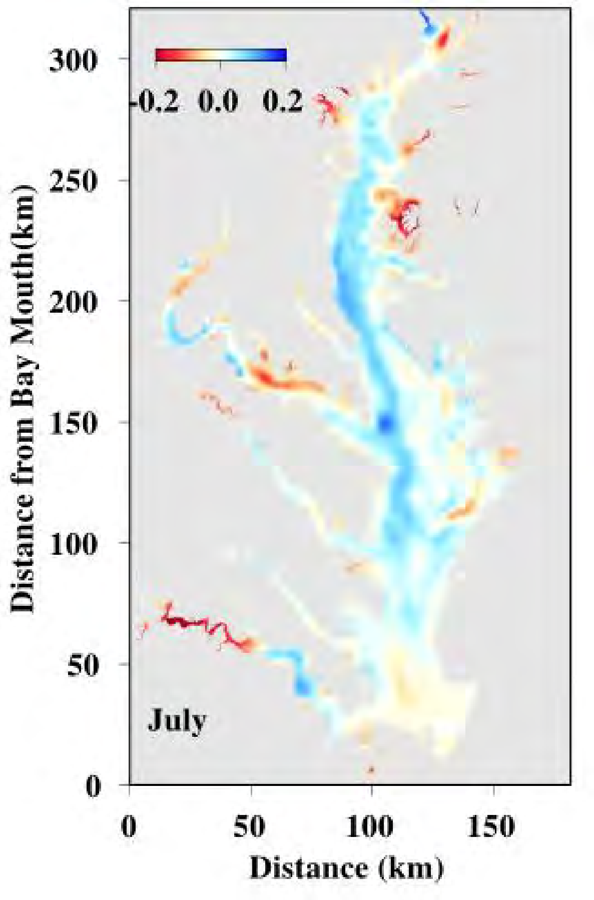
Probabilistic method (Kopp et al 2014)

Open boundary T: + 0.95 °C; S: + 0.18 psu (Thomas et al., 2017)

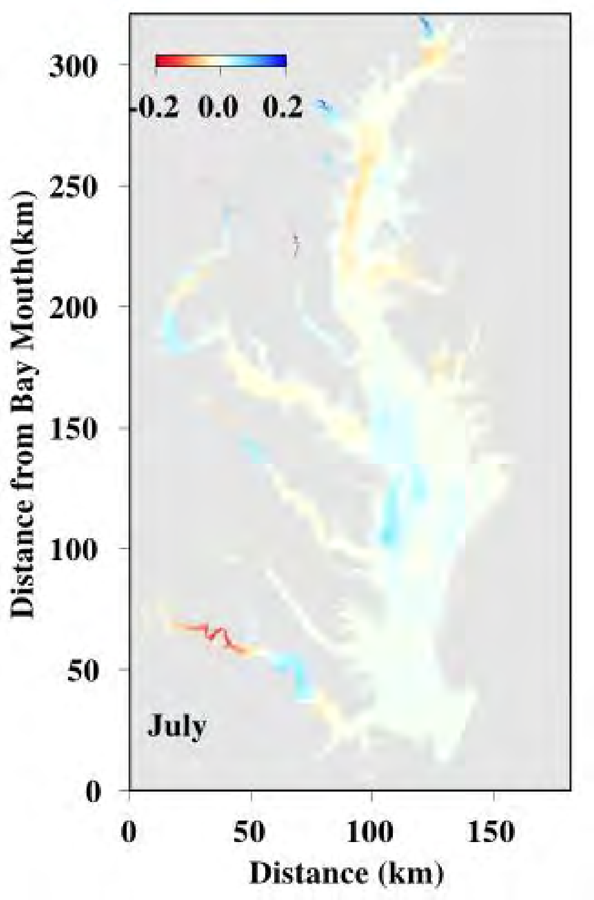
Bottom DO Change: 1995 to 2025

Keeping all other factors constant, sea level rise and increased watershed flow reduce hypoxia in the Bay, but the predominant influence are the negative impacts of increased water column temperature.

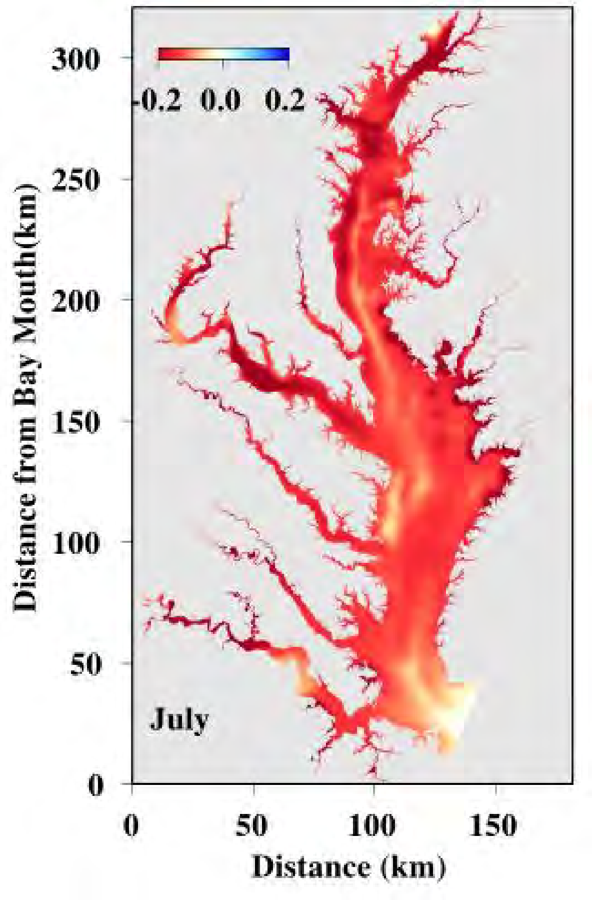
Sea Level Rise



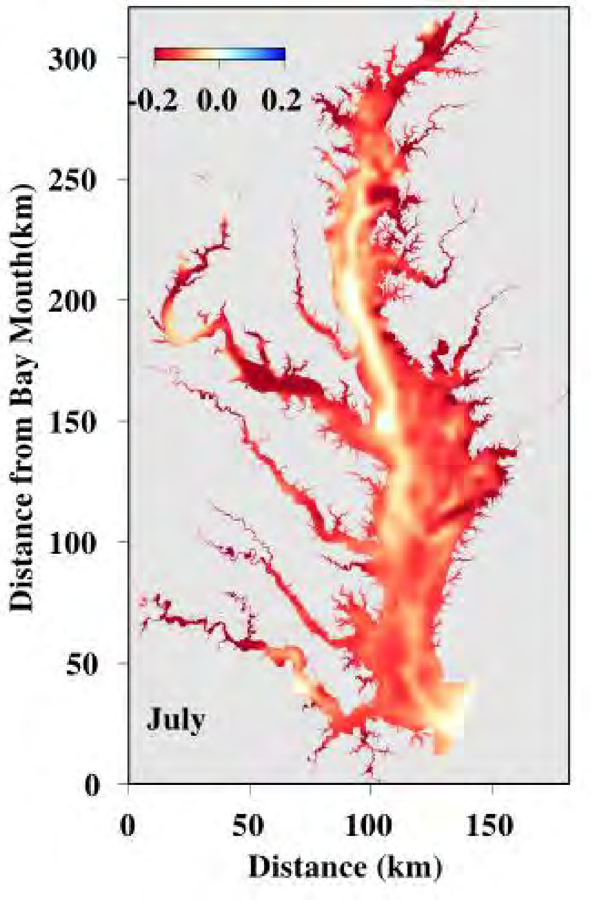
Watershed Flow



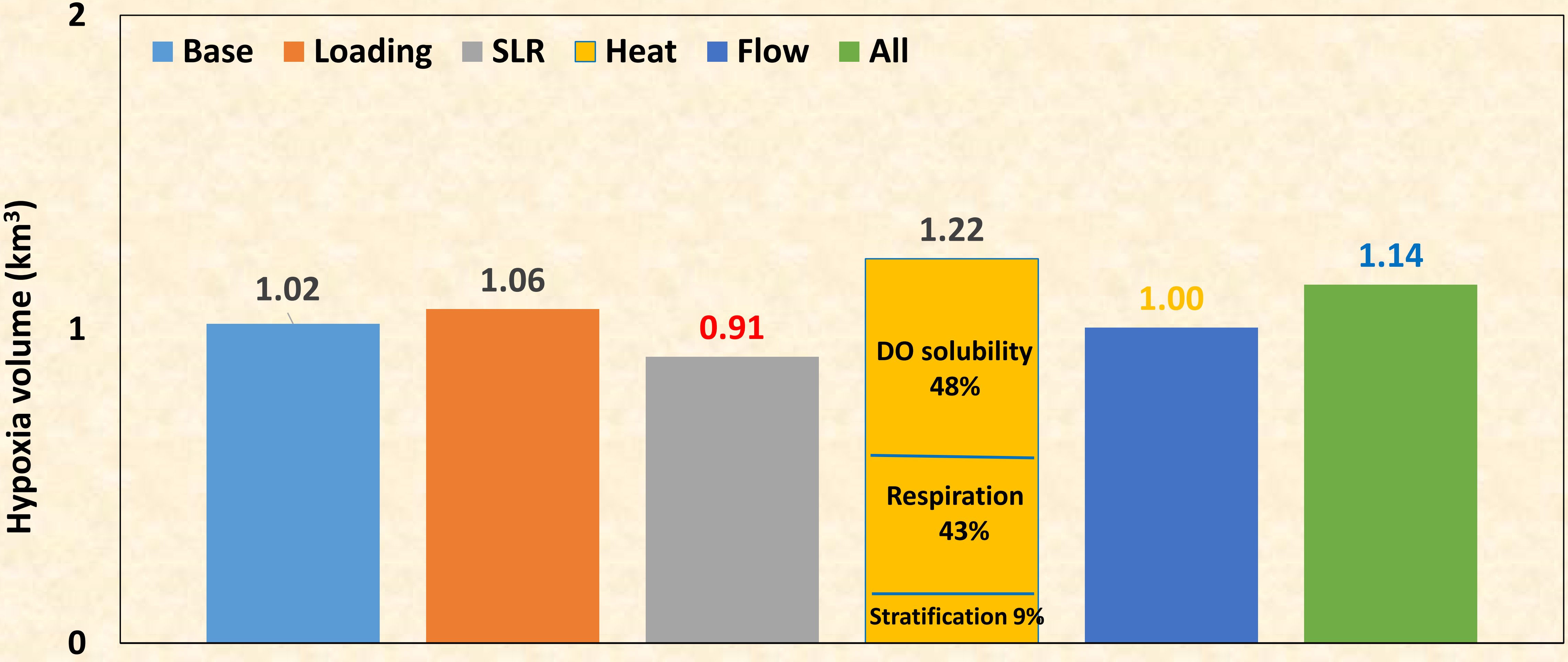
Increased Temp.



All Factors



Summer (Jun.-Sep.) Hypoxia Volume (<1 mg/l) 1991-2000 in the Whole Bay Under 2025 WIP3 Condition



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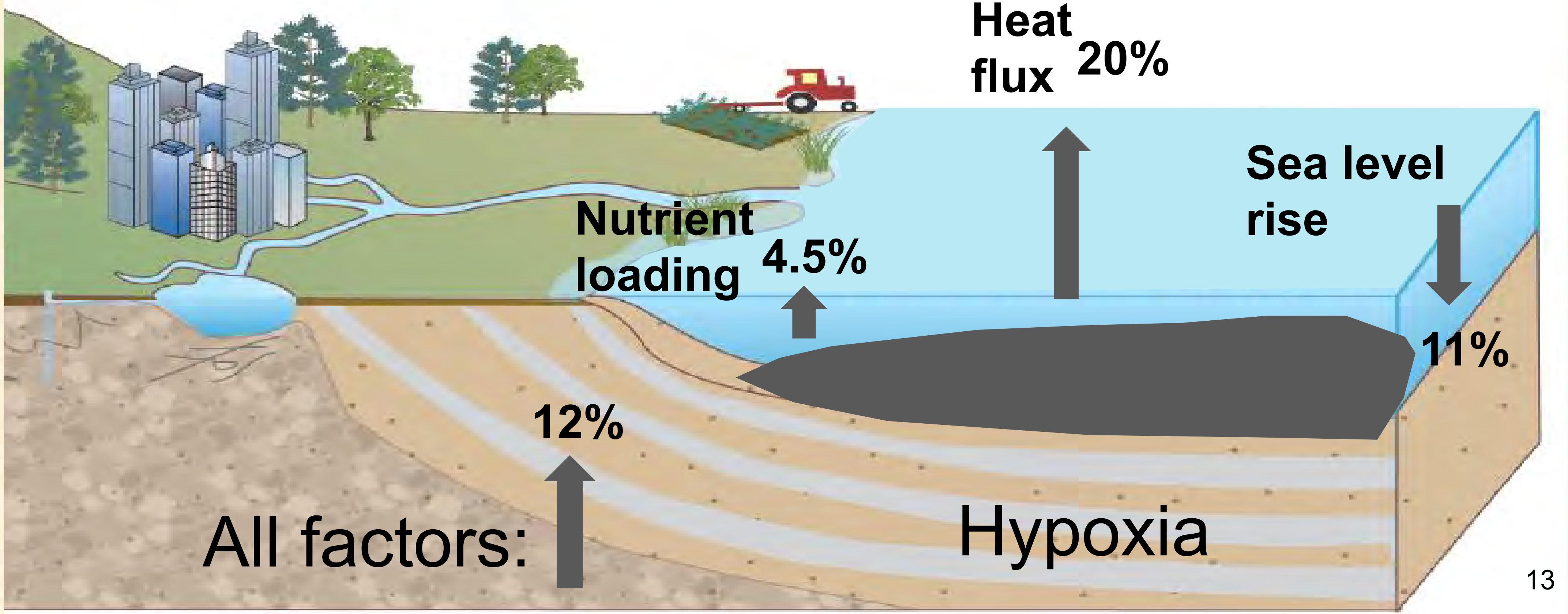
Elements of Hypoxia Volume Change: 1995 - 2025



Summary
Hypoxia volume change by 2025

Current Climate Change Only Scenarios

Air-temperature increase: 1.06 °C

Sea Level Rise: 0.22m

Flow

+2.4% est. 2025

TN

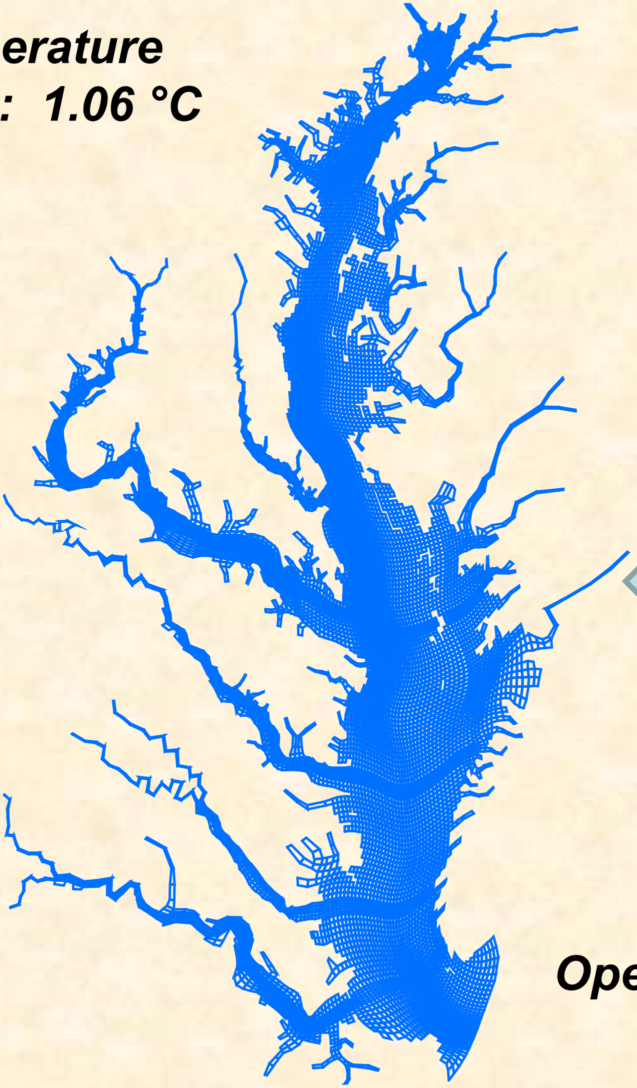
+2.6% est. 2025

TP

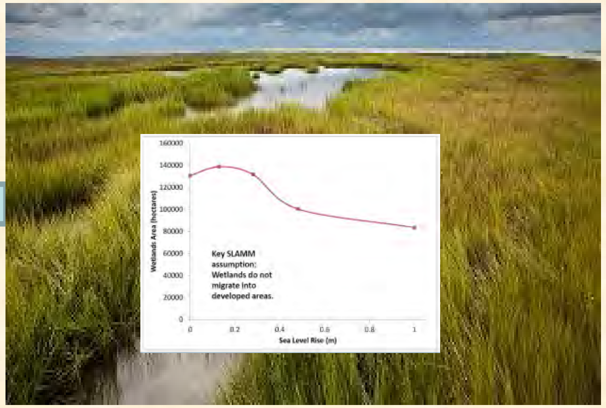
+4.5% est. 2025

Sediment

+3.8 est. 2025



Tidal wetland change



Open boundary delta T: + 0.95 °C; delta S: + 0.18 psu
(Thomas et al., 2017)

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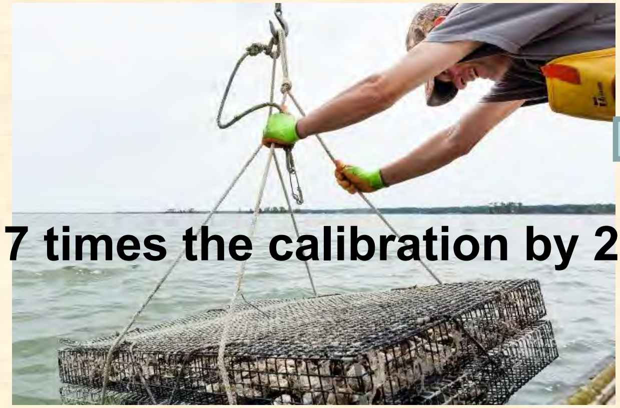
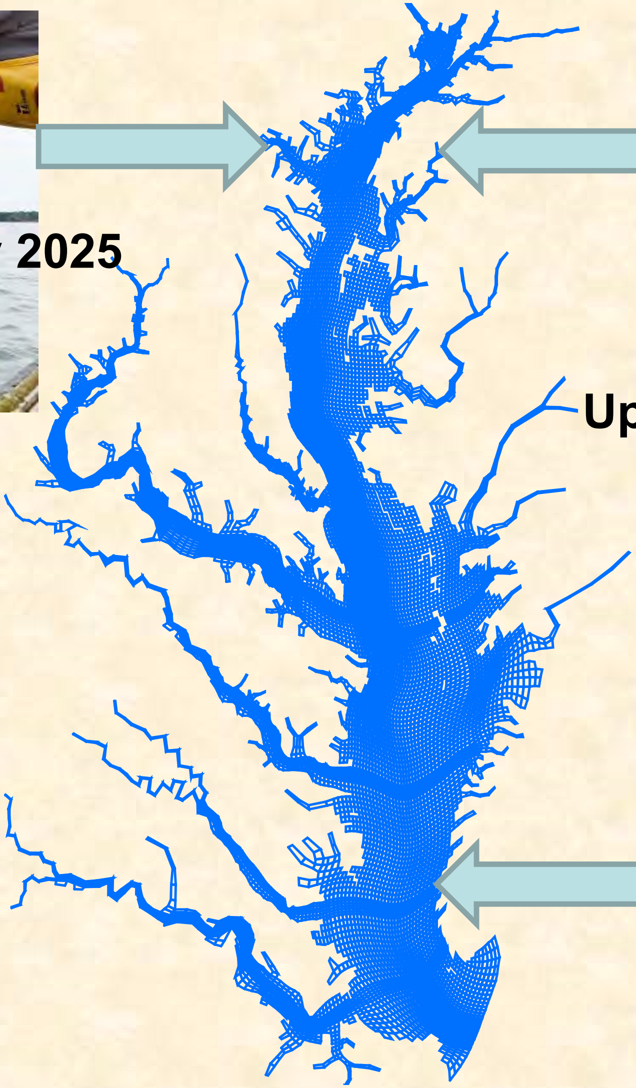
Scenarios for Estimated Future Land Use and Estuarine Practices for 2035, 2045, and 2055

Oyster aquaculture expansion



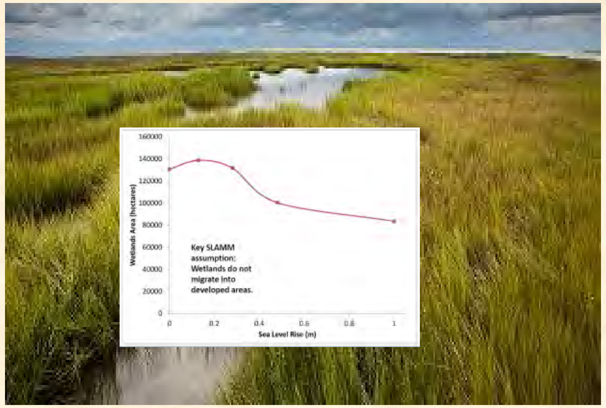
7 times the calibration by 2025



Land use change

Up to 1% increase in TN and 2% in TP

Tidal wetland change



The CBP Climate Change Assessment

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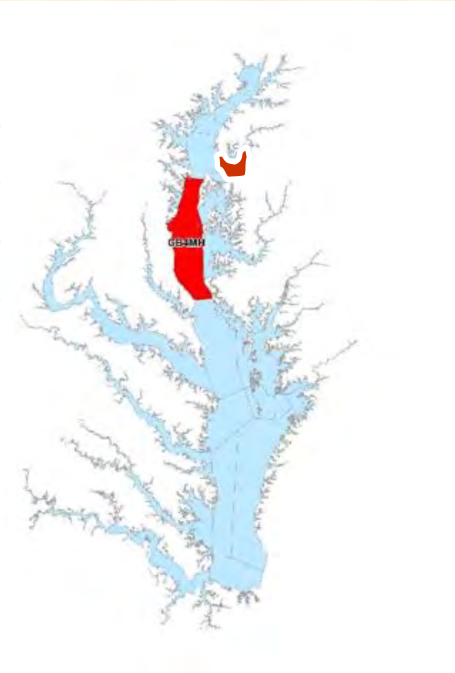
Achievement of **Deep Channel DO** water quality standard expressed as a incremental increase over the PSC agreed to (December 2017; July 2018) 2025 nutrient targets for growth and Conowingo Infill

CB Segment	State	2025 Climate 2025 Land Use 204TN 14.0TP 1993-1995 DO Deep Channel	2035 Climate 2025 Land Use 208TN 14.6TP 1993-1995 DO Deep Channel	2035 Climate 2035 Land Use 209TN 14.7TP 1993-1995 DO Deep Channel	2045 Climate 2025 Land Use 212TN 15.4TP 1993-1995 DO Deep Channel	2045 Climate 2045 Land Use 213TN 15.7TP 1993-1995 DO Deep Channel	2055 Climate 2025 Land Use 220TN 16.7TP 1993-1995 DO Deep Channel	2055 Climate 2055 Land Use 222TN 17.1TP 1993-1995 DO Deep Channel
CB3MH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB4MH	MD	**1.4%**	**2.9%**	**3.1%**	**4.5%**	**5.2%**	**6.9%**	**8.2%**
CB5MH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB5MH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
POTMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RPPMH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ELIPH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CHSMH	MD	**1.1%**	**1.6%**	**1.6%**	**2.2%**	**2.2%**	**3.3%**	**3.3%**



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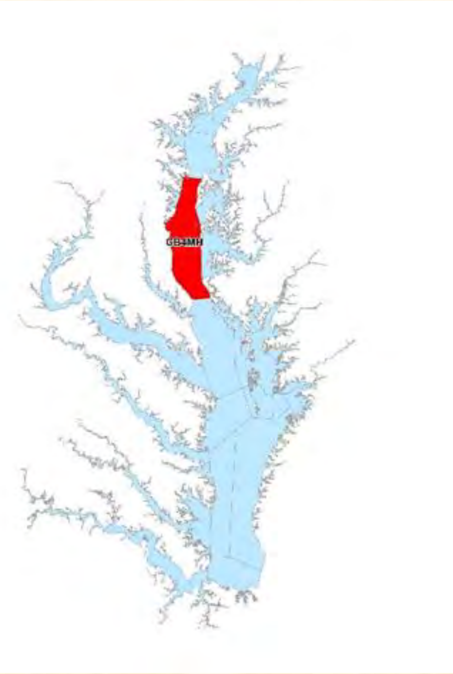
Achievement of Deep Water DO Water Quality Standard

Achievement of **Deep Water DO** water quality standard expressed as a incremental increase over the PSC agreed to (December 2017; July 2018) 2025 nutrient targets for growth and Conowingo infill

CB Segment	State	2025 Climate 2025 Land Use 204TN 14.0TP 1993-1995 DO Deep Water	2035 Climate 2025 Land Use 208TN 14.6TP 1993-1995 DO Deep Water	2035 Climate 2035 Land Use 209TN 14.7TP 1993-1995 DO Deep Water	2045 Climate 2025 Land Use 212TN 15.4TP 1993-1995 DO Deep Water	2045 Climate 2045 Land Use 213TN 15.7TP 1993-1995 DO Deep Water	2055 Climate 2025 Land Use 220TN 16.7TP 1993-1995 DO Deep Water	2055 Climate 2055 Land Use 222TN 17.1TP 1993-1995 DO Deep Water
CB3MH	MD	0.1%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
CB4MH	MD	**1.0%**	**1.6%**	**1.6%**	**2.0%**	**2.1%**	**2.6%**	**2.9%**
CB5MH	MD	**0.5%**	**0.9%**	**1.0%**	**1.3%**	**1.3%**	**1.6%**	**1.6%**
CB5MH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB6PH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB7PH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PATMH	MD	0.0%	**0.7%**	**0.7%**	**2.0%**	**2.2%**	**3.0%**	**3.0%**
MAGMH	MD	0.0%	0.0%	0.0%	0.2%	0.2%	-0.2%	0.4%
SOUMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SEVMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PAXMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
POTMH	MD	0.1%	0.3%	0.4%	0.7%	0.7%	0.9%	1.0%
RPPMH	VA	0.2%	**1.2%**	**1.4%**	**1.7%**	**1.8%**	**1.9%**	**1.9%**
YRKPH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ELIPH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SBEMH	VA	0.0%	0.0%	0.0%	0.5%	**0.6%**	**3.3%**	**4.0%**
CHSMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EASMH	MD	0.1%	0.2%	0.2%	0.4%	0.5%	0.5%	0.5%



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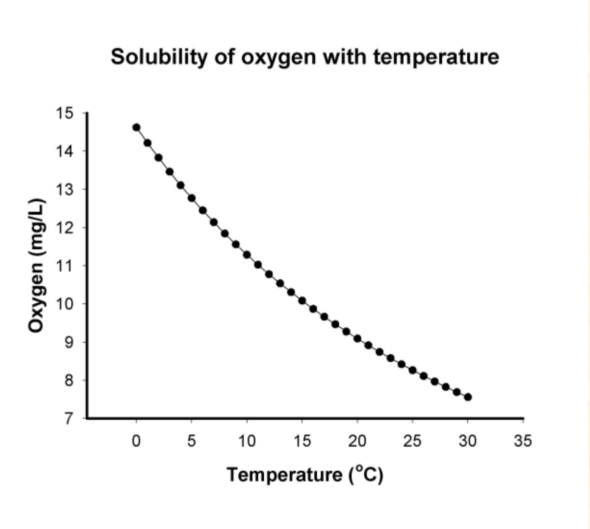
Achievement of Open Water DO Water Quality Standard

CB Segment	State	2025 Climate 2025 Land Use 204TN 14.0TP 1993-1995 DO Open Water	2035 Climate 2025 Land Use 208TN 14.6TP 1993-1995 DO Open Water	2035 Climate 2035 Land Use 209TN 14.7TP 1993-1995 DO Open Water	2045 Climate 2025 Land Use 212TN 15.4TP 1993-1995 DO Open Water	2045 Climate 2045 Land Use 213TN 15.7TP 1993-1995 DO Open Water	2055 Climate 2025 Land Use 220TN 16.7TP 1993-1995 DO Open Water	2055 Climate 2055 Land Use 222TN 17.1TP 1993-1995 DO Open Water
CB1TF	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB2OH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB3MH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB4MH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB5MH_MD	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB5MH_VA	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB6PH	VA	0.4%	0.7%	0.8%	1.0%	1.1%	1.3%	1.4%
CB7PH	VA	1.1%	1.8%	1.9%	2.8%	2.9%	4.0%	4.1%
CB8PH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
BSHOH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
GUNOH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
MIDOH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
BACOH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
PATMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
MAGMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
SEVMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
SOUMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
RHDMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
WSTMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
PAXTF	MD	3.3%	3.4%	3.3%	4.3%	4.3%	5.1	
WBRTF	MD	21.3%	28.6%	21.3%	43.6%	51.2%	58.8	
PAXOH	MD	6.1%	9.5%	11.0%	10.7%	12.0%	12.9	
PAXMH	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.1	
POTTF_DC	DC	1.8%	2.6%	2.7%	3.0%	3.2%	3.9	
POTTF_MD	MD	0.5%	0.6%	0.7%	2.0%	2.3%	2.9	
ANATF_DC	DC	5.1%	6.0%	6.4%	8.6%	9.2%	10.6	
ANATF_MD	MD	10.6%	16.4%	16.8%	24.7%	25.7%	29.8	
PISTF	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
MATTF	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	
POTOH1_M	MD	0.3%	0.5%	0.5%	0.9%	0.9%	1.4	
POTMH_MI	MD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RPPTF	VA	0.0%	0.0%	0.0%	0.0%	0.0%	1.7%	3.7%
RPPOH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RPPMH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CRRMH	VA	4.2%	5.6%	5.6%	7.1%	7.1%	8.9%	9.7%
PIAMH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
MPNTF	VA	16.6%	18.5%	18.1%	15.7%	16.2%	10.0%	11.0%
MPNOH	VA	3.6%	0.3%	9.8%	0.0%	0.0%	0.0%	0.0%
PMKTF	VA	8.9%	14.6%	10.0%	10.2%	10.2%	2.8%	3.3%
PMKOH	VA	2.9%	1.8%	5.3%	-2.6%	-2.6%	-3.3%	-3.3%
YRKMH	VA	2.3%	1.8%	4.5%	2.5%	3.2%	4.3%	5.3%
YRKPH	VA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
MOBPH	VA	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.2%
JMSTFL	VA	0.0%	0.6%	0.5%	1.1%	1.2%	1.2%	1.4%



Chesapeake Bay Program
Science, Restoration, Partnership

Chesapeake Partnership Accountability Framework

- December 2017 and updated July 2018 decisional model for tracking targets to 2025.
- 2019 CC Model for adjustment of July 2018 decisional model for CB watershed and Bay climate change risk.

- 7 Watershed Implementation Plans (WIPs) describe what amount, how, where, and when for **all implementation required to achieve water quality standards by 2025.**
    - Phase I in 2010
    - Phase II in 2012
    - **Phase III in 2019**

- 2-Year Milestones ensure short term progress

By the 2022-2023 milestones there will be quantifiable reductions needed to defend water quality standards from future climate risk.

Chesapeake Bay Program
Science, Restoration, Partnership

Climate Resiliency for Stormwater Management and Other BMPs

The PSC gave specific direction to the CBP Partnership at their December 2017 meeting to "… develop a better understanding of the BMP responses, including new or other emerging BMPs, to climate change conditions".

In 2019, the Management Board of the Chesapeake Bay Partnership following the direction of the PSC directed that:

- The design and accelerated adoption of stormwater management practices appropriately designed for increased rainfall volumes and intensities that are expected in the future for all counties in the Chesapeake watershed.
- Examination of the top tier ag and urban BMPs that are most vulnerable to future climate risk, with an emphasis on structural practices, that could be adapted to become more resilient to future climate conditions of increased rainfall intensities and volumes.
- A description of the co-benefits of BMPs that mitigate future climate risk, especially as they relate to the protection of local infrastructure and public health and safety, including green infrastructure, urban floodplain management, riparian buffers, tidal and non-tidal wetlands and other management actions.

Chesapeake Bay Program
Science, Restoration, Partnership

Climate Resiliency for Stormwater Management and Other BMPs

- In response to the direction the Urban Stormwater Workgroup and the Chesapeake Stormwater Network are working to maintain the resiliency of stormwater and restoration practices in the face of climate change in the Chesapeake watershed through an analysis of the vulnerability of urban stormwater BMPs to climate change and are leading the design of stormwater management practices that will maintain their performance despite increased rainfall and storm intensities under future climate conditions.
- In addition, under the Chesapeake Bay Trust GIT-funded projects the Urban Stormwater Workgroup will “Develop Probabilistic Intensity Duration Frequency (IDF) Curves” for the all counties of the Chesapeake Watershed by: 1) evaluation of downscaling methods and climate model combinations to assess their ability to replicate historical precipitation extremes, 2) downscaling of projected precipitation extremes for future periods, 3) quantification of methodological and climate model uncertainties for the projected precipitation extremes for future periods, 4) development of probabilistic intensity duration frequency (IDF) curves for all counties of Chesapeake Bay Watershed and the District of Columbia (DC), and 5) development of web-based tools and appropriate outreach to make results accessible to end-users.
- Finally, a STAC Science Synthesis Project will provide “A Systematic Review of Chesapeake Bay Climate Change Impacts and Uncertainty: Watershed Processes, Pollutant Delivery, and BMP Performance”. The technical synthesis is designed to answer three specific questions:
    1. How do climate change and variability affect nutrient/sediment cycling in the watershed?
    2. How do climate change and variability affect BMP performance?
    3. Which BMPs will likely result in the best water quality outcomes under climate uncertainty?"

Chesapeake Bay Program
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Key Points in Assessment of 2025 Climate Change Risk

- The new 2019 climate change assessment confirms the December 2017 climate change findings with a better model, providing better understanding of underlying processes, more specific findings on nutrient speciation, CSOs, wet deposition of nitrogen, etc.
- Loads have decreased by about half from the December 2017 estimates of the load required to respond to climate risks and achieve 2025 water quality standards. Now, depending on decisions to be made by the WQGIT, the additional load reduction estimated to be needed to respond to climate change risk are 5M lb TN (before was 9M lb TN). However, the estimated load reduction to address climate risk for 2035 is about twice that of the estimated 2025 nitrogen load reduction.

Attachment 3

Chesapeake Bay Program
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Principals' Staff Committee
December 17, 2020

Draft Actions/Decisions

Climate Change Final Decision

- Decision: The PSC reached consensus, with EPA deferring to the jurisdictions, on a final set of recommendations for how the partnership will evaluate climate change for 2025 and 2035, and on numeric targets and allocations for 2025 due to climate change. Specifically, they approved the following:
    - The 2020 update to the 2025 climate load allocations based on the latest modeling assessment.
    - Jurisdictions are expected to account for additional nutrient and sediment pollutant loads due to 2025 climate change conditions in a Phase III WIP addendum and/or 2-year milestones beginning in 2022.
    - Jurisdictions are expected to include a narrative in the 2022-2023 Milestones that describes the current understanding of 2035 climate change conditions, to the effect that: "Preliminary estimates for the climate impact through 2035 indicate a doubling of the 2025 load effect. The effect of climate change on our ability to meet the Bay's water quality standards is a significant and increasing concern."
    - In 2025, the Partnership will consider results of updated methods, techniques, and studies and revisit existing estimated loads due to climate change to determine if any updates to those 2035 load estimates are needed.

  The full set of recommendations to the PSC, including the specific call to continue efforts to improve understanding of the science and refine estimates of pollutant load changes due to 2035 climate change conditions, may be accessed by clicking here: Recommendations
- Note: The updated climate change *narrative language* is still being developed by the climate resilience and communications workgroups. The narrative is not needed until submission of 2022-2023 Milestones on 1/15/22.
- Note: New York (Jim Tierney) requested that the record reflect that future allocation decisions regarding the 2035 climate load should factor in fairness and equity.

Chesapeake Bay Program Funding

- Note: Jim Edward provided an overview of the 2020 budget breakdown within EPA offices, CBIG and CBRAP, Local Government Implementation, WIP Assistance and other funding categories, as well as the outlook for 2021. Joe Hatten suggested similar presentations from other federal agencies would be helpful on a future PSC agenda. Ann Swanson suggested having a more in-depth follow-up budget discussion at a future PSC meeting to discuss how CBP partners might help strategically direct future funding, and Sec. Strickler recommended more PSC discussion regarding discretionary funding. It was also suggested that a future PSC meeting should address monitoring program costs.

DEIJ Action Team Update

- Note: The DEIJ Action Team Co-Chairs, Jeff Seltzer (DC) and Meryem Karad (VA) provided an update on the Action Team's work and presented a proposed timeline for completing DEIJ Action Team tasks (i.e., development of draft and final DEIJ Strategy Implementation Plan and development of recommendations for establishing the Community Advisory Board). PSC members did not voice any objections to that timeline. (For a copy of the presentation and timeline click here and see slide 7.)
- Note: Several members acknowledged that funding will be a major factor in what can be accomplished. Sec. Grumbles recommended seeking foundation financial support to supplement and complete this work with non-governmental funding. Sec. Strickler agreed.

Planning for 2021 EC Actions

- Note: Sec. Strickler discussed Governor Northam's desire to have an EC event in the Spring/Summer, specifically an outdoor Chesapeake Bay experience (pending COVID-19 vaccinations), with the more formal EC meeting in December. The Governor intends to reach out directly to his EC counterparts. Diana Esher (EPA) requested that the PSC set a date for the initial EC meeting for when the new EPA Administrator is on board and can participate. Sec. Strickler discussed the following issues for the EC to act upon at their 2021 meetings: Climate change and strengthening prior EC language as well as further actions on the CAB and DEIJ. The Chair directed Ann Jennings to chair a PSC action team to develop draft language for a EC statement on climate change. No objections to the meetings, issues, and/or next steps were raised, though several PSC members cautioned that getting EC members to participate would be challenging. It was agreed that meetings would need to be virtual until a COVID-19 vaccine becomes widely available.

- Action: Rachel Felver will convene the EC Planning Team.

Conowingo WIP and Finance Strategy.

- Note: Co-Chairs Matt Rowe (MDE) and Jill Whitcomb (PADEP) provided a Conowingo WIP Steering Committee update on progress to date on a draft Conowingo WIP and the development of a draft Conowingo Finance Strategy. The partnership released the draft Conowingo WIP on October 14, 2020 for public input along with a pre-recorded webinar overview of the WIP and its actions. The public comment period was extended from December 21, 2020 to January 20, 2021 and public outreach and education is being conducted in Pennsylvania, Maryland, and New York. EPA noted that the agency would evaluate the draft Conowingo WIP and provide its evaluation by the end of January 2021. A revised draft timeline was presented to the PSC and the Steering Committee committed to keeping the PSC updated and involved in any necessary future changes. The Steering Committee also informed the PSC that the draft Conowingo Financing Strategy is under review and will be presented to the PSC at its next meeting. The Finance Strategy Team highlighted a key assumption in their memo is that the partnership will have the ultimate responsibility for funding implementation and that public funding alone will not be sufficient. Public-private partnerships will be necessary.

PSC Workplan

- Action**:** Sec. Strickler noted that Ann Jennings will make adjustments to the draft workplan based on the discussion today and distribute to PSC members with the Actions/Decisions.

Items for next PSC meeting

- Conowingo WIP
- Draft DEIJ Implementation Plan
- EC meetings

Attendance (Members names are in bold)

Jurisdictions	
Ben Grumbles Lee Currey Dinorah Dalmasy Paul Emmart Matt Rowe	Md Dept of the Environment
Jeannie Haddaway- Riccio Dave Goshorn	MD Dept of Natural Resources
Terrell Erickson	MD Dept of Agriculture
Jason Dubow	MD Dept of Planning
Tommy Wells Jeffrey Seltzer Katherine Antos John Maleri Ed Dunne	DC Dept of the Environment
Shawn Garvin Steve Williams Clare Sevcik Brittany Sturgis	DE Dept of Natural Resources & Environmental Control
Chris Brosch	DE Dept of Agriculture
Patrick McDonnell Aneca Atkinson Brian Chalfant Jill Whitcomb	PA Dept of Environmental Protection
Greg Hostetter Karl Brown	PA Dept of Agriculture
Cindy Dunn Matt Keefer	PA Dept of Conservation & Natural Resources
Matt Strickler Ann Jennings Meryem Karad	VA Office of the Secretary of Natural Resources
David Paylor James Martin	VA Dept of Environmental Quality

Bettina Ring Terry Lasher	VA Dept of Agriculture and Forestry
Jim Tierney Lauren Townley Cassandra Davis	NY Dept of Environmental Conservation
Scott Mandirola Teresa Koon Dave Montali	WV Dept of Env Protection
Joe Hatten	WV Dept of Agriculture
Ann Swanson Marel King Adrienne Kotula	Chesapeake Bay Commission
Federal Agencies	
Cosmo Servidio Diana Esher	EPA, Region 3
Dana Aunkst	Chesapeake Bay Program, EPA
Terrell Erickson	USDA
Sally Claggett	USFS
Sean Corson	NOAA
Wendy O'Sullivan	NPS
Amy Guise	USACE, Baltimore District
Sharon Baumann Kevin DuBois Jessica Rodriguez	DOD: Navy Region Mid-Atlantic Environmental Department
Scott Phillips Gary Shenk Renee Thompson	USGS
Genevieve LaRouche Chris Guy	USFWS
Advisory Committees	
Julie Lawson Jessica Blackburn	CAC
Ann Simonetti Jennifer Starr	LGAC
Andrew Miller	STAC
Federal Agencies	
Jim Edward Carin Bisland Bill Jenkins Greg Barranco	EPA

Kelly Shenk Suzanne Trevena Tuana Phillips Lewis Linker Lucinda Power Amy Handen Michelle Guck Doreen Vetter Rebecca Hindin Samantha Beers Vanessa Van Note Bo Williams Tom Damm Rick Balla Madeline Lambrix	EPA
Doug Austin	SEE
Garrett Stewart Chantal Madray Breck Sullivan Ivan Hernandez Julianna Greenberg Megan Ossmann Marjorie Zeff	Chesapeake Research Consortium
Rachel Felver Marisa Baltine	Communications Workgroup
Laura Cattell Noll	Local Leadership Workgroup
Kristin Saunders	UMCES
Jeff Corbin	Restoration Systems, LLC
Karl Blankenship	Chesapeake Bay Journal
Lisa Ochsenhirt	AquaLaw
Mark Bryer	The Nature Conservancy
Ridge Hall	Chesapeake Legal Alliance
Chris Pomeroy	AquaLaw
Heidi Bonnafon	WashCOG
Katherine Filippino	Hampton Roads Planning District
Kristin Reilly Peter Marx	Choose Clean Water Coalition
DG Webster	
PThompson	
J Denniston	

Attachment 4

Independent Statistics & Analysis
U.S. Energy Information
Administration

Battery Storage in the United States: An Update on Market Trends

July 2020

Independent Statistics & Analysis
www.eia.gov

U.S. Department of Energy
Washington, DC 20585

List of Acronyms

AEO	*Annual Energy Outlook*
AK/HI	Alaska and Hawaii
CAES	Compressed-Air Energy Storage
CAISO	California Independent System Operator
CPUC	California Public Utility Commission
CSP	Concentrated Solar Power
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
ERCOT	Electric Reliability Council of Texas
FERC	Federal Energy Regulatory Commission
GW	Gigawatt
IOU	Investor-owned utilities
ITC	Investment tax credit
IPP	Independent power producer
IRP	Integrated resource plan
ISO-NE	Independent System Operator of New England
kW	Kilowatt
kWh	Kilowatthour
LADWP	Los Angeles Department of Water and Power
MISO	Mid-Continent Independent System Operator
MW	Megawatt
MWh	Megawatthour
PGE	Pacific Gas and Electric
PJM	PJM Interconnection
PPA	Power purchase agreement
SCE	Southern California Edison
SDGE	San Diego Gas and Electric
SGIP	Self-Generation Incentive Program
SMUD	Sacramento Municipal Utility District

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Executive Summary

Large-scale battery storage systems are increasingly being used across the power grid in the United States. In 2010, 7 battery storage systems accounted for only 59 megawatts (MW) of power capacity, the maximum amount of power output a battery can provide in any instant, in the United States. By 2015, 49 systems accounted for 351 MW of power capacity. This growth continued at an increased rate for the next three years, and the total number of operational battery storage systems has more than doubled to 125 for a total of 869 MW of installed power capacity as of the end of 2018.

This report explores trends in battery storage capacity additions in the United States and describes the state of the market as of 2018, including information on applications, cost, ongoing trends, and market and policy drivers. These observations consider both power capacity and energy capacity, the total amount of energy that can be stored by a battery system. Some key observations are as follows:

At the end of 2018, 869 megawatts (MW) of power capacity,[1] representing 1,236 megawatthours (MWh) of energy capacity,[2] of large-scale[3] battery storage was in operation in the United States.

- Over 90% of large-scale battery storage power capacity in the United States was provided by batteries based on lithium-ion chemistries.
- About 73% of large-scale battery storage power capacity in the Unites States, representing 70% of energy capacity, was installed in states covered by independent system operators (ISOs) or regional transmission organizations (RTOs).
- Alaska and Hawaii, with comparatively smaller electrical systems that account for 1% of total grid capacity in the United States, accounted for 12% of the power capacity in 2018, or 14% of large-scale battery energy capacity.
- Historically, the majority of annual battery installations have occurred within the PJM Interconnection (PJM), which manages energy and capacity markets and the transmission grid in 13 eastern and Midwestern states and the District of Columbia, and California Independent System Operator (CAISO) territories. However, in 2018, over 58% (130 MW) of power capacity additions, representing 69% (337 MWh) of energy capacity additions, were installed in states outside of those areas.

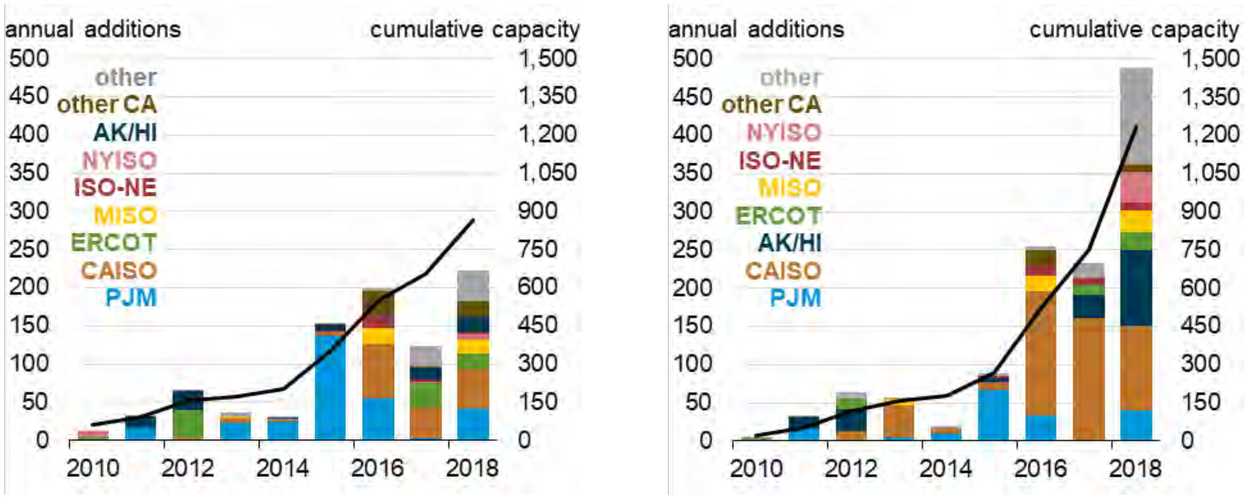
---

[1] As the maximum instantaneous amount of power output, power capacity is measured in units such as megawatts (MW)

[2] As the total amount of energy that can be stored or discharged by a battery storage system, energy capacity is measured in megawatt-hours (MWh)

[3] Large-scale refers to systems that are grid connected and have a nameplate power capacity greater than 1 MW.

Figure ES1. Large-scale battery storage capacity by region (2010–2018)



power capacity
megawatts

energy capacity
megawatthours

Sources: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Approximately one third (32%) of large-scale battery storage power capacity (and 14% of energy capacity) in the United States in 2018 was installed in PJM.

- In 2012, PJM created a new frequency regulation market product for fast-responding resources, the conditions of which were favorable for battery storage. However, changes implemented in 2017 in PJM's market rules have reduced the number of battery installations in the region.
- Most existing large-scale battery storage power capacity in PJM is owned by independent power producers (IPPs) providing power-oriented frequency regulation services.

Installations in CAISO accounted for 21% of existing large-scale battery storage power capacity in the United States in 2018, but they accounted for 41% of existing energy capacity.

- In 2013, the California Public Utility Commission (CPUC) implemented Assembly Bill 2514 by mandating that the state's investor-owned utilities procure 1,325 MW of energy storage by 2020.
- Large-scale installations in California tend to provide energy-oriented services and tend to serve a wider array of applications than systems in PJM.
- Four California utilities held nearly 90% of small-scale[4] storage power capacity in the United States in 2018.

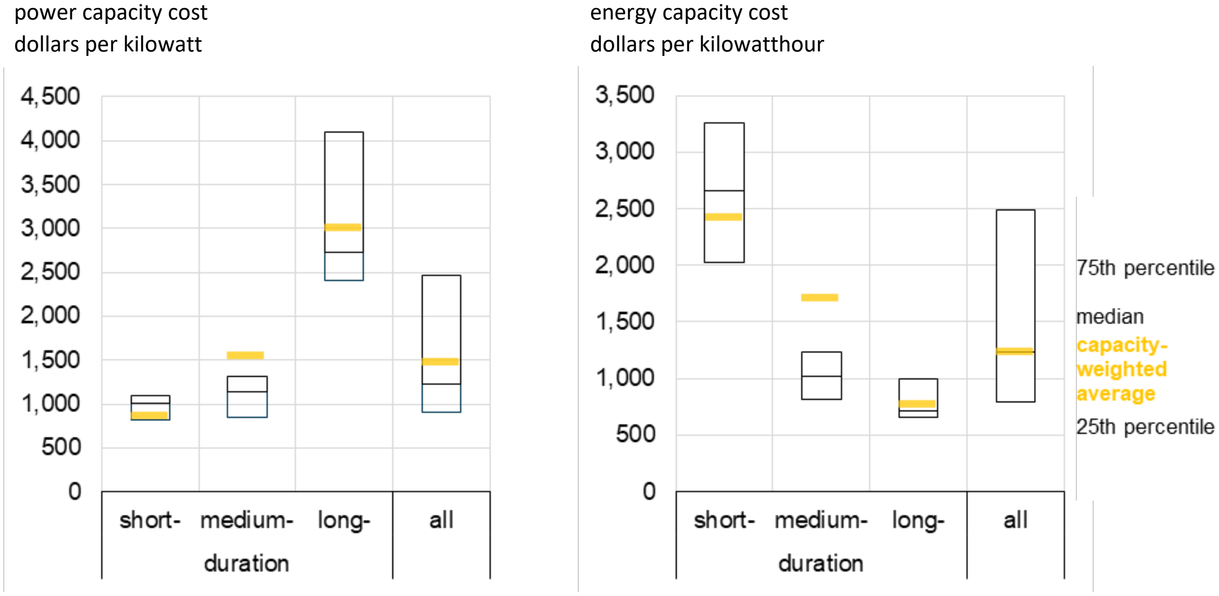
---

[4] Small-scale refers to systems connected to the distribution network and have a nameplate power capacity less than 1 MW.

Battery storage costs have been driven by technical characteristics such as the power and energy capacity of a system.

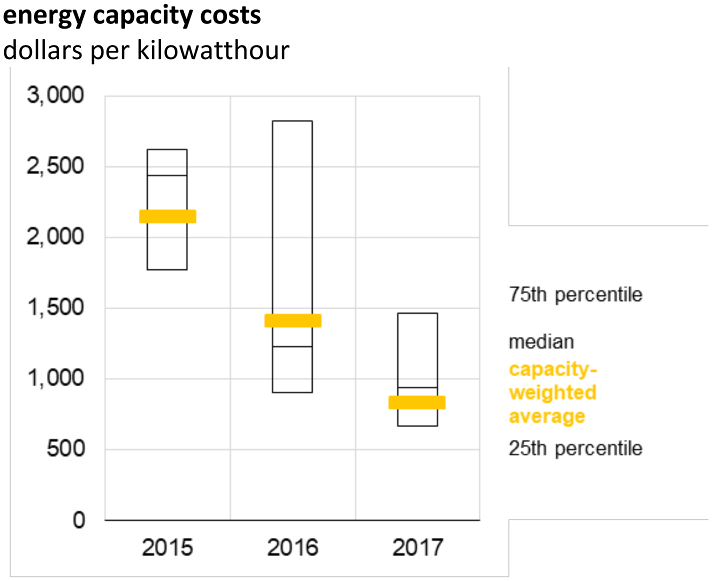
- On a per-unit of power capacity basis, total installed system costs for batteries of shorter duration have been less expensive than long-duration systems (Figure ES2).
- In terms of costs per-unit of energy capacity, the reverse has been true—longer duration batteries have typically had lower normalized costs compared with shorter-duration batteries (Figure ES2).
- Over time, average costs per-unit of energy capacity have decreased by 61% between 2015 and 2017, from $2,153/kWh to $834/kWh (Figure ES3).

Figure ES2. Total installed cost of large-scale battery storage systems by duration (2013 -2017)



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Figure ES3. Total installed cost of large-scale battery storage systems by year



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Introduction

This report examines trends in the installation of batteries for large-scale electricity storage in the United States by describing the current state of the market, including information on applications, costs, and market and policy drivers.

This report focuses on battery storage technologies, although other energy storage technologies are addressed in the appendix. Electrical, thermal, mechanical, and electrochemical technologies can be used to store energy.

The capacity of battery storage is measured in two ways: *power capacity* and *energy capacity*. Generation is often characterized in terms of power capacity, which is the maximum amount of power output possible in any instant, measured in this report as megawatts (MW). However, batteries can sustain power output for only so long before they need to recharge. The *duration* of a battery is the length of time that a storage system can sustain power output at its maximum discharge rate, typically expressed in hours. The energy capacity of the battery storage system is defined as the total amount of energy that can be stored or discharged by the battery storage system, and is measured in this report as megawatthours (MWh).

Hydroelectric pumped storage, a form of mechanical energy storage, accounts for most (97%) large-scale energy storage power capacity in the United States. However, installation of new large-scale energy storage facilities since 2003 have been almost exclusively electrochemical, or battery storage.

This report explores trends in both large-scale and small-scale battery storage systems. EIA defines large-scale (or utility-scale) systems as being connected directly to the electricity grid and having a nameplate power capacity (the maximum rated output of a generator, usually indicated on a nameplate physically attached to the generator) greater than 1 MW. Small-scale refers to systems that have less than 1 MW in power capacity. Such systems are typically connected to a distribution network, the portion of the electrical system that delivers electricity to end-users.[5]

---

[5] Large-scale and small-scale reporting conventions are derived from the reporting requirements of the EIA *Electric Generators Report* (Form EIA-860) survey and the EIA *Electric Power Industry Report* (Form EIA-861) survey. The reporting cut-offs for these surveys are based entirely on the power capacity of the generator.

Large-Scale Battery Storage Trends

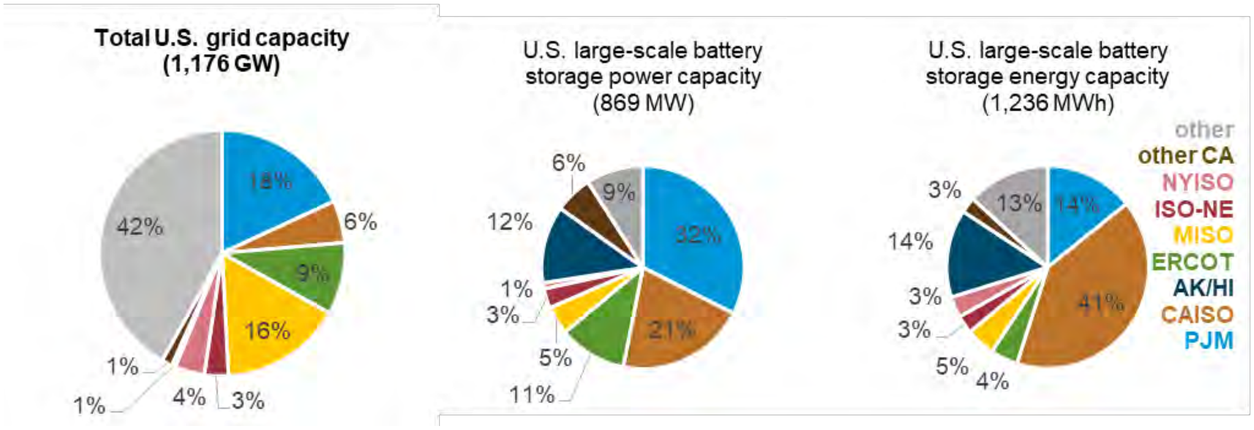
The first large-scale[6] battery storage installation recorded by EIA in the United States that was still in operation in 2018 entered service in 2003. Only 59 MW of power capacity from large-scale battery storage systems were installed between 2003 and 2010. However, this sector has experienced growth in recent years. Between 2011 and 2018 there were 810 MW of power capacity from large-scale battery storage added leaving a total of 869 MW battery storage power capacity operational by the end of 2018.

Most of existing U.S. power capacity has been installed by independent power producers in the PJM Interconnection (PJM), which coordinates the movement of electricity through all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia. Regulated utilities in the California Independent System Operator (CAISO) territory have procured significant amounts of storage capacity as well. The United States observed a new record for annual power capacity additions in 2018 when it saw 222 MW of large-scale battery storage installed, breaking the previous record of 199 MW added in 2016.

Regional Trends

As shown in Figure 1, about 73% of large-scale battery storage power capacity and 70% of energy capacity in the United States is installed in areas covered by independent system operators (ISOs) or regional transmission organizations (RTOs)[7]. The ISOs and RTOs, depicted in Figure 2, account for 58% of total grid capacity in the United States and have the largest shares of storage capacity relative to their shares of installed grid capacity. The disproportionate share of large-scale battery storage across the ISOs and RTOs may result from differences in market design and state policies (See Market and Policy Drivers section).

Figure 1. Large-scale power and energy capacity by region (2018)



Sources: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

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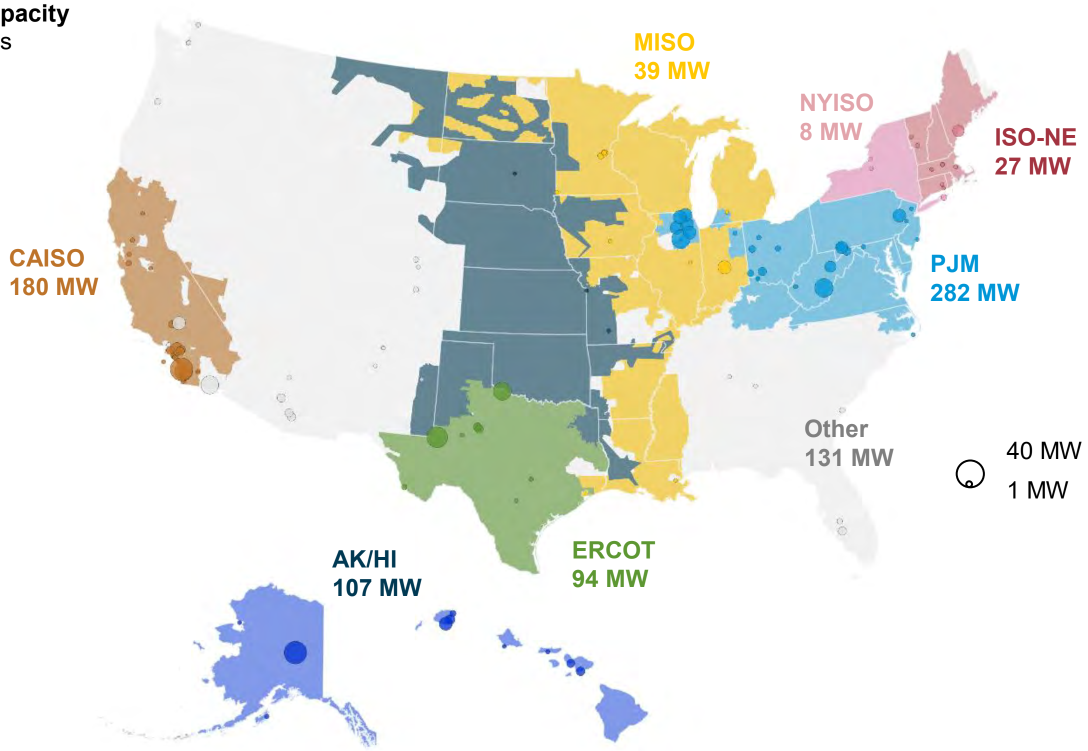
[6] Large-scale refers to systems that are grid connected and have a nameplate power capacity greater than 1 MW.

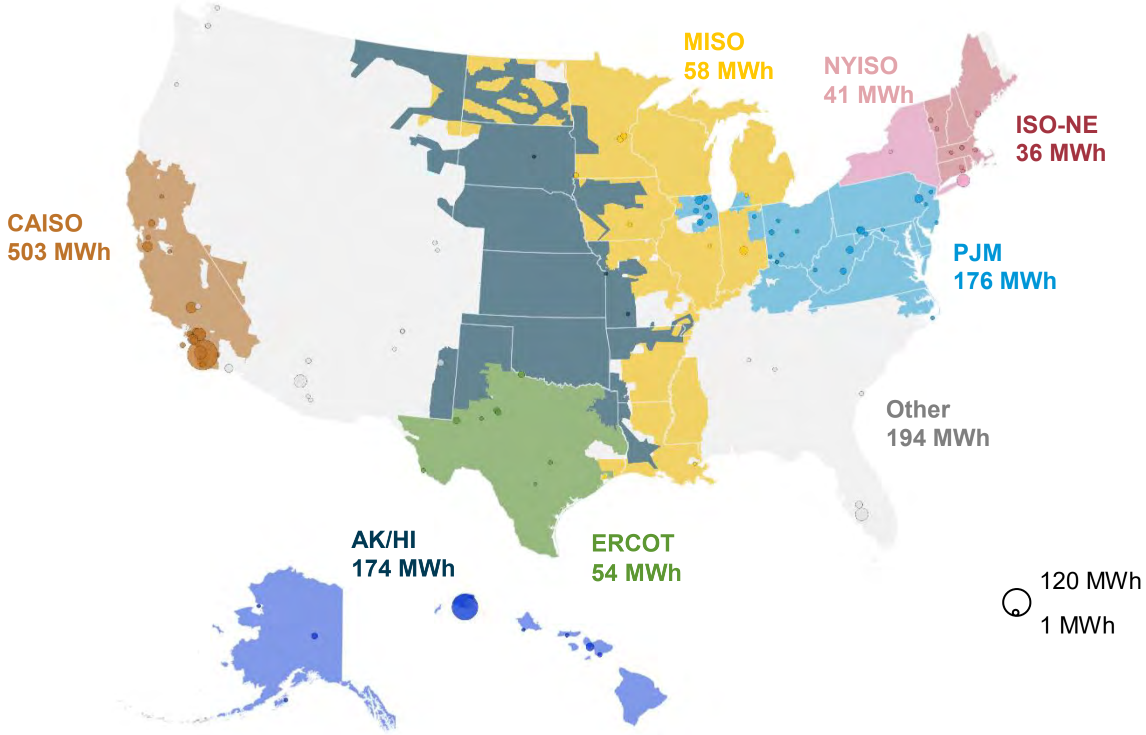
[7] ISOs and RTOs are independent, federally regulated non-profit organizations that ensure reliability and optimize supply and demand bids for wholesale electric power.

Figure 2 Large-scale battery storage installations by region (2018)

power capacity
megawatts



energy capacity
megawatthours

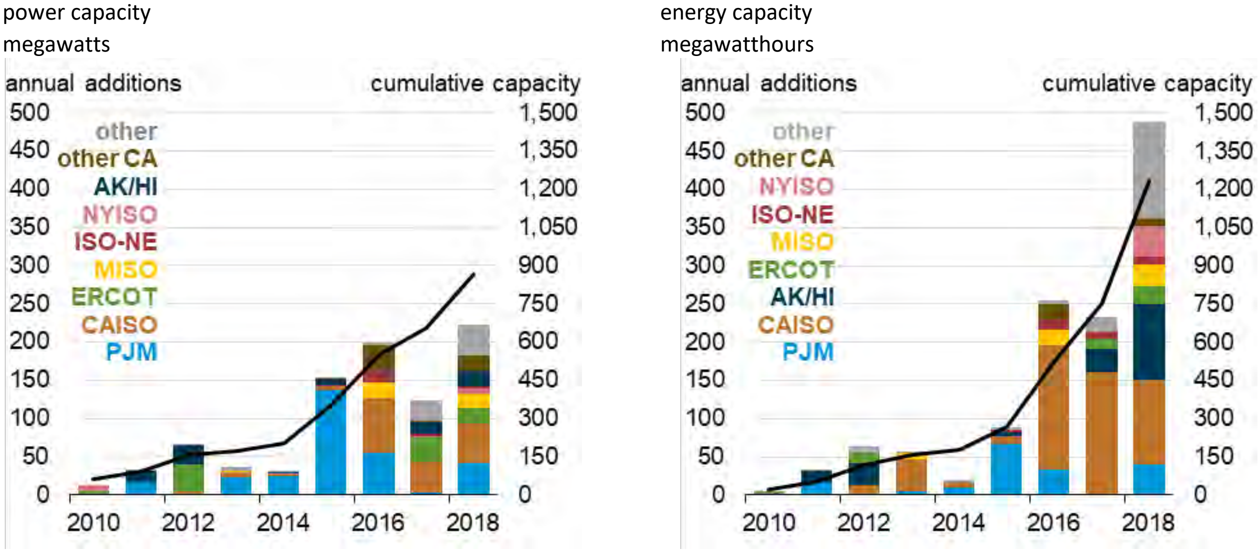


Sources: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*
Notes: Energy capacity data for large-scale battery storage installed in 2018 are based on preliminary estimates.

Between 2003 and 2018, 922 MW of large-scale battery storage power capacity across 134 systems was installed in the United States, three-quarters of which was installed between 2015 and 2018. More than 30% of existing large-scale battery storage power capacity as of 2018 was located in the PJM Interconnection (Figure 2), most of which was built from 2014-2016. This was most likely the result of changes in PJM's market for frequency regulation (a grid service that helps balance momentary differences between electricity demand and supply within the transmission grid) in 2012 which created a specific requirement for fast response resources, such as batteries. In 2015, PJM put a cap on the market share for fast responding resources due to grid reliability concerns,[8] and PJM has had relatively flat storage growth since these changes were implemented.

Installations in PJM tend to be power-oriented with larger capacities but shorter durations to serve frequency regulation applications. In 2018, large-scale battery storage installations in PJM had an average power capacity of 10.8 MW and an average duration of 45 minutes. This matches the average duration that was observed in 2017 for PJM.

Figure 3. Large-scale battery storage capacity by region (2003–2018)



Sources: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Although installations in CAISO accounted for 21% of existing large-scale battery storage power capacity in the United States in 2018, they accounted for 41% of existing energy capacity (Figure 3). California's need for battery storage has been for reliability purposes, so large-scale battery storage installations tend to be energy-oriented with small power capacities but long durations.

In 2018, large-scale battery storage installations in CAISO had an average power capacity of 6 MW and duration of 3.5 hours (Figure 4). This is longer than the average duration of 3.2 hours in CAISO in 2017. Other markets in the United States show a mix of power- and energy-oriented battery installations.

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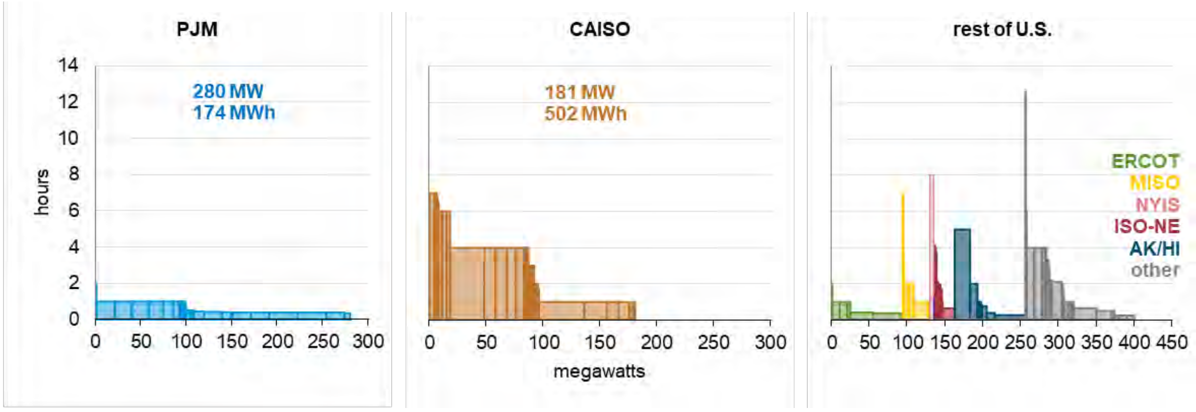
[8] FERC Docket No. ER19-1651-000, PJM Interconnection ORDER ON CONTESTED SETTLEMENT, https://elibrary.ferc.gov/idmws/file_list.asp?document_id=14845834

Of the power capacity in California, 37% was procured by Southern California Edison and San Diego Gas and Electric to address reliability risks as a result of constraints on the natural gas supply following a leak at Aliso Canyon, a major natural gas storage facility in the region. The California Public Utilities Commission (CPUC) requires generation resources to provide at least four hours of output to contribute to reliability reserves. As a result, large-scale battery storage installations in California tend to need larger energy capacities to qualify as reliability resources. (See Market and Policy Drivers for more information on California's activities related to energy storage.)

Figure 4. Power capacity and duration of large-scale battery storage by region (2018)



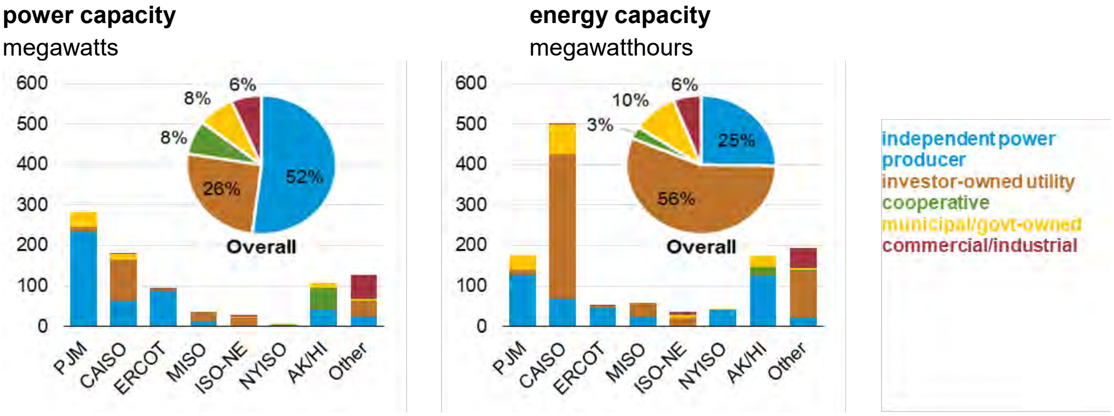
Source: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Note: Energy capacity data for large-scale battery storage installed in 2018 are based on preliminary estimates. Duration is calculated by dividing nameplate energy capacity (in megawatthours [MWh]) by maximum discharge rate (in megawatts [MW]), except in cases where the maximum discharge rate was not available, in which case the nameplate rating was used instead.

Ownership Trends

At the end of 2018, slightly more than half (52%) of the existing power capacity of large-scale battery storage in the United States was owned by independent power producers (IPPs) while more than half (56%) of large-scale battery storage in terms of energy capacity was owned by investor-owned utilities (IOUs) (Figure 5). This ownership structure reflects the dominance of IPPs in PJM with its power-oriented storage applications and the IOU ownership of energy-oriented reliability assets in CAISO.

Figure 5. Large-scale battery storage capacity by region and ownership type (2018)



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Although there are relatively fewer large-scale battery storage installations outside of PJM and CAISO, some noteworthy points emerge in other regions. Most (94%) of the installations in the Electric Reliability Council of Texas (ERCOT), which is regulated by the Public Utility Commission of Texas, are owned by IPPs. Of the eight installations in Mid-Continent Independent System Operator (MISO), six are owned by IOUs. In Alaska, most large-scale battery storage energy capacity is owned by IPPs, while the power capacity is split between cooperatives and IPPs. State-owned utilities in the U.S. own 8% of large-scale battery storage power capacity, driven by a single large (30 MW/20 MWh) installation in southern California owned by the Imperial Irrigation District.

Chemistry Trends

Chemistry Descriptions

Battery storage technologies make use of several different battery chemistries. The most common that have seen large-scale deployment[9,10,11] in the United States include:

- **Lithium-ion** technology, which represented more than 90% of the installed power and energy capacity of large-scale battery storage in operation in the United States at the end of 2018. Lithium-ion batteries have high-cycle efficiency (they don't lose much energy between recharge and discharge) and fast response times. In addition, their high energy density (stored energy per unit of weight) makes them the current battery of choice for most portable electronic and electric vehicle applications.
- **Nickel-based** batteries were used in some of the earliest large-scale battery storage installations in the United States, including a 2003 system added in Fairbanks, Alaska. Since then, the deployment of this battery chemistry has been limited. Nickel-based batteries typically have high energy density and reliability but relatively low cycle life (fewer recharge/discharge cycles before degrading performance beyond specifications for the application).
- **Sodium-based** battery storage accounted for 2% of the installed large-scale power capacity and 6% of the installed large-scale energy capacity in the United States at the end of 2018. Sodium based battery storage is an established technology based on abundant materials with a long cycle life suitable for long-discharge applications. These systems require high operating temperatures as they utilize molten sodium to operate (~300°C).
- **Lead acid** is one of the oldest forms of battery storage; its development began in the mid-1800s. Lead acid is widely used as a starter battery in vehicles. Lead acid covered only 1% of large-scale battery storage capacity installed at the end of 2018 in the United States and has seen limited grid-scale deployment because of its relatively low energy density and cycle life.
- **Flow battery** systems have one or more chemical components that are dissolved in a liquid solution. The chemical solutions are typically stored in tanks and separated by a membrane. The overall battery capacity is determined by tank size and can be expanded to meet different applications. They have a long cycle life, and their operational lifetime is projected to be long. At the end of 2018, flow batteries represented less than 1% of the installed power and energy capacity of large-scale battery storage in the United States.

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[9] Akhil, Abbas A., et al. *DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA*. January 2015. http://www.sandia.gov/ess/publications/SAND2015-1002.pdf

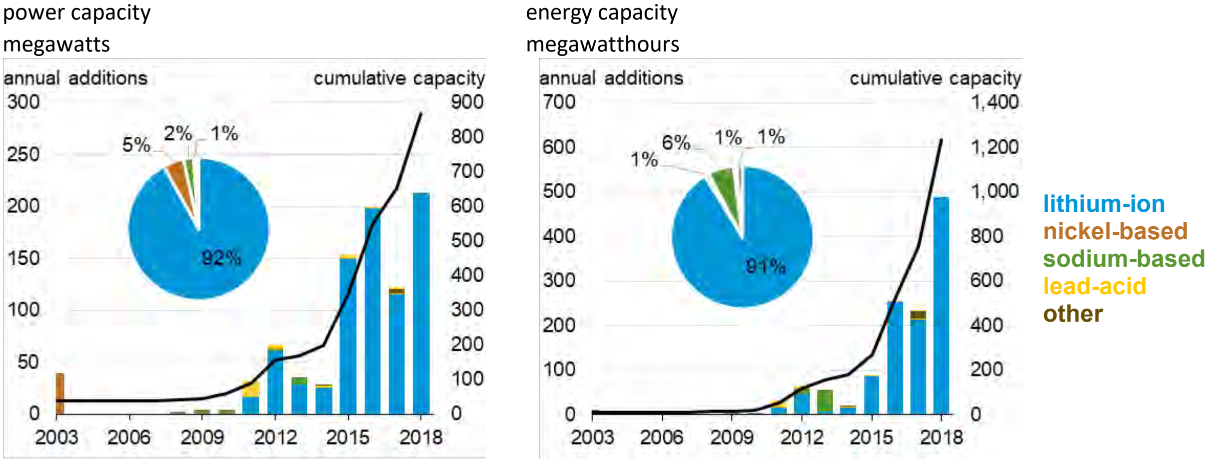
[10] Chen, Haisheng, et al. *Progress in electrical energy storage system: A critical review*. Progress in Natural Science, March 2009.

[11] Luo, Xing, et al. Overview of current development in electrical energy storage technologies and the application potential in power system operation. Applied Energy, January 2015

Chemistry Trends

The earliest large-scale battery storage installations in the United States used nickel-based and sodium-based chemistries (Figure 6). However, since 2011, most installations have opted for lithium-ion batteries, including retrofits of older systems that initially relied on different chemistries. For example, in 2012, Duke Energy added 36 MW of lead-acid battery storage to its Notrees wind power facility in West Texas. When the lead-acid batteries were first installed, the battery system participated in the region's frequency regulation market, which required rapid charging and discharging that significantly degraded the batteries. In 2016, Duke Energy replaced the original lead-acid batteries with better performing lithium-ion batteries.[12]

Figure 6. Large-scale battery storage capacity by chemistry (2003–2018)



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Flow batteries are an emerging energy storage technology. The first large-scale flow battery storage system in the United States was installed in Washington in 2016 by Avista Utilities. Two more flow batteries were installed in 2017 by electric utilities in Washington and California. The vanadium based electrolyte used in these flow battery systems is stored in large tanks and pumped through a separately connected electrode system. This configuration allows for greater energy capacities at lower prices, but it lowers the round trip efficiency[13] of the stored electricity as a result of the operation of the pumps.[14] Other battery storage chemistries and technologies are in different phases of development but have yet to see significant deployment in large-scale grid applications in the United States.

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[12] Duke Energy, *Duke Energy to upgrade its Notrees Energy Storage System*, June 2015, https://news.duke-energy.com/releases/duke-energy-to-upgrade-its-notrees-energy-storage-system

[13] Round-trip efficiency is the battery system efficiency over one cycle, measured as the amount of energy discharged to a specified depth over the amount of energy consumed to bring the system back up to its specified initial state of charge.

[14] Amerseco, Inc., *Demonstrating the Benefits of Long-Duration, Low-Cost Flow Battery Storage in a Renewable Microgrid*, December 2019, https://www.serdp-estcp.org/Program-Areas/Installation-Energy-and-Water/Energy/Microgrids-and-Storage/EW19-5312

Current Applications

Batteries have both physical and operational constraints, such as power output and discharge duration. These constraints affect individual battery technology choices that are often made with the intent of optimizing the delivery of certain types of services or providing specific applications to the electricity grid. In some cases it is also possible or even necessary to combine applications to maximize the value of the system. For a more complete discussion, please refer to the reference work cited below.

Application Descriptions

The leading types of existing battery applications[15] include the following:

- **Frequency regulation** helps balance momentary differences between electricity demand and supply within the transmission grid, often in order to help maintain interconnection frequencies close to 60 Hertz.
- **Spinning reserve** is the unused dispatchable generating capacity of online assets that provides grid frequency management, which may be available to use during a significant frequency disturbance, such as during an unexpected loss of generation capacity. This reserve ensures system operation and availability. Dispatchable generators are those that can be turned on or off in order to meet immediate needs of the system.
- **Voltage or reactive power support** ensures the quality of power delivered by maintaining the local voltage within specified limits by serving as a source or sink of reactive power (the portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment).
- **Load following** supplies (discharges) or absorbs (charges) power to compensate for load variations—this application is a power balancing application, also known as a form of ramp rate control.
- **System peak shaving** reduces or defers the need to build new central generation capacity or purchase capacity in the wholesale electricity market, often during times of peak demand.
- **Arbitrage** occurs when batteries charge during periods when electrical energy is less expensive and discharge when prices for electricity are high, also referred to as electrical energy time-shift.
- **Load management** provides a demand side customer-related service, such as power quality, power reliability (grid-connected or microgrid operation), retail electrical energy time-shift, demand charge management, or renewable power consumption maximization (charging the battery storage system during periods when renewable energy is greatest so as to consume the maximum renewable energy from the battery system, i.e. charging with solar during the day or charging with wind during high wind periods).
- **Storing excess wind and solar generation** reduces the rate of change of the power output from a non-dispatchable generator in order to comply with local grid requirements related to grid stability or prevent over production or over-production penalties. Non-dispatchable generators cannot be turned on or off in order to meet immediate needs and are often intermittent resources (generators with output controlled by the natural variability of the energy source, for example wind and solar).

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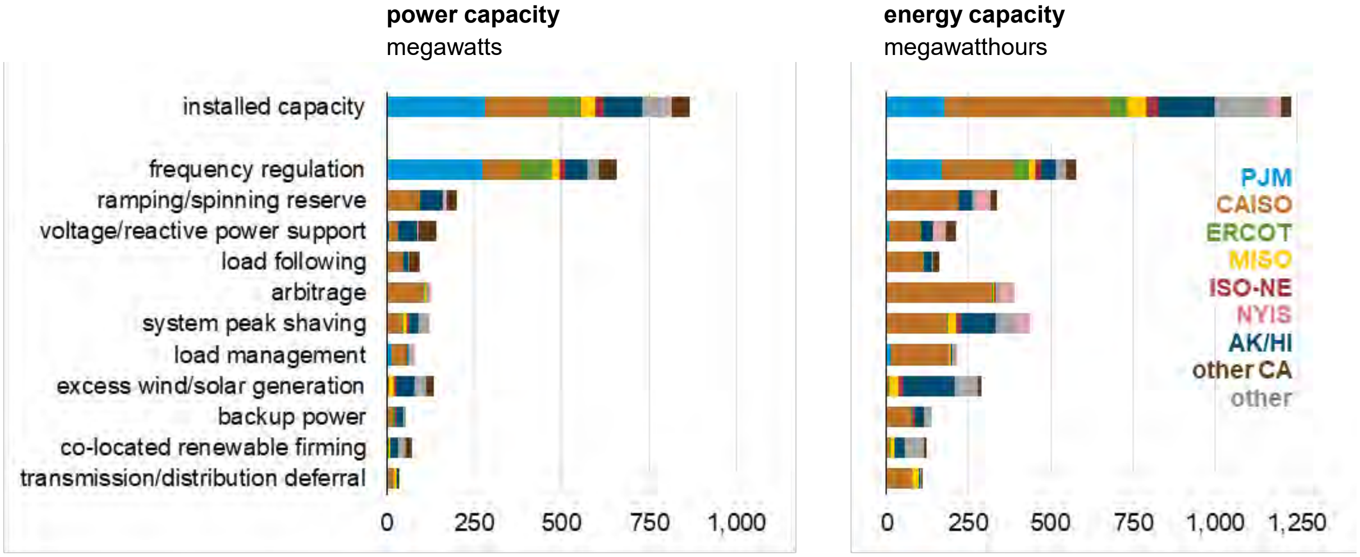
[15] DNV-GL, *Recommended Practices: Safety, operation and performance of grid-connected energy storage systems*, September 2017, https://rules.dnvgl.com/docs/pdf/DNVGL/RP/2017-09/DNVGL-RP-0043.pdf?_ga=2.80787476.2095102769.1516371272-888917498.1516371272

- **Backup power**, following a catastrophic failure of a grid, provides an active reserve of power and energy that can be used to energize transmission and distribution lines, provides start-up power for generators, or provides a reference frequency.
- **Transmission and distribution deferral** keeps the loading of the transmission or distribution system equipment below a specified maximum. This application allows for delays in transmission upgrades, avoids the need to upgrade a transmission system completely, or avoids congestion-related costs and charges.
- **Co-located generator firming** provides constant output power over a certain period of time of a combined generator and energy storage system. Often the generator in this case is a non-dispatchable renewable generator (for example, wind or solar).

Applications by Region

Figure 7 illustrates the total amount of power and energy capacity that was available for each application in the United States in 2018. In the United States, 75% of large-scale battery storage power capacity provides frequency regulation, which helps systems quickly balance unexpected differences in electricity supply and demand. Installations in PJM have driven this trend, where a specific market product for fast-ramping frequency regulation led independent power producers to rapidly deploy large-scale battery storage. Installations in CAISO as of 2018 tended to serve a wider array of applications than those in PJM because many had been procured by regulated utilities to serve multiple applications without necessarily being directly compensated for each application through market mechanisms.

Figure 7. Applications served by large-scale battery storage (2018)



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Figure 7 is based on information provided by EIA-860 survey respondents regarding their market region and the applications that battery storage systems provided in 2018. A survey respondent was permitted to select more than one application provided by each battery system.

EIA-860 survey respondents reported that storage in PJM was used for primarily only one application (frequency regulation), while batteries installed in CAISO were used for several (2.7 applications on average). Batteries installed in Alaska and Hawaii were diversely used (4.0 applications on average).

Battery Storage Costs

Costs for battery storage technologies depend on technical characteristics such as the power capacity and energy capacity of a system.

Cost Background

This discussion of costs is divided into three main categories based on the nameplate duration of the battery storage system, which is the ratio of nameplate energy capacity to nameplate power capacity.

- The short-duration battery storage category includes systems with less than 0.5 hours of nameplate duration.
- The medium-duration battery storage category includes systems with nameplate durations ranging between 0.5 hours and 2.0 hours.
- The long-duration battery storage category includes all systems with more than 2.0 hours of nameplate duration.

The average characteristics of the categorized sample data are summarized in Table 1. These categorizations are used in this report to illustrate the importance of defining the system characteristics when discussing costs, especially regarding power capacity versus energy capacity. The reported capital cost values are from large-scale battery storage systems installed across the United States between 2013 and 2017 and include multiple reported battery chemistries.

As shown in Table 1, for costs reported between 2013 and 2017, short-duration battery storage systems had an average power capacity of 11.7 MW, medium-duration systems had an average capacity of 7.2 MW, and long-duration battery storage systems had 6 MW. The average energy capacity for the short- and medium-duration battery storage systems were 4.2 and 6.6 MWh, respectively. The average for the long-duration battery storage systems was 23.5 MWh, between 4 and 6 times more than the average energy capacity of short and medium duration battery storage systems.

Table 1. Sample characteristics of capital cost estimates for large-scale battery storage by duration (2013 -2017)

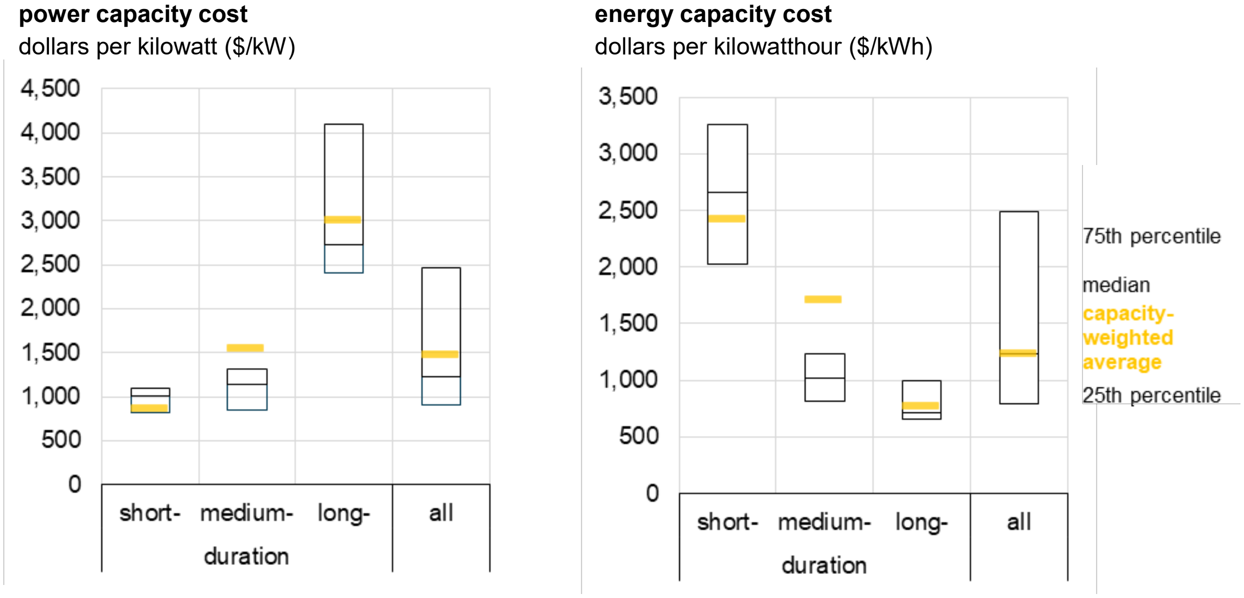
	Short-duration <0.5 hours	**Medium-duration** 0.5–2 hours	**Long-duration** >2 hours
Number of battery systems with reported costs available	22	20	16
Average of nameplate power capacity, megawatts (MW)	11.7	7.2	6.0
Average of nameplate energy capacity, megawatthours (MWh)	4.2	6.6	23.5
Average of nameplate duration, hours	0.4	1.1	4.2
Capacity-weighted cost per unit power capacity, dollars per kilowatts ($/kW)	864	1,554	3,006
Capacity-weighted cost per unit energy capacity, dollars per kilowatthour ($/kWh)	2,425	1,710	772

Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Cost Results

Based on costs reported between 2013 and 2017, battery systems with shorter durations typically had lower normalized power capacity costs measured in dollars per kilowatt ($/kW) than batteries with longer nameplate durations (Figure 8). The opposite was generally true when examining normalized energy capacity costs measured in dollars per kilowatthour ($/kWh) because total system costs for longer-duration systems are spread out over more stored energy. Nonetheless, the range of normalized cost values was driven by technological and site-specific requirements.

Figure 8. Total installed cost of large-scale battery storage systems by duration (2013 -2017)



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Normalized energy capacity costs have decreased over time (Table 2, Figure 9). The capacity-weighted average installed cost of large-scale batteries fell by 34% from $2,153/kWh in 2015 to $1,417/kWh in 2016. This trend continued into 2017 with another decrease in average installed costs of 41% to $834/kWh. This trend ultimately resulted in a total 61% decrease in average installed costs between 2015 and 2017.

Table 2. Sample characteristics of capital cost estimates for large-scale battery storage by year

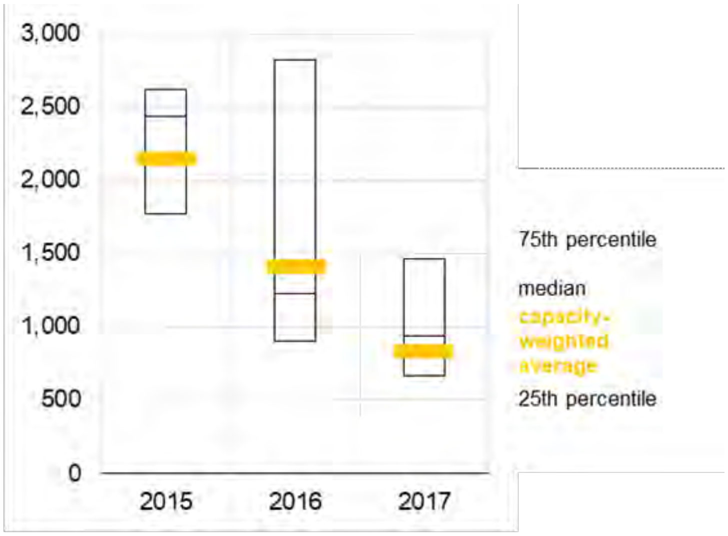
	2015	2016	2017
Number of battery systems with reported costs available	10	21	22
Average of nameplate power capacity, megawatts (MW)	12.7	10.4	5.6
Average of nameplate energy capacity, megawatthours (MWh)	5.4	12.2	10.6
Average of nameplate duration, hours	0.5	1.5	1.8
Capacity-weighted cost per unit power capacity, dollars per kilowatts ($/kW)	913	1,664	1,587
Capacity-weighted cost per unit energy capacity, dollars per kilowatthour ($/kWh)	2,153	1,417	834

Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Figure 9. Total installed cost of large-scale battery storage systems by year

energy capacity costs

dollars per kilowatthour



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*
Note: Cost observations for installation years 2013 and 2014 were dropped from this figure as a result of small sample sizes for those respective years.

Unlike non-storage technologies, battery storage can supply and consume energy at different times of the day, creating a combination of cost and revenue streams that makes it challenging to directly compare to generation technologies. They are not stand-alone generation sources and must buy electricity supplied by other generators to recharge and cover the round-trip efficiency losses experienced during cycles of charging and discharging.

There are two major challenges in determining the profitability and cost of battery storage systems. First, quantifying the competitiveness of a battery storage technology with other technologies operating on the grid must consider the individual markets that the storage technology is planning to be used in and what revenue opportunities exist for the technology. The second challenge involves the degradation of the system over time, which is the lasting and continuous decrease in either a battery's power or energy performance or both and is linked to use or age of a battery component or system.

The performance can be characterized by the full cycle power input and output at an agreed-upon charge/discharge rate. There are two general options that can be employed to ensure reliable performance during a storage system's lifetime:

- **Overbuilding**: adding more storage or discharge capacity behind the inverter than is needed, so that as the system ages it will maintain a capacity at or above the contracted capacity required of the system.
- **Continual Upgrades**: replacing some portion of the storage system to maintain the agreed-upon performance during its lifetime.

The two approaches to meeting performance requirements affect the installed capital costs of the system. Overbuilding storage capacity leads to a higher initial installed capital cost, while continual upgrades lead to higher operation and maintenance costs throughout the lifetime of the storage facility. Therefore, comparing only the normalized capital cost of various battery systems, as shown in **Figure 8**, does not capture the variation in the lifetime costs. The costs collected and presented in this report are not sufficient to capture all of these nuances.

Other Cost Metrics

In addition to the capital costs presented in this section, EIA has observed trends in battery storage costs arising from the negotiated price of electricity for projects that are financed through power purchase agreements (PPAs). PPAs are contracts between electricity suppliers and electricity buyers (or offtakers) at a fixed price per unit of electricity delivered. They represent a predictable, long-term source of revenue to the project. The negotiated electricity prices under a PPA are heavily influenced by each project's specifications, contract terms, and other localized factors. Observing PPA prices can give an indication of cost trends over time; however, PPA prices are not comparable to total capital costs of the system.

Small-Scale Energy Storage Trends

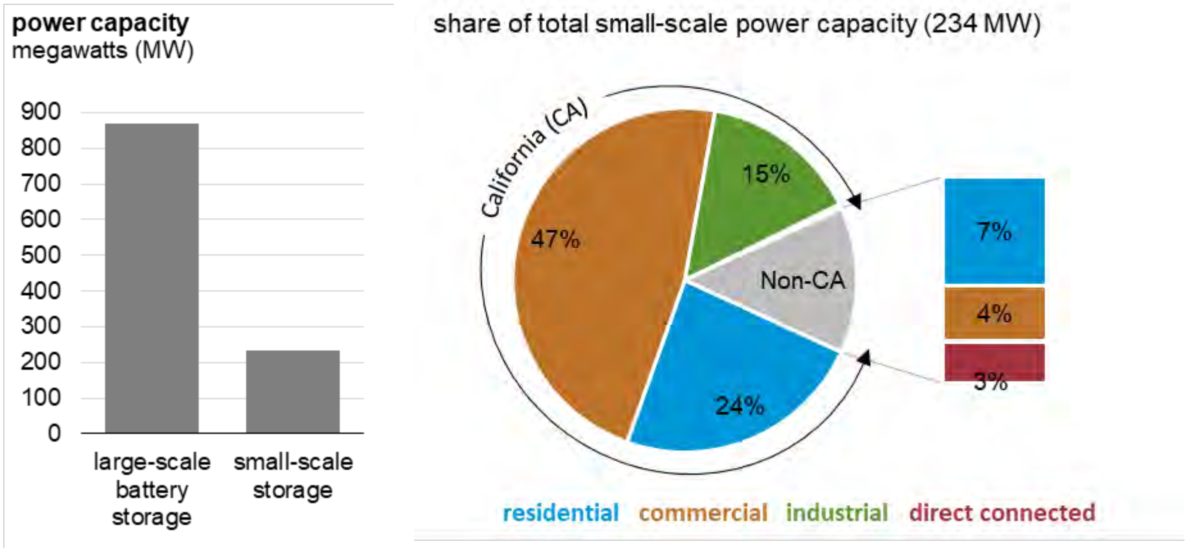
In 2018, utilities reported 234 MW of existing small-scale storage power capacity in the United States. A little more than 50% of this capacity was installed in the commercial sector, 31% was installed in the residential sector, and 15% was installed in the industrial sector. The remaining 3% was directly connected to the distribution grid, such as by the utility at their own distribution substation.

The data collected for small-scale applications depend on the electric utility's access to information about installations in its territory. If end users of storage systems are installing systems for purposes where the system would not interact with the distribution network—for example back-up applications—the electricity distribution utility may not know about those system installations. Utilities collect information on small-scale storage systems primarily through inter-connection agreements. Because these agreements are designed by the utilities, the information about storage units may not be collected in a consistent format across all utilities.

Small-Scale Energy Storage Trends in California

As shown in Figure 10, in 2018, 86% of reported small-scale storage power capacity in the United States was in California and, specifically, was owned by six utilities: Southern California Edison (SCE), Pacific Gas and Electric (PGE), San Diego Gas and Electric (SDGE), Los Angeles Department of Water and Power (LADWP), Sacramento Municipal Utility District (SMUD), and City of Moreno Valley. In 2018, most installations of small-scale storage in the commercial sector in California were in SCE's territory (64% of such capacity) and SDGE's territory (22%). Most installations (95%) of small-scale storage in the industrial sector in California were in PGE's territory.

Figure 10. Small-scale energy storage capacity by sector (2018)



Source: U.S. Energy Information Administration, Form EIA-861, *Annual Electric Power Industry Report*
Note: Data collected on small-scale storage may include forms of energy storage other than batteries. Direct-connected storage is not located at an ultimate customer's site but is in front of the meter or connected directly to a distribution system or both. Direct-connected storage in California and industrial storage outside of California are less than 1% of the total and are therefore not depicted in the figure.

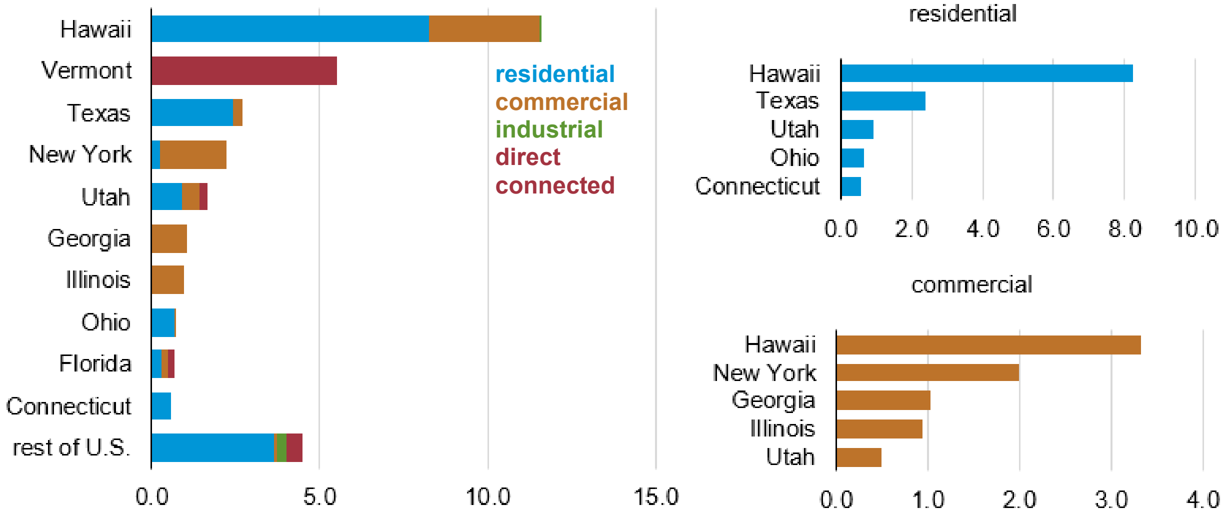
California’s large share of small-scale energy storage power capacity can be attributed to the state’s Self-Generation Incentive Program (SGIP), which provides financial incentives for installing customer-sited distributed generation. Installations receiving rebates through SGIP contribute to California’s 2013 energy storage mandate (Assembly Bill 2514), which requires 200 MW of customer-sited energy storage to be installed by 2024. In May 2017, the California Public Utilities Commission implemented Assembly Bill 2868 by ordering SCE, PGE, and SDGE to procure up to an additional 500 MW of distributed energy storage, including no more than 125 MW of customer-sited energy storage.

Small-Scale Energy Storage Trends in the Rest of the United States

After California, the states with the most small-scale storage power capacity in 2018 were Hawaii, Vermont, and Texas, and much of this capacity was installed in the residential sector (Figure 11). Minimal small-scale storage power capacity in the industrial sector existed outside of California. In the commercial sector, small-scale storage was mostly available in Hawaii and New York, as well as other states, notably in Georgia, Illinois, and Utah.

Figure 11. Small-scale energy storage capacity outside of California by sector (2018)

power capacity
megawatts



Source: U.S. Energy Information Administration, Form EIA-861, *Annual Electric Power Industry Report*

Small-scale energy storage system are typically owned by end-users. Direct-connected storage systems are installations not located at an ultimate customer’s site but rather in front of the meter or connected directly to a distribution system or both. In Vermont, Green Mountain Power Corporation reported the largest amount of direct-connected battery storage power capacity. Green Mountain operated front-of-the meter battery storage systems for customers that totaled 5.5 MW of power capacity in 2018.

Market and Policy Drivers

As discussed previously, battery storage is technologically capable of serving many applications, each with benefits for one or more participants in the electricity system, including transmission and distribution system operators, generation resources, and consumers. However, the functional ability of storage to serve these applications can be limited or not well defined under existing market rules and other policies. This situation has begun to change as the technology has matured and industry stakeholders in some regions have gained experience financing, procuring, and operating storage installations. Most of the activity has been led by wholesale market operators and state-level regulators.

Wholesale Market Rules

ISOs and RTOs are independent, federally-regulated non-profit organizations that ensure reliability and optimize supply and demand bids for wholesale electric power. They are technology neutral and must ensure market rules do not unfairly preclude any resources from participating, as enforced by the Federal Energy Regulatory Commission (FERC). Many existing market rules may not take into account the unique operating parameters and physical constraints of battery storage as both a consumer and producer of electricity. However, recent actions by FERC and ISOs/RTOs have begun to carve a path for storage to participate in the individual markets.

A notable example is FERC Order 755, issued in 2011, which required ISO/RTO markets to provide compensation to resources that can provide faster-ramping frequency regulation. As a result of Order 755, PJM split its frequency regulation market into a fast-ramping service and a slower-ramping service. By the end of 2015, more than 180 MW of large-scale battery storage capacity had come online in the PJM territory. However, in 2015 PJM began observing operational issues due to overdependence on the fast-ramping regulation service, which mainly consisted of resources such as batteries with duration restrictions, as opposed to the slower-ramping service, which generally consisted of resources which could be operated much longer (but took longer to come online)[16]. PJM thus changed its frequency regulation signals, and installations of large-scale battery storage in the region stalled since PJM made these changes.

Other system operators have also implemented relevant changes to market rules, including developing unique asset classes for storage, specifying participation models, lowering minimum size requirements, allowing for aggregation, and defining duration requirements. However, these regions have not seen large-scale battery storage deployment at the same level as PJM. In February 2018, FERC issued Order No. 841 requiring system operators to remove barriers to the participation of electric storage resources in the capacity, energy, and ancillary services markets. Each ISO/RTO under FERC jurisdiction was required to revise its tariff to include market rules that recognize the physical and operational characteristics of electric storage resources and to implement the revisions upon FERC's approval of

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[16] PJM , "Fast Response Regulation (RegD) Resources Operational Impact," July 01,2017. https://www.pjm.com/~/media/committees-groups/committees/oc/20150701-rpi/20150701-fast-response-regulation-resources-operational-impact-problem-statement.ashx

tariff compliance. As of May 2020, all ISO/RTO's had filed multiple tariff revisions but none have been fully approved by FERC.

State-Level Policy Actions

Other than FERC activities described in the previous section, federal policies involving energy storage have been limited.[17] Most policy actions involving energy storage have been at the state level and include setting procurement mandates, establishing incentives, and requiring incorporation of storage into long-term planning mechanisms.

Policy Actions in California

California has introduced several measures related to energy storage. In 2013, the California Public Utility Commission (CPUC) implemented Assembly Bill 2514 by setting a mandate for its investor-owned utilities to procure 1,325 MW of energy storage across the transmission, distribution, and customer levels by 2020. All of the capacity must be operational by 2024. In May 2017, CPUC implemented Assembly Bill 2868 by ordering its investor-owned utilities to procure up to an additional 500 MW of distributed energy storage, including no more than 125 MW of customer-sited energy storage. The Self-Generation Incentive Program, which provides financial incentives for installing customer-sited distributed generation, has designated $48.5 million in rebates for residential storage systems 10 kW or smaller and $329.5 million for storage systems larger than 10 kW.

Press reports in 2017 indicated that 100 MW, or about 37% of existing battery storage power capacity in California, was installed in response to a leak at the Aliso Canyon Natural Gas Storage Facility outside Los Angeles in October 2015.[18] According to these reports, in May 2016, to help address resulting reliability risks as a result of constraints on natural gas supply, the CPUC authorized the Southern California Edison electric utility to hold an expedited solicitation for energy storage. As a result, 62 MW of battery storage capacity was added to the system in December 2016. In addition, the CPUC expedited an ongoing procurement of 38 MW of battery storage by San Diego Gas and Electric, which was installed in early 2017.

Policy Actions in the Rest of the United States

As of May 2020, five states besides California have also set energy storage mandates or targets. In 2015, Oregon passed House Bill 2193-B, directing two electric utilities to each procure 5 MWh of storage energy capacity by 2020. In August 2018, Massachusetts enacted House Bill 4857 ("An Act to Advance Clean Energy"), directing the Massachusetts Department of Energy Resources set an energy storage target of 1,000 MWh by 2025. In October 2018, New York announced a target of 3,000 MW of energy storage by 2030. In May 2018, New Jersey enacted the Clean Energy Act, P.L. 2018, which set a target of 2,000 MW of energy storage by 2030. In February 2020, Virginia passed House Bill 1526, which set a 3,100 MW energy storage goal by 2035. In addition, some states, such as Nevada, allow storage systems

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[17] One exception is the investment tax credit (ITC), which is a credit to income tax liability proportional to the capital expenditures originally intended for certain renewable energy technologies, including solar and wind. Energy storage installed at a solar or wind facility can be considered part of the energy property of the facility and can receive a portion of the tax credit.

[18] Green Tech Media, "Tesla, Greensmith, AES Deploy Aliso Canyon Battery Storage in Record Time," January 31, 2017, https://www.greentechmedia.com/articles/read/aliso-canyon-emergency-batteries-officially-up-and-running-from-tesla-green#gs.bvJdDKY

to be included in state-level renewable portfolio standards. Aside from targets, some states have provided financial incentives for energy storage installations, including grants, support for pilot projects, and tax incentives. In 2018, Maryland passed Senate Bill 758, offering a tax credit of 30% on the installed costs for residential and commercial systems.

Many states require utilities to produce integrated resource plans (IRPs) that demonstrate each utility's ability to meet long-term demand projections using a combination of generation, transmission, and energy efficiency investments, while minimizing costs. Incorporating storage into IRPs can be a challenge because storage is different from conventional electricity generators and demand-side resources. For example, storage has unique operational constraints, can be interconnected at various points throughout the system, can serve a variety of applications, and is faced with policy and regulatory uncertainty that may affect system profitability. Nonetheless, some states have begun to require utilities to include storage in integrated resource plans, including Arizona, California, Connecticut, Colorado, Florida, Indiana, Kentucky, Massachusetts, New Mexico, North Carolina, Oregon, Utah, Virginia, and Washington. New York and Vermont include storage in their state energy plans.[19]

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[19] PV Magazine, "Utilities are increasingly planning for energy storage," December 7, 2017, https://pv-magazine-usa.com/2017/12/07/utilities-are-increasingly-planning-for-energy-storage-w-charts/

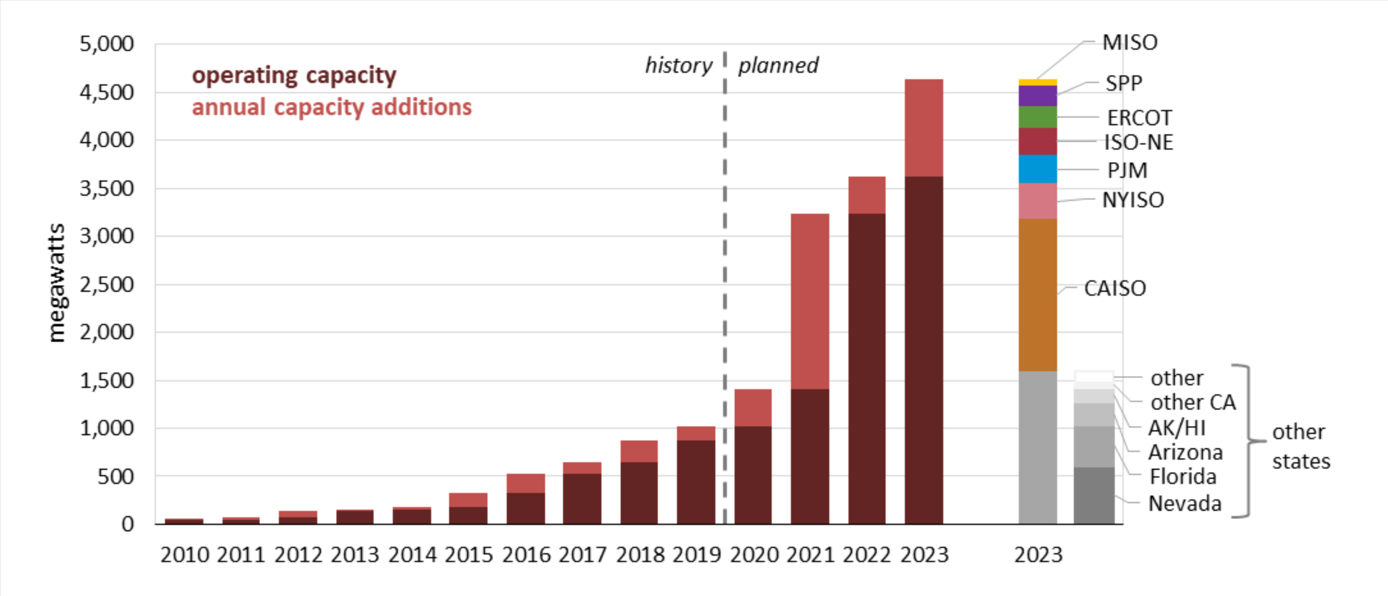
Ongoing Trends

For the short term, EIA assesses future battery capacity installation trends using planned generator additions reported by project developers, both for stand-alone battery storage systems and for those co-located with other electricity generating technologies such as solar or wind. EIA provides long-term projections on future battery capacity installations in the *Annual Energy Outlook*.

Near-Term Planned Capacity Additions (2020–23)

As of December 2019, project developers reported to EIA that they planned to make 3,616 MW of large-scale battery storage operational in the United States between 2020 and 2023. Given the short planning period required to install a storage facility, the reported planned capacity does not necessarily reflect all the possible builds during this period, but the reported planned capacity can be used as an indicator of trends.

Figure 12. Large-scale battery storage cumulative power capacity (2010–2023)



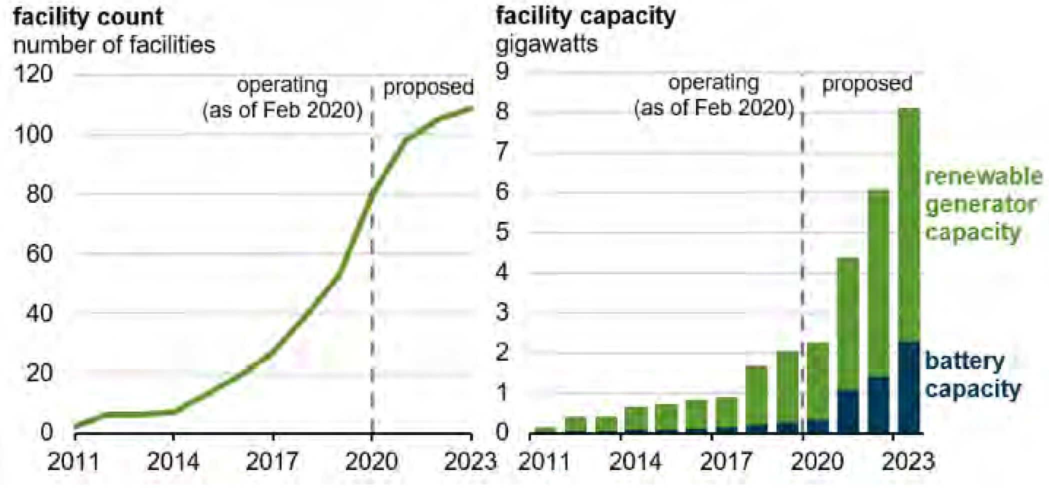
Source: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*

California accounted for 38% of planned battery storage power capacity reported as of December 2019. These planned additions put California in line to meet its energy storage mandate (Assembly Bill 2514), which requires its investor owned utilities to install 1,325 MW of energy storage across the transmission, distribution, and customer levels by 2024. New York and Massachusetts also have state mandates for energy storage and have planned battery storage projects in the upcoming years. Virginia and New Jersey have mandates but have not reported any planned energy storage builds to EIA (See Market and Policy Drivers for more information). Several states without policy mandates show relatively strong growth in storage in the upcoming years, including Nevada, Florida, and Arizona.

Co-Located Battery Storage Projects

Pairing renewable energy power plants with energy storage is a trend of increasing importance as the cost of energy storage declines. The number of solar and wind generation sites co-located with battery storage systems has increased from 19 paired sites in 2016 to 53 sites in 2019. Data reported for proposed projects suggest that the number of co-located sites may double by 2023 from 2019 levels.

Figure 13. Count and capacity of renewable plus storage facilities (2011–2023)



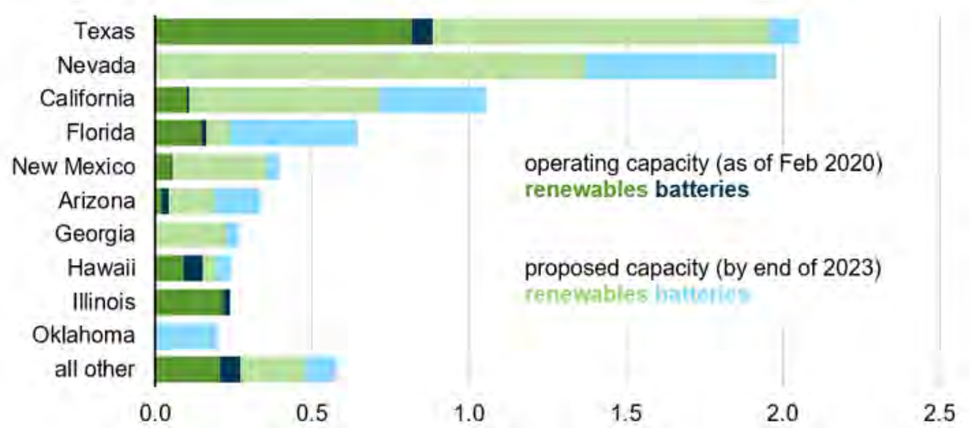
Source: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report.*

Among the benefits of these co-located projects, the most critical is the ability to take advantage of common onsite infrastructure to store renewable-generated energy produced during periods of low electricity prices and low demand, and later supply that stored energy to the grid when both demand and electricity prices are higher. Solar and wind technologies are the more common generators that benefit from battery storage because of their intermittent operation. The benefits of later pairing battery storage can also be realized even after the renewable energy power plant has initially entered into operation. More than 25 solar and wind power plants have added battery storage systems after their original operation date. As of February 2020, more than 90% of the operating capacity from co-located battery and renewable generation sites were located in nine states. Texas had the most co-located battery storage capacity with 886 MW (renewable plus storage capacity) as of February 2020 (Figure 14). On average, existing co-located projects have a renewable nameplate capacity to battery power capacity ratio of 6:1, and planned projects have a power capacity ratio of 2:1. As of 2019, 10 of the 53 co-located facilities accounted for more than half of the combined renewable and battery storage capacity. Of all operating battery storage capacity in the United States as of 2019, 25% was installed in paired systems, while of all the operating solar capacity in the United States, only 2% was in paired with an energy storage system. By December 2023, 2.3 gigawatts (GW) of the 4.9 GW (47%) of operating battery storage is planned to be paired onsite with renewable generation.

Figure 14. Operating and planned renewable plus storage capacity, top 10 states

power capacity

gigawatts



Source: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory*; U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*.

Long-Term Projected Capacity Additions (2020–2050)

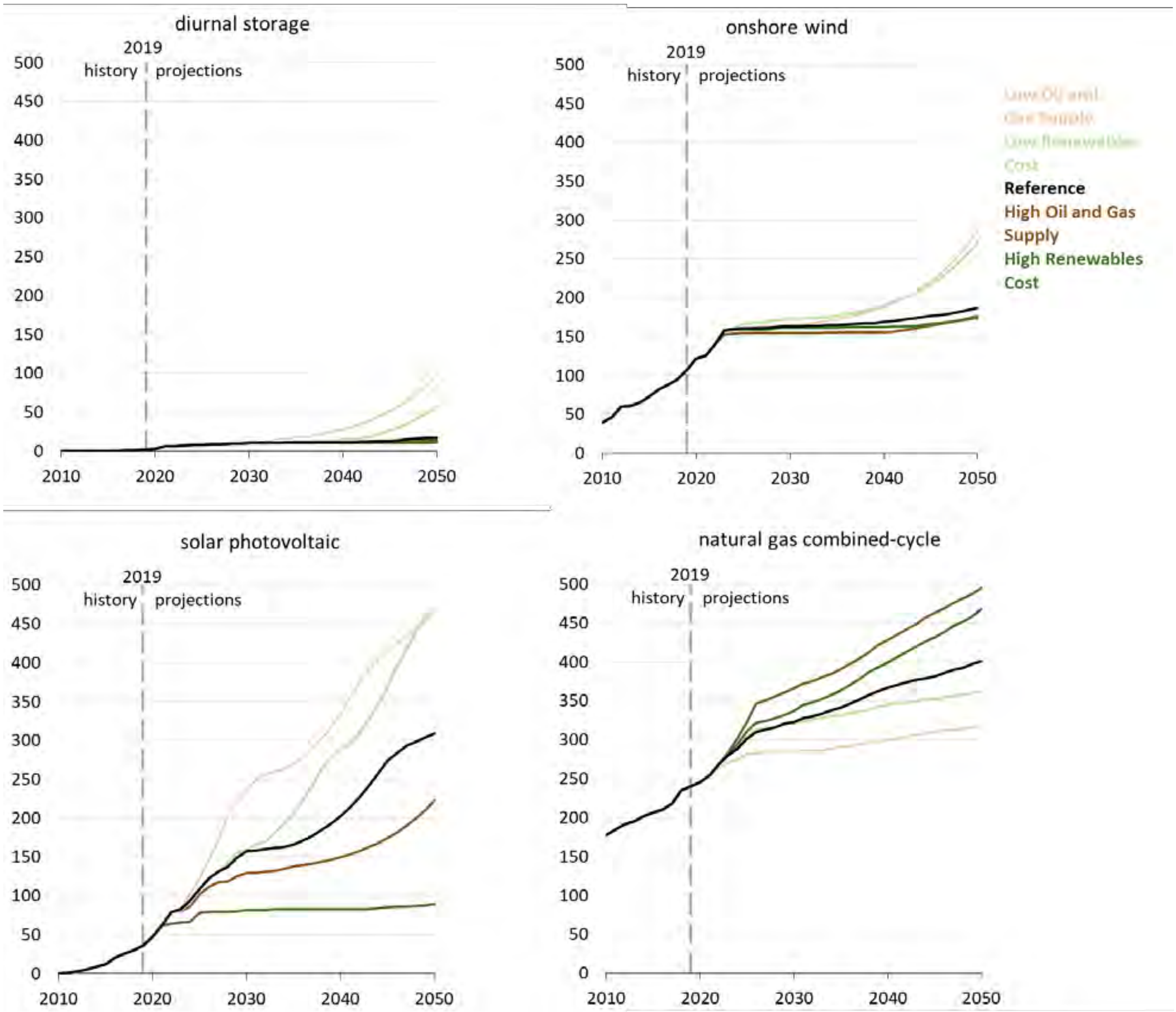
The *Annual Energy Outlook 2020* (AEO2020) provides projections to 2050 on the supply and demand needs for energy markets in the United States. The Reference case, which assumes implementation of current U.S. laws and policies, projects large-scale battery storage capacity to grow from 1 GW in 2019 to 17 GW in 2050 (Figure 15Figure 14).

In addition to the Reference case, AEO2020 examines the sensitivity of model results to changes in various assumptions. In the Low Renewables Cost case, where the costs of renewable technologies are assumed to decline at a faster rate, ending at 40% lower than the Reference case by 2050, higher levels of energy storage support increased solar and wind capacity additions. In the Low Oil and Gas Supply case, less availability of natural gas results in higher natural gas prices. Because natural gas-fired combined-cycle generating units and solar facilities compete with each other, increased natural gas prices promote the growth of solar and thus storage as in the Low Renewables Cost case. In addition, the high price of natural gas used by combustion turbine peaking units allows more market opportunity for energy arbitrage, which also supports the growth of energy storage. These factors contribute to the Low Oil and Gas Supply case showing the most storage capacity additions of any of the AEO2020 projections.

Figure 15. AEO2020 power capacity by case and selected technology, 2050

power capacity

gigawatts

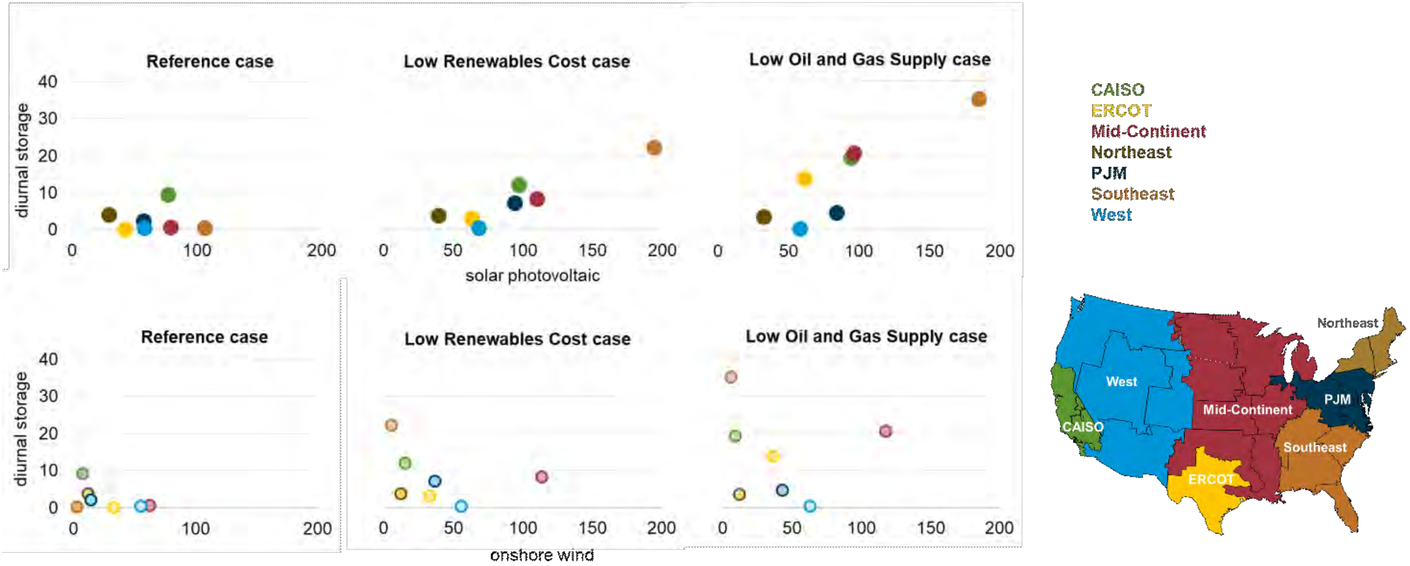


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2020*

When looking at the regional trends in the Reference case and side cases (Figure 16), growth in energy storage capacity follows growth in solar photovoltaic (PV) capacity, but it does not correlate strongly with growth in wind generation capacity. The Southeast region is very sensitive to the varying assumptions in the side cases, showing strong growth relative to the Reference case in both the Low Oil and Gas Supply case and Low Renewables Cost case. All cases show limited storage growth in the Northeast, PJM, and West regions.

Figure 16. AEO2020 regional diurnal storage versus solar photovoltaic power and wind capacity, 2050

power capacity
gigawatts



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2020*

Because long-term planning models are designed to deliver multi-decade results with many complex interactions, modelers often have to simplify their modeling of energy storage technologies. One simplification that has significant consequences for the representation of energy storage technologies is the temporal resolution of the model. EIA's AEO2020 included energy storage as a four-hour battery system that can be used to avoid curtailments of excess solar- and wind-generated electricity, shift energy within a day, and help meet regional reliability requirements; however, modeling sub-hourly markets, such as battery systems participating in frequency response, remains a challenge. As a result, EIA's AEO projections as shown do not represent all of the available storage technology options nor the full suite of applications that storage can serve. See the list of possible applications for storage in the Current Applications section of this report.

EIA has been collaborating with other modeling entities on a multi-model comparison[20] to enhance the representation of technologies that challenge conventional long-term planning model design, such as wind, solar, and energy storage. The representation of battery storage in the AEO will continue to develop as the markets and applications for energy storage evolve.

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[20] Cole, Wesley, et al, *Variable Renewable Energy in Long-Term Planning Models: A Multi-Model Perspective*, November 2017, https://www.energy.gov/eere/analysis/downloads/variable-renewable-energy-long-term-planning-models-multi-model-perspective.

Appendix A: Other Storage Technologies

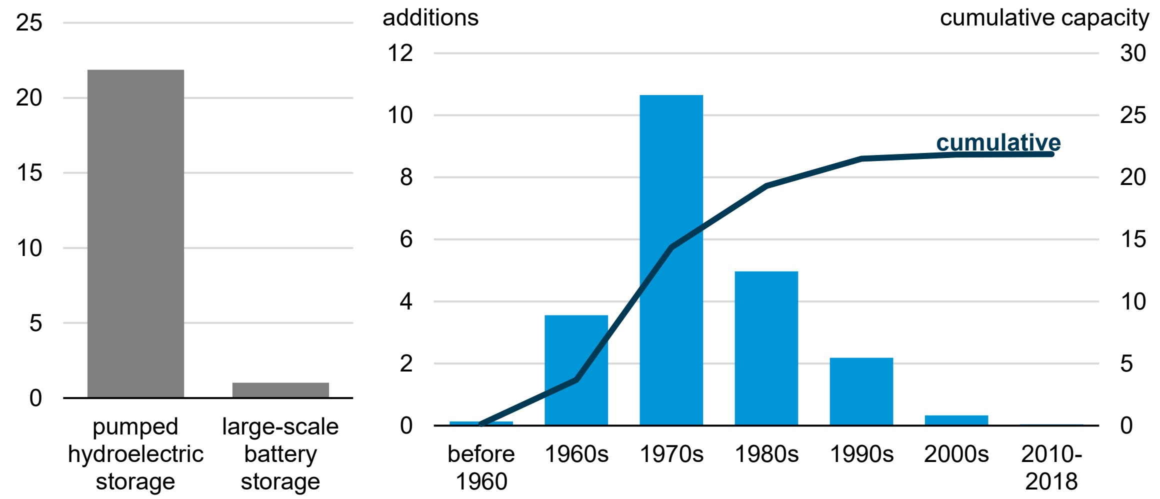
This report has focused primarily on electrochemical energy (or battery) storage; however, energy storage can take other forms including electrical, thermal, and mechanical. Electrical energy storage includes capacitors and superconductors. Thermal storage includes water, ice, molten salts, and ceramics. Mechanical includes technologies such as hydroelectric pumped storage, flywheels, and compressed-air energy storage (CAES).

Hydroelectric pumped storage uses electricity to pump water into an elevated reservoir so it can be used to drive a hydroelectric turbine when electricity is needed. Although the United States has significantly more operating hydroelectric pumped storage capacity than battery storage capacity, most of it was installed in the 1970s and early 1980s (Figure 17). California, Virginia, and South Carolina account for most of the existing hydroelectric pumped storage capacity. The largest single facility in the United States was installed in 1985 in Bath County, Virginia, and has a capacity of 3 GW.

Figure 17. Hydroelectric pumped storage capacity (1960–2018)

power capacity

gigawatts



Source: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*

Flywheels store energy by using an electric motor to speed up a spinning mass, which can then be used later to spin a turbine to produce electricity. To reduce losses, the mass is spinning in a nearly frictionless enclosure. Flywheels are well suited to provide power-oriented applications that require many charge and discharge cycles. Three large-scale flywheel systems are currently operating in the United States: a 20 MW system in New York, a 20 MW system in Pennsylvania, and a 2 MW system in Alaska. One standby flywheel system of 5 MW currently exists in Texas.

CAES uses electricity to compress air and store it in an underground cavern. The air is then expanded through a turbine when electricity is needed. The only operable large-scale CAES system in the United States is a 110 MW system that was installed in Alabama in 1991 by PowerSouth Energy Cooperative.

The Apex Bethel Energy Center is a 317 MW CAES system in Texas that is expected to enter operation in 2022.

Thermal storage systems take excess energy produced during the day to heat salt or other materials that can be used later to power a steam turbine. Thermal storage can also be used as a distributed energy resource, for example, by chilling water overnight to use for space cooling during summer days. All existing large-scale thermal energy storage in the United States uses concentrated solar power (CSP) technology. CSP reflects rays from the sun to a receiver to produce steam directly or to heat up alternative fluids, which are used to generate steam through a heat exchanger. The steam is then run through a turbine to generate electricity. Some of these alternative heat transfer or storage fluids can store energy for long durations, and they can be used to generate steam and electricity at night using thermal solar energy gathered during the day. Of the eight CSP projects currently in operation (totaling 1,775 MW) only Arizona Solar One LLC's Solana Generating Station plant in Arizona (295 MW) and Tonopah Solar Energy LLC's Crescent Dunes Solar Energy plant in Nevada (110 MW) employ energy storage.

Other energy storage technologies are in different phases of development but have yet to see significant deployment in large-scale grid applications.

Document Content(s)

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Attachment 7

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A new solution to mitigate hydropeaking? Batteries versus re-regulation reservoirs

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ABSTRACT

Hydropower plants frequently operate at high output during peak hours and at low output (or even shutoff) during off-peak hours. This scheme, called “hydropeaking”, is harmful to downstream ecosystems. Operational constraints (minimum flows, maximum ramps) are frequently used to mitigate the impacts of hydropeaking. However, they reduce the operational flexibility of hydroelectric dams and increase the operational cost of power systems. Another approach to mitigating ecological impacts from hydropeaking is using structural measures, such as re-regulation reservoirs or afterbays. The first contribution of our work is to study the cost-effectiveness of these re-regulation reservoirs in mitigating ecological impacts from subdaily hydropeaking. Our second contribution is assessing energy storage (specifically, batteries) to mitigate the financial impacts of implementing peaking restrictions on dams, which represents the first attempt in the literature. Understanding these mitigation options is relevant for new hydropower dams, as well as for existing ones undergoing relicensing processes. For this, we formulate an hourly mixed-integer linear optimization model to simulate the annual operation of a power system. We then compare the business-as-usual (unconstrained) hydropower operations with ecologically constrained operations. The constrained operation, by limiting hydropower ramping rates, showed to obtain flows close to the natural streamflow regime. As next step, we show how re-regulation reservoirs and batteries can help to achieve these ecological constraints at lower costs. While the former are cost-effective for a very broad range of investment costs, the latter will be cost-effective for hydropeaking mitigation from 2025 onwards, when their capital costs have fallen. If more stringent environmental constraints are imposed, both solutions become significantly more attractive. The same holds for scenarios of more renewable generation (in which the operational flexibility from both alternatives becomes more valuable). After 2030, batteries can match the cost-effectiveness of expensive re-regulation reservoirs. Our findings are valuable for policy and decision makers in energy and ecosystem conservation.

1. Introduction

Hydropeaking refers to an operational scheme of a hydropower plant, in which the plant operates at high capacity during high-value, “peak” hours and at low capacity (or even shutoff) during low-value, “off-peak” hours. This practice results in highly fluctuating downstream flows. Although river flows have a natural variation, fluctuations at the subdaily scale caused by hydropower plants are far more severe and impact the downstream river ecosystems (Dibble et al., 2015; Yin et al., 2018). Fish populations face degradation of habitat and increased mortality due to stranding caused by a rapid fluctuation of the water level (Scruton et al., 2003). Benthic populations face the risk of drifting due to high differences in water velocities (Cristina Bruno et al., 2010). Riparian plants face both physiological and physical constraints because of the shifts between submergence and drainage, and erosion of substrates (Bejarano et al., 2018). There are further physical

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Nomenclature of the model

Sets

g	Power plants
t	Time
ta	Alias index for time steps

Variables

$P_{g,t}$	MWh, Generated energy by plant g at time step t
P_t^{uns}	MWh, Unserved energy at time step t
P_t^{cur}	MWh Curtailed energy from the grid at time t
P_t^{char}	MWh, Energy stored into BESS (charging) at time step t
P_t^{disc}	MWh, Energy supplied by BESS (discharging) at time step t
Q_t^{out}	m^3/s, Outflow to the river at time step t
Q_t^{spill}	m^3/s, Spilled flow at time step t
Q_t^{turb}	m^3/s, Turbine flow at time step t
$B_{g,t}$	-, Plant on/off (binary variable)
RB_t	-, Richard-Baker flashiness index at time step t
$RampNeg_t$	(m^3/s)/h, Down ramping rate at time step t
$RampPos_t$	(m^3/s)/h, Up ramping rate at time step t
SoC_t	%, Battery state of charge at time step t
R_t	m^3, Re-regulation reservoir stored volume at time step t
V_t	m^3, Reservoir stored volume at time t
MIT	\$, Resulting annuity cost of mitigation option

Inputs

c^g	\$/MWh, Variable generation cost of plant g
c^{uns}	\$/MWh, Penalty for unserved energy
D_t	MW, Demand at time step t
$P_{t,}^{max,}\ P_t^{min}$	MW, Maximum power output of plant g
Q_t^{in}	m3/s. Natural inflow into the reservoir
$R^{min}R^{max}$	m3/s, Minimum/maximum volume of the re-regulation reservoir
V^{min}, V^{max}	m3/s, Minimum/maximum volume of the reservoir
c^{BE}	\$/MWh, Cost of battery energy capacity
c^{BP}	\$/MW, Cost of battery power capacity
Δt	s, Time step size
C	MWh, Rated battery energy capacity
DoD	%, Maximum battery depth of discharge
η	%, Battery charging/discharging efficiency
MIF	m3/s, Environmental minimum flow
MRR	(m^3/s)/h, Maximum ramping rate
N	MW/(m^3/s), Hydropower plant yield
$tMin^{on}$	h, Minimum online time of coal power plant

stressors caused by hydropeaking, such as temperature anomalies (Carpentier et al., 2017) and modification in the sediment dynamics. Altogether, water bodies with extreme fluctuations can lead to reduced populations of macroinvertebrate communities and become fishless (Poff and Zimmerman, 2010). A comprehensive overview of the impacts of hydropeaking on the river ecology is given by Zimmerman et al. (2010).

New power market structures (Kern et al., 2012) and variable renewable systems may exacerbate these impacts (Haas et al., 2015). Since hydropower has distinct operational advantages over other renewable technologies, new installations are projected to increase significantly (Zarfl et al., 2014). This motivates the search for new models and solution methods to tackle complex hydropower systems (Feng et al., 2018) including their multiple purposes (Hu et al., 2014), as well as for cost-effective ways of mitigating the ecological impacts of hydropeaking.

Indicators of Hydrologic Alteration (Richter et al., 1996) and Environmental Flow Components (Mathews and Richter, 2007), among other environmental flow statistics, are approaches often used for quantifying the disruptive ecological effects of dams and other human activities on streamflow patterns. For quantifying the impacts of hydropeaking on streamflow regime, it is necessary to use statistics that apply on higher (hourly) resolutions to capture the *subdaily* hydrologic alteration (Cristina Bruno et al., 2010). Many previous studies used the streamflow “flashiness” index from Richards-Baker (R-B) (Baker et al., 2004) to study impacts related to hydropeaking (Olivares et al., 2015). The R-B flashiness index essentially quantifies hour-to-hour changes in streamflow as a proportion of total flow experienced. Other popular metrics include the number of reversals, percent of total flow (Lundquist and Cayan, 2002), and coefficient of diel variation (McKinney et al., 2001).

In general, the ecological impacts of hydropeaking can be mitigated by introducing operational constraints on dam operators. Examples include maximum ramping rates, which limits hour-to-hour differences in reservoir discharge, and minimum flows (He et al., 2018). But these operational constraints cause dam owners (or power fleet owners) to incur increased operational costs (Guisández et al., 2013) because the peaking capacity of hydropower needs to be replaced by expensive thermal peaking plants such as natural gas or diesel. To avoid or reduce this additional cost, physical mitigation options such as re-regulation reservoirs (RRR) or afterbays downstream of the hydroelectric dam (Richter and Thomas, 2007) can be implemented together with operational restrictions.

The ecologic and economic value of RRR has been explored earlier (Olivares, 2008). Further, RRR have been analyzed for different projects from a technical point of view, including dams converted to pumped-storage hydropower that then essentially operate as batteries (Pérez-Díaz et al., 2012). But, so far, there are no studies about the cost-effectiveness (including investment costs) of RRR as a mitigation alternative.

Another option for mitigating the impacts of hydropeaking is energy storage, such as pumped hydro storage, compressed air energy storage, power to gas (electrolyzers), and batteries (Kousksou et al., 2013). The first two have shown a slow development in recent years (Hart and Sarkissian, 2016). Power to gas is considered to be a promising technology by some regions but still in early stages of deployment (Hart and Sarkissian, 2016). Battery energy storage systems (BESS), however, are rapidly increasing their installation rates and are projected to soon be viable for energy peaking purposes in power systems (Child et al., 2017b). Lower-cost BESS could conceivably substitute for the peaking ability usually provided by conventional hydropower plants, by storing hydropower produced during off-peak hours and discharging this power during peak hours. The market for grid-scale BESS is growing quickly, reaching volumes in 2015 that were four times larger than any prior year (Hart and Sarkissian, 2016). Future projections for the year 2030 indicate (Li-ion BESS) cost reductions of the order of 60%–80% (Breyer et al., 2017). A potential downside of BESS is their (still) limited lifetime. Current stationary BESS come with warranties of about 10,000 cycles but only if the state of charge is controlled adequately. At, say, two cycles per day, this equals to about 13.5 years, standing in great contrast to conventional peaking technologies (and RRR) that last several decades.

Still, BESS are already being implemented in systems to address reliability issues and help incorporate renewables. For example, the largest Li-ion BESS (100 MW) has just been deployed in Australia, and another 50 MW in South Korea (IRENA, 2015), which aims to install 2000 MW of battery storage by 2020. On the other side of the globe, California has a new bill requesting 1300 MW of storage power capacity by 2024 (Legislative Counsel, 2010) to support its transition to a fully renewable system. The attractiveness of BESS investments is growing through shared-economy models; here a peak-shaving application of BESS has shown to achieve financial returns above 30% per year (Lombardi and Schwabe, 2017). From a grid operator's point of view, grid-scale BESS has proven to significantly decrease operational costs (Goebel et al., 2017). Also for industrial applications, large-scale BESS can be deployed cost-effectively, for example in mining operations (Pamparana et al., 2017). More generally on storage technologies, two recent publications systemized modeling approaches for investment planning with storage (Haas et al., 2017) and the need for storage in highly renewable power systems (Cebulla et al., 2018). Together, the two publications looked at over 100 studies. These and many other studies focus on the viability of BESS for improving economic and reliability outcomes in power systems. However, none of them has addressed how BESS can potentially reduce human pressure on sensitive freshwater ecosystems below dams.

The novelty of our work lies in comparing the cost-effectiveness of RRR and BESS in mitigating (subdaily) hydrologic alteration downstream of hydropower plants. Specifically, the questions to be answered are:

i) Cost-effectiveness: What is the techno-economic performance of RRR and BESS in mitigating the hydrologic alteration caused by a hydropower plant?
ii) Selection: Which alternative is better? When do we pick an alternative over the other?

To answer these questions, we designed a case study. There, we explored increasing shares of renewable generation, different stringencies of environmental constraints, hydrologic years, and a wide range of investment costs of RRR and BESS.

The results of this work have important implications for how exogenous changes in grid technology in coming decades could alter the use of hydroelectric dams and make it more feasible to reduce the impacts of dams on downstream ecosystems. This is relevant for both new hydro dams and for relicensing of existing ones. For example, in South America and in Chile, massive amounts of solar energy projects are forecasted; for their integration, the existing hydropower park could buffer the day-night cycle but not without exacerbating the hydrologic alteration (Haas et al., 2018b, 2015). Globally, developing regions project over 700 GW of new hydropower dams in the next 20 years (Zarfl et al., 2014), whereas developed countries more commonly face relicensing processes of existing operations. For example, in the U.S. alone, 35 GW of hydropower plants need to renew their license before 2030 (Federal Energy Regulatory Commission, 2018). All these situations will require a careful assessment of how to cope with hydropeaking to protect the ecology of their water bodies.

The work is organized into five sections. The methods and model are described in Section 2. The case study is detailed in Section 3, with results discussed in Section 4. Finally, conclusions and future work are presented in Section 5.

2. Methods and electricity model

We study a system in which new environmental regulations impose strict maximum ramping rates (MRR) that limit variations in streamflow downstream of the hydroelectric dam. To reduce the resulting system costs (arising from the lower flexibility), an RRR and a BESS are added to the system. We will examine, i) whether RRR and BESS are efficient in reducing those over-costs (while complying with the environmental constraints), and ii) under which conditions one alternative is better than the other.

Power system and market operations are represented here using a hydrothermal dispatch model, such as can be found in the literature (Olivares et al., 2015). The particularity of our model is that it explicitly models RRR and BESS, under the imposition of environmental constraints. The model uses mixed integer linear programming (MILP) to minimize the operational costs (mainly fuel) on an hourly resolution for a 1-year simulation period (8760 time steps).

The model is designed to run in 4 distinct modes, one for each of the three mitigation alternatives (a gray area of Fig. 1-a) plus the base case:

1) Business as usual (BAU), where the dam operator is functionally unconstrained;
2) Operational constraints;
3) RRR (together with the operational constraints); and
4) BESS (together with the operational constraints).

Business-as-usual is used as a benchmark for measuring the cost increase in the other options. Under the operational constraints, the dam operator is obligated to meet the environmental constraint (MRR) only by altering the reservoir release pattern. In theory, this is where the overall system should suffer the highest increase in operational costs. In the RRR alternative, an RRR is built downstream of the dam, and therefore the MRR constraint is imposed on its releases (but not strictly on the releases of the upstream hydropower plant). And lastly, when deploying BESS, MRR is imposed on the reservoir releases again, while the batteries assist in “shifting” power production by storing hydropower during low-value hours and releasing it during high-value hours. The corresponding equations for each mitigation alternative are also shown in Fig. 1-a.

We apply our tool to a hypothetical case study composed of hydropower reservoirs, coal-fired, diesel-fired, solar photovoltaic, and (onshore) wind power plants, as illustrated in Fig. 1-a. We test our findings for different scenarios of water flows; different shares of renewable technologies in the power system; and varying degrees of stringency in the constraints on hydropeaking (MRR). We also test a broad range of investment cost inputs for the RRR and BESS.

In the remainder of the section, we will explain the electricity model (Fig. 1-a), including the modeling of the hydropeaking mitigation options (gray area Fig. 1-a). In section 3, we will show the relevant inputs of the case study, starting in section 3.1 with the hydrologic scenarios (Fig. 1-b) and the generation mix scenarios (Fig. 1- c). Then in section 3.2, we will detail the studied MRR values (Fig. 1- d) and the investment costs of the mitigation options (Fig. 1- e). In section 3.3 we will then explain the procedure of the cost-benefit analysis (Fig. 1-f).

2.1. Objective function

The objective function of the hydrothermal dispatch model is to minimize the total operational cost Z of the system (shown in eq. (1)). For this, the model allocates values to both binary and continuous decision variables controlling the “on/off” status and amount of generation $P_{g,t}$ of each power plant. The first term from the left is the operational cost of generation from the power plants (fuel costs and variable operation and maintenance cost c_g). The

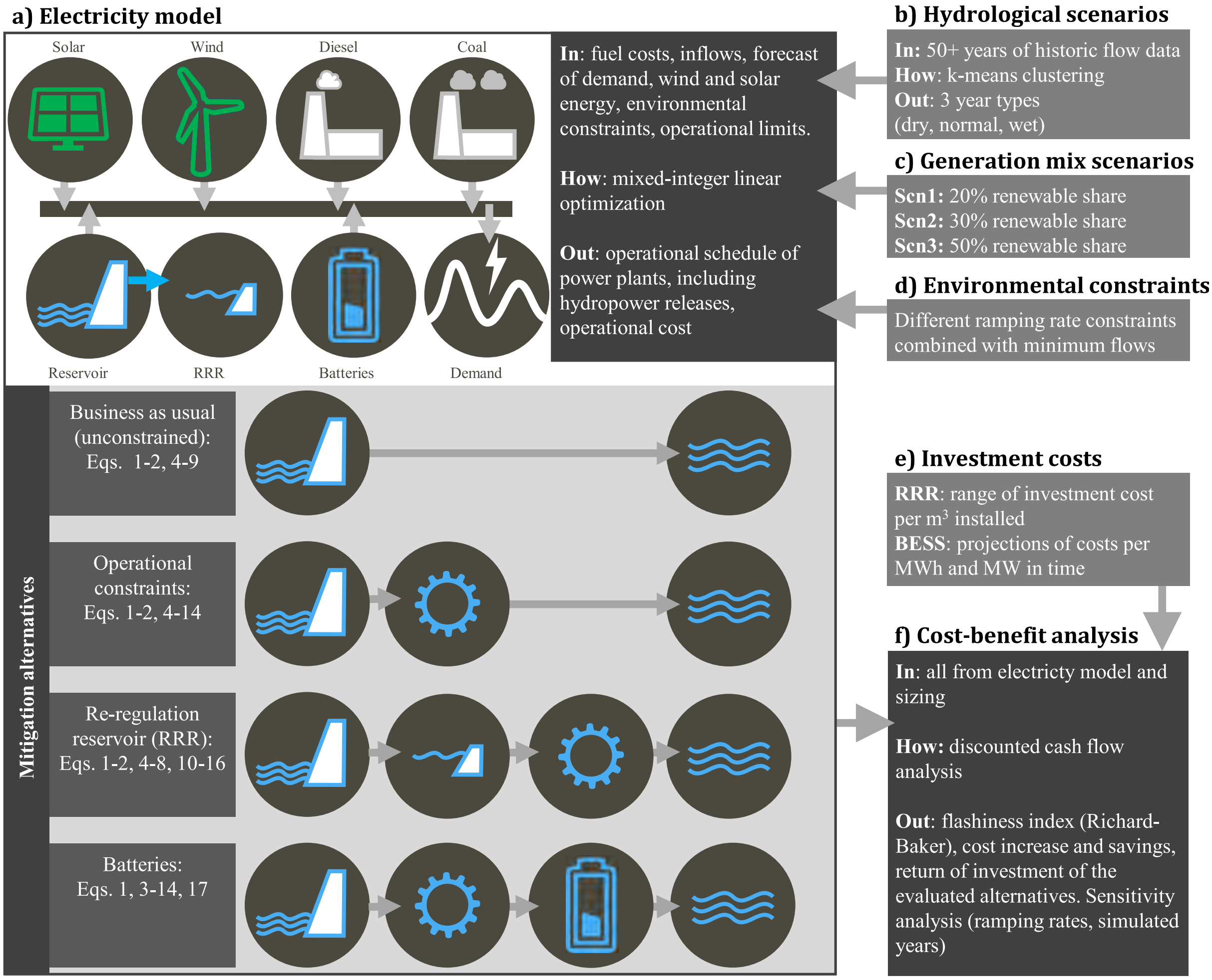

Fig. 1. Framework of the study. Each box refers to a segment of this study, detailing the inputs and outputs. a) Electricity model with the different mitigation options. b) Three hydrological years as inputs to the electricity model. c) Three generation mix scenarios with growing renewable shares. d) Ramping rates (combined with minimum flows). e) Different investment costs of RRR and BESS. f) Cost-benefit analysis.

second term is the penalty c_{uns} for unserved energy P_t^{uns}.

$$Min\ Z = \sum_{t,g}^{T,\ G} c_g P_{g,t}\Delta t + \sum_{t}^{T} c_{uns} P_t^{uns}\Delta t,\ \ \forall t,g \tag{1}$$

2.2. Energy balance

Our model uses a uni-nodal energy balance (i.e. no transmission constraints), where the generation plus the unserved energy needs to meet demand D_t (eq. (2)). In situations of overproduction from renewable technologies, the model has the option to curtail energy P_t^{cur}. For the mitigation option with BESS, the energy flows from and to the batteries (P_t^{disc}, P_t^{char}) need to be considered (eq. (3)).

$$\sum_{g}^{G} P_{g,t} + P_t^{uns} - P_t^{cur} = D_t,\ \ \forall t,g \tag{2}$$

$$\sum_{g}^{G} P_{g,t} + P_t^{uns} - P_t^{cur} + P_t^{disc} - P_t^{char} = D_t,\ \ \forall t,g \tag{3}$$

2.3. Power plants

2.3.1. Technical minimum and maximum power output

The maximum output of each power plant is limited by its installed capacity P_g^{max}. Additionally, if it is on (i.e. $B_{g,t} = 1$), it has to respect its technical minimum $P_g^{\min}$ (eq. (4)).

$$B_{g,t}\ P_g^{min} \le P_{g,t} \le B_{g,t} P_g^{max},\ \ \forall\ t,g\ \varepsilon\ \mathbb{G} \tag{4}$$

2.3.2. Renewable power plants

The wind and solar power plants are considered as inputs to the system. Excess energy can be handled with the variable for energy curtailment P_t^{cur}. The production profiles are hourly and modeled with perfect foresight. Neglecting forecast errors is unfavorable for the investment of storage devices (Moreno et al., 2017), making this a conservative assumption (for the profitability of RRR and BESS).

2.3.3. Thermal power plants

It takes several hours for a coal power plant to start and shut down, therefore minimum online ($tMin_{g,t}^{on}$) and offline times need to be considered. Eq. (5) shows the formulation for the online time. The offline time is analogous. More details on how this is applied can be found in Olivares et al. (2015). Ramping rates of thermal power plants are not active constraints, given that during an hourly time frame an online coal power plant can move from its minimum to maximum power output. Older coal power plants might be less flexible, which would further increase the value of water. Neglecting this makes our study more conservative in terms of the profitability of mitigation options.

$$\sum_{ta=t}^{t+tMin^{on}_{g,t}-1} B_{g,ta} \geq tMin^{on}_{g,t}(B_{g,t} - B_{g,t-1}), \quad \forall\ t \tag{5}$$

To take into account the reduced efficiency of the coal power plant when operating at partial load, we introduced an additional term to the objective function (but not shown for the sake of simplicity). This inefficiency is viewed as an additional cost to the operation. To keep the model linear, we implemented a piecewise-linear approximation of the efficiency curve.

As for diesel power plants, the above minimum on- and offline time is set to 1 h and can be disregarded for this reason. Further, they are not constrained by ramping rates. Their efficiency is assumed to be constant, which is another assumption that makes our study more conservative for the mitigation alternatives.

2.3.4. Hydropower constraints

Power generation from the hydropower plant is modeled with a constant yield N from turbined water Q_t^{turb} to power P_t^g, which is a common approach in energy planning (eq. (6)). This yield is the product of the hydraulic head, specific density of water, gravity and the efficiency of the turbogeneration units. The stored water V_t is constrained by the volume (V^{min}, V^{max}) of the reservoir in eq. (7). The water balance (eq. (8)) ensures the volume continuity of water. Q_t^{in} is the natural inflow to the hydropower reservoir, Q_t^{turb} the turbined flow, and Q_t^{spill} the spilled flow. In absence of RRR, the flow in the river Q_t^{Out} corresponds to the turbined flow Q_t^{turb} plus the spilled flow Q_t^{spill} (eq. (9)). The water volume at the beginning and end of the simulation horizon is set to half of its maximum capacity.

$$P_t^g = NQ_t^{turb}, \quad \forall\ t \tag{6}$$

$$V^{min} \leq V_t \leq V^{max}, \quad \forall\ t \tag{7}$$

$$(V_t - V_{t-1})/\Delta t = Q_t^{in} - Q_t^{turb} - Q_t^{spill}, \quad \forall\ t \tag{8}$$

$$Q_t^{Out} = Q_t^{turb} + Q_t^{spill} \tag{9}$$

2.4. Mitigation options

2.4.1. Environmental constraints

In this model, we applied two types of environmental constraints (as hard-constraints to the model). The first is minimum flows MIF (eq. (10)), meaning that the flow returned to the river always has to be greater or equal than that value. This is a constraint commonly found in hydropower plants. The second constraint is maximum ramping rate MRR, which stipulates that the absolute difference between flows Q_t^{out} of two consecutive time steps is below that value. This holds for up- and down-ramping, which is captured in eq. (11) with the use of the absolute value. While we will only use one value for MIF, we will subject MRR to sensitivities in the case study.

$$Q_t^{Out} \geq MIF, \quad \forall\ t \tag{10}$$

$$\left|Q_t^{Out} - Q_{t-1}^{Out}\right| \leq MRR, \quad \forall\ t \tag{11}$$

To model an absolute value in linear programming, we require further steps. The first step is to include two auxiliary variables for separately accounting for the positive and negative ramps ($RampPos_t$ and $RampNeg_t$). Their sum needs to be below the allowed MRR (eq. (12)). Additionally, we define them as positive variables (eq. (13)). Therefore, the difference in the flow returned to the river Q_t^{out} between two consecutive hours is either captured in the variable of positive or negative ramps. For example, if $Q_t^{out} = 110$ and $Q_{t-1}^{out} = 100$, the flow difference is 10 (right hand side of eq. (14)). From the left hand side of eq. (14), it follows that $RampPos_t = 10$ because $RampNeg_t$ can only adopt positive values and will consequently become zero. Finally, eq. (12) would make sure that $10 + 0$ is below the allowed MRR.

$$RampPos_t + RampNeg_t \leq MRR, \quad \forall t \tag{12}$$

$$RampPos_t, RampNeg_t \geq 0. \tag{13}$$

$$RampPos_t - RampNeg_t = Q_t^{out} - Q_{t-1}^{out}, \quad \forall t \tag{14}$$

2.4.2. Re-regulation reservoir constraints

The water balance in the RRR (if installed) depends on the plant's turbined flow from upstream Q_t^{turb}, spilled flow from upstream Q_t^{spill}, and its releases Q_t^{RRR} (eq. (15)). The instream flow results directly from the releases of the RRR (eq. (16)). The water level in the RRR at the beginning and end of the simulation horizon is also equal to half of its capacity.

$$\frac{R_t - R_{t-1}}{\Delta t} = Q_t^{turb} + Q_t^{spill} - Q_t^{RRR}, \quad \forall t \tag{15}$$

$$Q_t^{Out} = Q_t^{RRR} \tag{16}$$

Note that Q_t^{RRR} is a decision variable, which means that the operation of the RRR is decided by the optimization model. This implies that the hydropower reservoir can operate more freely, and that the RRR is in charge of determining releases such that the MRR and MIF are met.

2.5. Battery energy storage system

Within the optimization, batteries are modeled in terms of their energy balance and their maximum depth of discharge. Capacity-fade and replacement at the end of their life are considered ex-post in the discounted cash flow analysis.

The energy balance of the BESS depends on the energy charged to and discharged from it (P_t^{char}, P_t^{disc}), corrected by its efficiencies η. The left-hand side of eq. (17) shows the change of state of charge SoC_t of the battery, which is expressed in percentage. Multiplied by its nominal energy capacity C, it gets a dimension of energy (MWh). Due to technical reasons, only a part of the battery's nominal energy capacity can be used, for which we correct by the factor of maximum depth of discharge DoD. Fig. 2 clarifies the terms of this energy balance. Further, the batteries are constrained by their installed power capacity and by their installed energy capacity (not shown for the sake of brevity).

$$C \cdot DoD \cdot (SoC_t - SoC_{t-1})/\Delta t = \eta P_t^{char} - P_t^{disc}\Big/\eta, \ \forall t \tag{17}$$

Analogous to the RRR, the battery's operation (P_t^{char}, P_t^{disc}) is

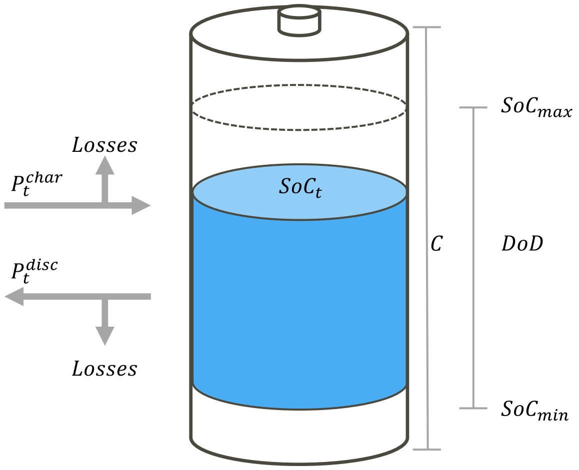

Fig. 2. Energy balance of the battery, adapted from Lombardi and Schwabe (2017).

found by the model. In other words, when the hydropower reservoir has a more limited operation in order to meet the MRR and the MIF, that missing flexibility is provided by the batteries.

3. Case study

3.1. General description and scenarios

In this section, we will detail the inputs of the case study. The considered power system is composed of one of each thermal, hydro, and renewable power plants. We decided to work with a hypothetical test system to reduce computational time; the user-defined installed capacities result in a mix that could roughly resemble central Chile. To take into account the variability of demand (Alvarez et al., 2017), inflows (Haas et al., 2015), and solar and wind power generation (Molina et al., 2017), we used profiles from central Chile (Rapel). Inflows and load profiles correspond to historical data, whereas solar and wind time series are synthetic based on validated models (Department of Geophysics - University of Chile and Ministry of Energy of Chile, 2012a, 2012b). The main model inputs can be found in the supplementary material (Anindito, 2018).

The results of the hydropeaking mitigation alternatives might depend on the power system under study. Therefore, we define three scenarios with growing renewable energy capacity (20%, 30%, 50% in terms of energy with solar and wind in equal parts). All of them have the same hydro, coal, and diesel power capacity. This is done for capturing the current development of renewable deployment and the behavior of the hydropower production (which can show an exacerbated hydropeaking scheme under these conditions (Kern et al., 2014)). The load is assumed to have no growth for ease of comparison. Table 1 shows the resulting dimensions. The mean hydropower generation depends on the considered hydrologic scenarios (see next paragraph), which directly impact the diesel- and coal-based generation. Growing renewable shares also affect the fossil generation (but we verified that the resulting coal power plant achieves an economically feasible capacity factor).

The considered power system is rather small. Therefore, it could be viewed as a fleet of a single power company, an isolated power system, or a sub-system (of a larger power system that for example suffers from transmission bottlenecks). Besides keeping computing times small, using a small power system is motivated by the ease of illustrating the behavior of its different elements and solutions (as opposed to large systems where the cross-effects are more complex to understand). One limitation of this approach is that when strictly constraining the operation of hydropower, only coal[1] and diesel are left for the provision of flexibility, which could influence the total costs. In a larger system that would be equivalent to constraining all existing hydropower plants. However, in reality, not all hydropower plants are equivalently constrained, due to differences in licensing (i.e. some will need to meet stricter operational constraints than others). Therefore, our scenarios are valid for providing general guidelines in systems where flexibility is scarce. In systems with many flexible power plants (e.g. gas), the resulting energy price profiles might be less variable (Kern and Characklis, 2017). Our estimations may be less transferable to those situations.

Hydro-thermal power systems are strongly influenced by water availability. For example, a dry year usually translates to higher costs because the system becomes more reliant on fossil generation. Also, hydropower operations can depend on hydrologic conditions: for example, wet years are typically associated with larger, but more stable flows, in contrast with normal years where frequent peaking is observed as a consequence of having a great need to maximize the value of water (Kern and Characklis, 2017). This motivates us to explore three different hydrologic scenarios: dry, normal and wet years. From historical flow data (55 years) we used the k-means clustering method to divide the data into three groups, and then the years closest to their respective cluster centers were selected as representative. Fig. 3 shows the selected wet, normal, and dry year, which represent 15, 17, and 23 time series (of their corresponding cluster), respectively. All three hydrologic years are used to analyze the performance of each mitigation alternative. The combination of the three power systems and the three hydrologic years produces nine scenarios.

To get an idea about the variability of renewable resources and demand in these scenarios, see Fig. 4. Panel a), which shows the inputs for a whole year (green area corresponds to the combined wind and solar generation, and the blue area to the reservoir inflows, expressed in equivalent energy). For each time step, the gap between demand and variable renewable energy production (i.e. netload) must be covered by thermal generators or hydropower production (hydropeaking). Panel b) shows the resulting operation from the model for two selected weeks. Here, it becomes clear how variabilities in net load are matched with coal, diesel, and hydropower. The lower plot (b) shows how there can be spilled energy when hydropower ramps are constrained.

3.2. Mitigation alternatives: operational constraints, re-regulation reservoir, and battery energy storage systems

Here we will provide the details of the mitigation alternatives, starting with the MRR and MIF, followed by RRR and BESS.

In terms of operational constraints, we used a fixed value for MIF ($5\ m^3/s$) and explored a wide range of MRR levels. However, for the sake of brevity, our discussion will focus on only two of them. The first MRR is very strict, allowing an hourly change in streamflow of only $10\ m^3/s$ (equal to 3% of the installed capacity of the hydropower plant). This would correspond to a very stringent environmental regulation, which, as we will see, can restore the natural regime. The second one allows for hourly changes of $25\ m^3/s$. From a power system perspective, this is also strict (only 9% per hour). However, it allows going from 0 to 100% and back within a day, which from an ecological point of view is very unnatural (a natural

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[1] It should be noted that the rate of change of power output in the coal operation is not constrained (it is not uncommon in certain places to use coal as a peaking technology) in the model. Given the similarity in operating costs per kWh for both coal and gas, we decided to omit gas technologies.

Table 1
Detail of power system scenarios.

Power plant type	Scenario 1 (20% RES)			Scenario 2 (30% RES)			Scenario 3 (50% RES)		
	Min power (MW)	Mean power (MW)	Max power (MW)	Min power (MW)	Mean power (MW)	Max power (MW)	Min power (MW)	Mean power (MW)	Max power (MW)
Hydropower reservoir	30	varies	300	30	varies	300	30	varies	300
Solar power plant	0	75	200	0	75	250	0	150	500
Wind power plant	0	75	210	0	75	265	0	150	530
Coal power plant	150	varies	300	150	varies	300	150	varies	300
Diesel Power Plant	0	varies	300	0	varies	300	0	varies	300
Demand	340	600	750	340	600	750	340	600	750

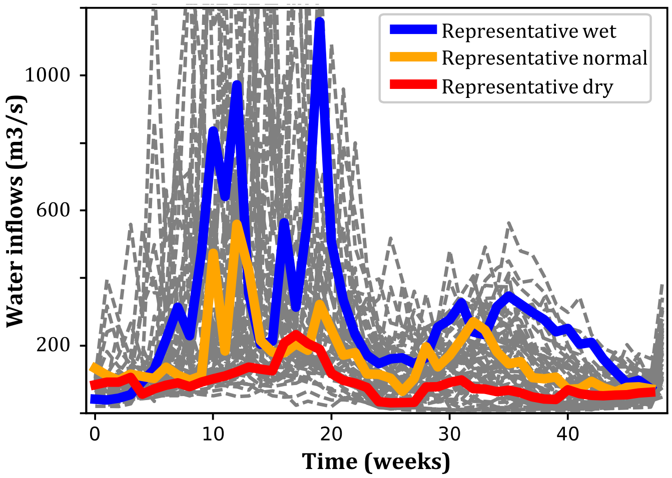

Fig. 3. Hydrologic years used in the case study.

flood, for example, takes several days).

Previous studies have shown that an effective size of the re-regulation reservoir (RRR) for hydropeaking mitigation (without considerations of costs) is somewhere below 4 h of storage capacity (Olivares, 2008). Larger sizes are better for reducing hydrologic alteration but are more costly. After trial and error, we defined a rather small size of 0.33 h of energy storage capacity (i.e. an energy storage capacity of 100 MWh for a hydropower plant of 300 MW). Apart from keeping costs low, another reason to choose the smallest RRR as possible (while still adhering to ramping constraints), is that larger RRR are inherently more challenging construction projects, given the potential for adversarial downstream water users and social opposition. The resulting dimension of our RRR is 0.36 Mm^3 -or a pool of, say, 200 m × 200 m and 9 m deep. We estimate the cost of building an RRR from a database of reservoirs used for flood protection (Keating et al., 2015), given the structural similarities involved. On that data, we applied a regression (Local Polynomial Regression). Fig. 5 shows the resulting cost distribution of RRR as a function of their volume. The cost-spread

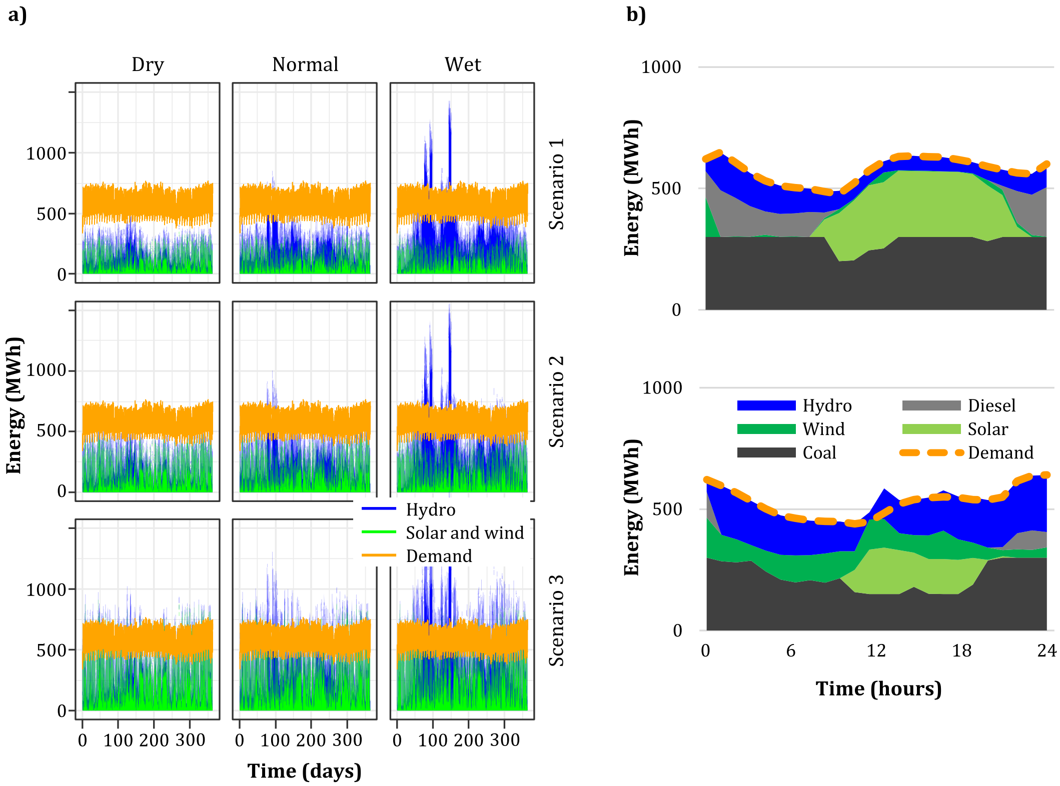

Fig. 4. Variability of energy profiles. a) Yearly energy inputs for the different scenarios (power systems and hydrologic years). b) Power system operation for selected weeks (output of the optimization).

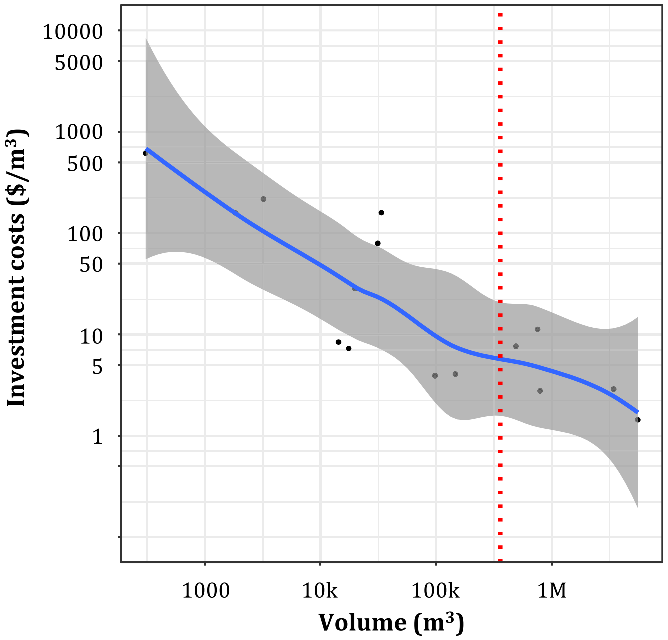

Fig. 5. Re-regulation reservoir cost prediction.

(gray band in Fig. 5) for one given volume reveals large differences between projects. This gray band englobes 95% of all costs, which implies that values above that band correspond to the 2.5% most expensive reservoirs costs (and the ones below the cheapest 2.5%). For our RRR size (0.36 Mm^3), indicated by the red line, we see that the expected, lowest 2.5%, and highest 2.5% costs are about 5, 2, and 25 $/m^3. This cost range is fully explored in the discussion section.

The energy capacity of the battery is chosen to be equal to the RRR, i.e. 100 MWh (or 129 MWh if measured as the nominal storage capacity of the battery). BESS of this size can already be found in wholesale power systems today (U. S. Department of Energy, 2018). The power capacity is an additional design parameter and is determined using an expansion planning problem (external to our framework), attaining a value of 40 MW that makes economic sense for many of the scenarios considered in this study. This results in an energy-to-power ratio of 2.5 h, which is a very frequent value of current Li-ion installations (U. S. Department of Energy, 2018). Again, the rather small size of batteries (and RRR) responds to the stakeholder logic of finding the minimum investment able to comply with the environmental regulations. Larger sizes, of course, might be more effective but not as profitable as the ones considered here. Also for batteries, we performed a sensitivity to investment costs. Contrary to the RRR, Li-ion costs do not depend on location. Their cost rather depends on their worldwide deployment in the coming decades (i.e. experience curve of new technology). As there are many cost projections available, and we did not want to condition our results on only one particular study, we consequently explored the complete range of possible investments costs.

3.3. *Cost-benefit analysis*

The cost-benefit analysis relies on the calculation of discounted cash flows. A 40-year project horizon is considered for each alternative. For comparison, we use the Internal Rate of Return (IRR).[2] The higher this rate, the more attractive the investment is. A general rule is that the IRR should be at least above the discount rate of the company (which differs among each sector and company) in order to be considered a plausible investment. In the power sector, that rate is generally higher than 10%.

The “revenues” resulting from each mitigation alternative are calculated as the cost difference between a case in which the dam owner meets the MRR using operational constraints alone and case in which physical mitigation alternatives (RRR or BESS) are used. After finding the “revenues” associated with each mitigation alternative under each hydrologic condition (i.e. dry, normal, wet year), an annual expected value can be estimated by weighting each hydrologic year by its respective frequency in the historical record (see section 3.1). The expenses are the investment cost of each mitigation alternative. In the case of batteries, they additionally show replacement costs for the energy component to account for the gradual capacity fade and their final replacement every ten years.

4. Results and discussion

In this section, we will first introduce the operation of the mitigation alternatives, then we will compare their cost-effectiveness to finally discuss which alternative is more attractive. We wrap up the section with a discussion on uncertainties inherent to planning.

First, we will look at the operation of a sample week. Fig. 6 shows how the mitigation alternatives operate under the power system scenarios (columns) and hydrologic scenarios (rows). We can see how the business-as-usual discharges are the most

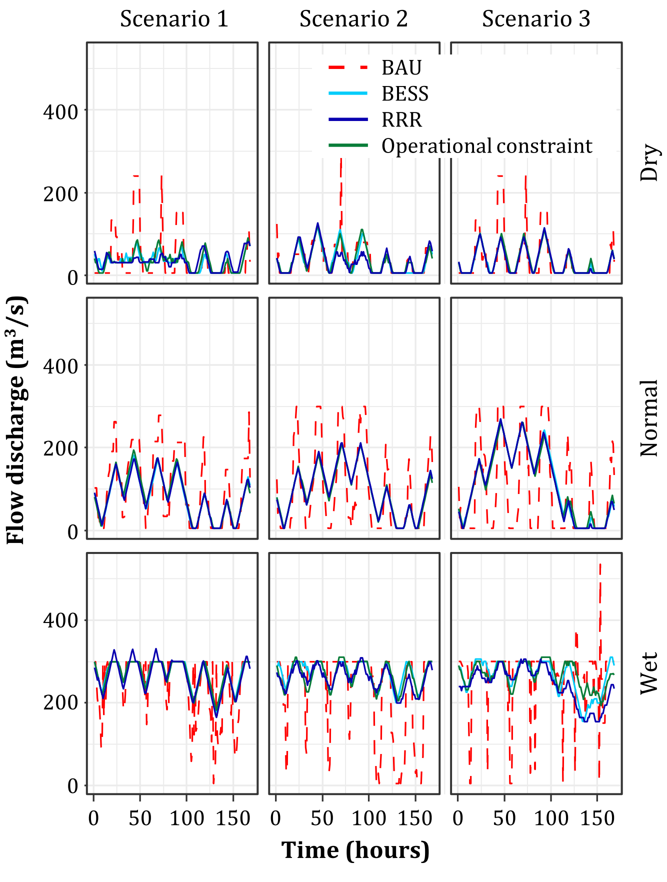

Fig. 6. Hydropower releases (of a sample week) of the different mitigation alternatives, for the different hydrologic and power system scenarios.

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[2] Discount rate that makes the net present value equal to zero.

fluctuating for all scenarios. The release pattern gets smoothened by the enactment of the environmental constraints. The cases with an RRR or BESS are very similar in replicating this smoothened operation, as a direct result of obeying the (same) environmental constraints.

To draw a more generalized conclusion, we proceed to compute the subdaily streamflow fluctuations into one flashiness index, the R-B index (Baker et al., 2004). This index is large for highly pulsating flows and zero for constant releases. We calculate one R-B value for each run. That is, the 8760 hourly releases (associated with the optimal use of the hydroelectric dam within the larger context of the hydrothermal dispatch) are summarized into a single number. We repeated this for all power system scenarios, water type years, and MRR values ranging between 0 and 50 $m^3/s/h$.

Fig. 7 shows these resulting R-B indexes. From here, we see how the business as usual case (red-dashed lines) exhibits a large flashiness, which varies with the scenarios considered between 0.1 and 0.3. Wet years are characterized by a lower flashiness, whereas normal and dry years are more extreme. This is in-line with the literature (Olivares et al., 2015), although dry years can also show a more steady behavior if strong minimum flows are in place (Kern and Characklis, 2017). We also see from Fig. 6 that all mitigation alternatives perform similarly in making the flows smoother (again, as a direct response to the acting environmental constraints). We attribute the slight divergences (between a stricter MRR and the corresponding R-B index) to the fact that our tool only sees the MRR as a hard constraint and does not solve for the optimal R-B index (that relationship is not necessarily monotonic) and to convergence levels. However, in general terms, we can affirm that the more stringent the MRR, the lower the resulting flashiness index is. This is helpful for policy making, as an easy operational rule (MRR) effectively translates into improving an ecologically relevant (hydrological) index (R-B). The achieved R-B value depends on the hydrologic scenario, but the overall trend remains clear. In general terms, we see that constraining the releases with an MRR around 10–30 $m^3/s/h$ shows to achieve a flashiness around 0.05, for most scenarios. This is the *order of magnitude* of the natural flow's flashiness according to the literature (Zimmerman et al., 2010) (in our plot, the black dotted line shows a referential R-B index equal to 0.03), although the actual number depends on the river.

4.1. *Cost-effectiveness of batteries and re-regulation reservoirs*

Implementing MRR inherently makes hydropower less operationally flexible, leading to higher operational costs because the system now depends on more expensive thermal peaking technologies (e.g. diesel), which is shown in Fig. 8. We see how an MRR less stringent than 50 $m^3/s/h$ does not impact the system costs (lines are horizontal) for most scenarios. For MRR of around 20–30 $m^3/s/h$, the system begins to suffer from a more expensive operation, impacting the system by a couple of percents, which is consistent with previous studies (Haas et al., 2015). This is especially true for high renewable energy scenarios because they rely more strongly on operational flexibility. The operational costs increase most during dry years (the overall flexibility is scarcer). The opposite is true for wet years, with cost increases of about 10% or lower. The combination of dry years with highly renewable systems constitutes the most unfavorable situation in terms of cost increase under MRR.

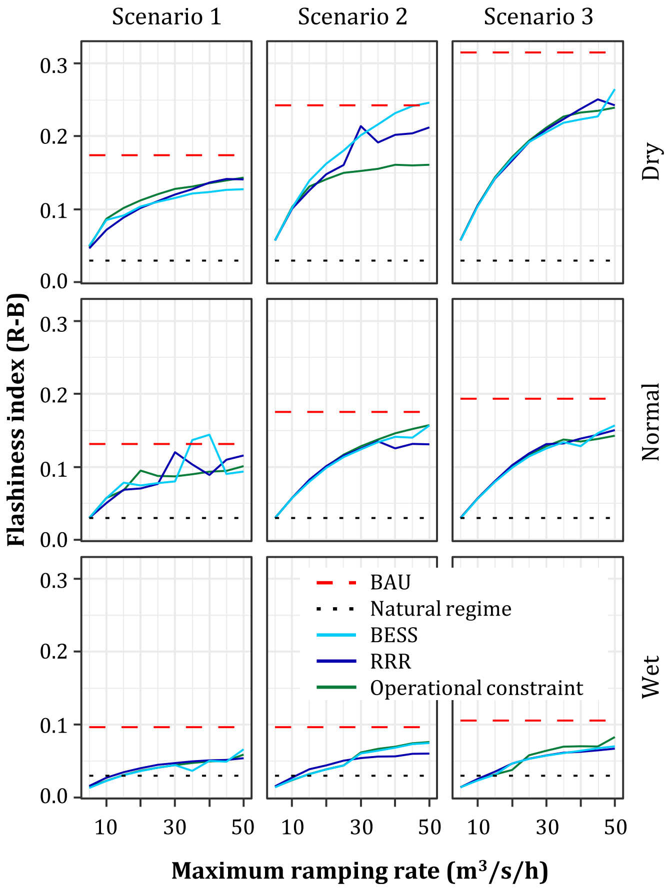

Fig. 7. Flashiness of releases of the different mitigation alternatives, for the different hydrologic and power system scenarios.

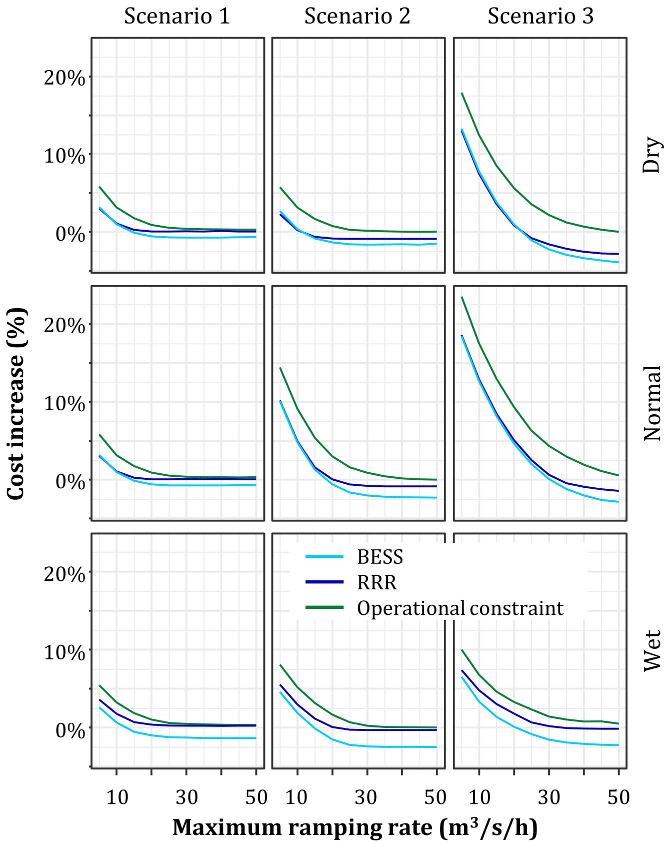

Fig. 8. Cost increase of the power system of the different mitigation alternatives, under the different hydrologic scenarios and power system configurations.

Fig. 8 also shows that the implementation of an RRR or BESS results in significant reduction in the system's operational costs for all scenarios. For looser MRR constraints, RRR performs slightly worse than BESS, in economic terms. This is because BESS can also provide other services (e.g. energy arbitrage). In very stringent MRR cases, both RRR and BESS converge to the same number. In these cases, BESS are mainly dedicated to meeting the MRR constraints.

Remember that the cost difference between the operational constraints (green line in Fig. 8) and a mitigation alternative in place (BESS and RRR, light and dark blue lines in Fig. 8) represent the "revenues" that are evaluated in the cost-benefit analysis (which is then weighted by the frequency of hydrologic year). In the next paragraphs, we will determine whether these "revenues" cover the capital cost of the mitigation alternatives. Given the sensitivity of our power system, which reacts for MRR equal to 30 $m^3/s/h$ or stricter, we will focus our analysis on two particular cases: MRR = 10 and MRR = 25.

Although reservoirs are a mature technology, their investment costs vary broadly with location. To provide a more general recommendation, we explored a wide range of possible investment costs for RRR and calculated their profitability. This is shown in Fig. 9. The dotted color lines represent the IRR for the different hydrologic scenarios, and the thick black line the resulting weighted average. As a general observation, the profitability is positive (in most cases) and grows with lower investment costs. The dotted vertical line represents the "lower bound" for the RRR profitability (i.e. the 2.5% percentile of the most expensive RRR, see section 3.2). The intersection between this vertical and the expected IRR equals at least 25% for all scenarios (with the exception when MRR25 is applied to scenario 1). In other words, 97.5% of possible RRR costs could give us more than 25% expected IRR. Comparing scenarios 1 to 3, it becomes clear that the IRR increases as more renewable sources are introduced to the system. More stringent operational constraints, i.e. smaller MRR (moving from the right to left column in Fig. 9), translate into higher profitability in all power system scenarios.

For BESS, to capture the cost uncertainty inherent to new technologies, we also explored a wide range of investment costs. Note that BESS have two cost components, one for the energy capacity ($/kWh, related to the battery packs) (Curry, 2017) and one for the power capacity ($/kW, related to the inverter) (Child et al., 2017a). As a consequence, we decided to plot the results in the form of IRR-isoquants. In Fig. 10, the x-axis and the y-axis are inputs (investment costs for energy and power), and the straight black lines are our outputs (IRR). The colored points are cost-projections for the next years from recent studies (Child et al., 2017b). For example, the area below the black-dotted line corresponds to all the investment cost combinations that reach profitability above 40%. Using the cost projections, this would be reached in 2050 (for scenarios 2 with MRR10).

The least convenient case is the power system with lower shares of renewables (scenario 1 in Fig. 10). Here, BESS become profitable (IRR>10%) only in the long-term when stringent MRR are applied.

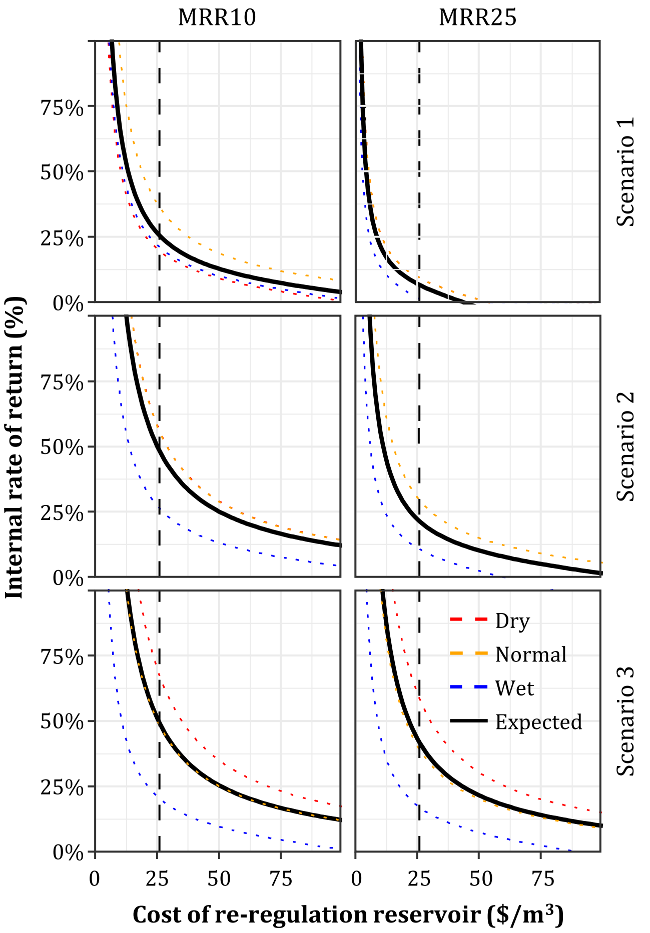

Fig. 9. Profitability of re-regulation reservoir under different reservoir costs assumptions, for the different hydrologic and power system scenarios.

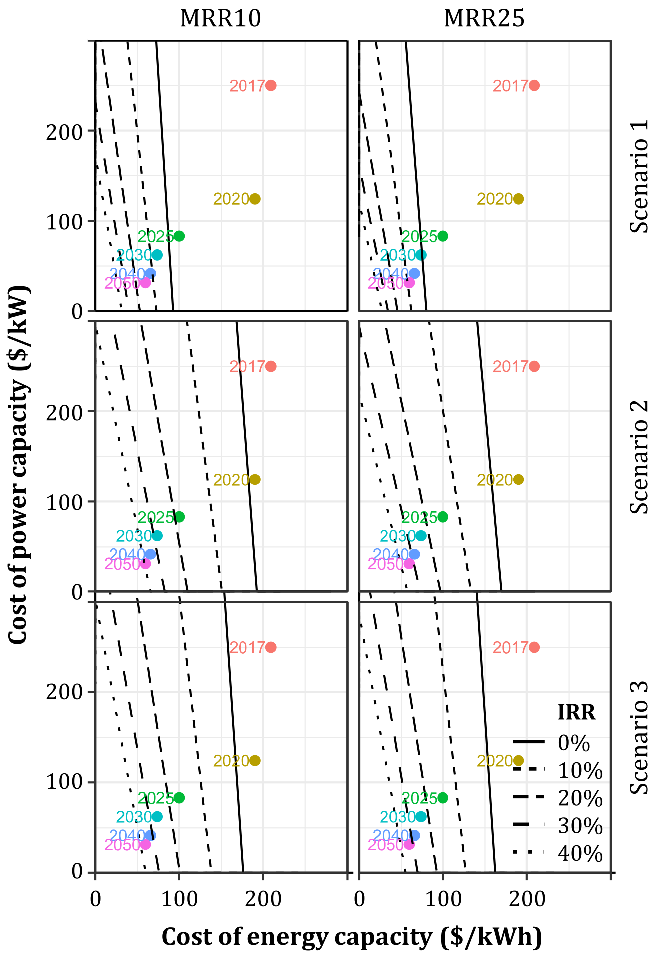

Fig. 10. Profitability of BESS under different cost assumptions, for the different hydrologic and power system scenarios.

For medium and high shares of renewables (scenarios 2 and 3), the profitability of BESS is below 10% before 2020, making it unattractive until that year. In 2025 a major jump happens: the IRR is above 15% for most cases, which is highly appealing. After that year the situation keeps on improving.

4.2. Batteries or re-regulation reservoirs for mitigation of hydropeaking?

The cost-benefit analysis shows that an RRR is cost-effective for a very broad range of possible project capital costs. A more stringent maximum ramping rate makes it even more attractive. This also holds for highly conservative cost assumptions for the RRR. However, the cost-benefit analysis does not take into account the time needed for constructing the RRR nor how the construction could potentially interfere with hydropower operation (i.e. lower head in downstream cascading plants or thermal power generation during the construction). Since construction cost and duration can vary greatly between sites, a more detailed RRR analysis is suggested for future work and for site-specific analysis.

For BESS, results suggest that they will be a cost-effective mechanism for allowing power systems to reclaim the value of peaking hydropower that may be lost to regulatory constraints in the near future. Current battery cost projections show them to be cost-effective (>10% expected IRR) from around 2025 onwards for systems with mid and high shares of renewables. The deployment of BESS in real power systems shows that they are already attractive in providing other services such as power reserves and energy arbitrage (Haas et al., 2018a), even in the absence of environmental constraints. This implies that the optimal size and operation of the BESS depends on different power system services in place (and their pricing scheme). Meeting operational constraints can be understood as an environmental service, which could become yet another stream of income of BESS.

BESS could be preferred if a re-regulation reservoir is not feasible, for example, due to land unavailability or social opposition. In the future, BESS could be the preferred alternative, especially with the increasing share of renewable energy in power grids. This is especially relevant for dams that need re-licensing. If the cost of building an RRR is high, the results show that a BESS can be a competitive alternative in the near future. BESS should begin to enter into discussions related to hydropeaking mitigation, especially given the typically long duration (e.g. 30 years) of operating license agreements at many dams.

For example, in the US, 10 GW of hydropower capacity is scheduled to go through the re-licensing process before 2025, and another 16 GW before 2030 (Federal Energy Regulatory Commission, 2018). During this process, the legally binding operational balance between dam operations and environmental impacts (including any potential restrictions on hydropower peaking) will be fixed for another period of 30 years. If power systems soon have a wider range of cost-effective options (i.e. BESS) for offsetting the economic penalties associated with ramping restrictions, this information could be directly useful in informing re-licensing discussions.

In summary, RRR are highly cost-effective, even using high-cost assumptions. In contrast, BESS can only be cost-effective starting from 2025. The cost-effectiveness of BESS can only match that of re-regulation reservoir if the cost of building an RRR is high, after 2030.

4.3. Limitations, uncertainties, and future work

There are several sources of uncertainties inherent to investment planning. To systematically assess the financial attractiveness of two alternatives for hydropeaking, we designed a wide range of scenarios. We explored a broad spectrum of investment cost parameters (for BESS and RRR), varying levels of constraints on hydropeaking, different power system configurations, and different water availability represented by hydrologic years; and attained in total about 5000 scenarios. Some sources of uncertainties that we did not consider are detailed below.

As expected, we detected that the profitability highly depends on the power system configuration, such that we recommend to run numbers specific to each case if the generation mix differs from ours, or if particular pricing mechanisms are in place. Particular attention should be directed to the available sources of flexibility (e.g. storage, peaking technologies, transmission). More flexible systems could delay the year in which BESS become viable, but it doesn't seem like something that would impact the relative performance of RRR vs. BESS.

For integrating renewable generation, both variability and uncertainty need to be addressed. In the present study, we tackled the variability by considering a full year with hourly resolution (and different weather years) but did not deal with the uncertainties as our optimization problems were deterministic. Accounting for forecast errors would likely increase the profitability of storage, because of their inherent ability to move energy through time. Our approach can be seen equivalent to operating the storage devices in the day-ahead market, without participating in the reserve markets.

Impact of climate change on hydrologic regimes is another point that worries energy planners. In general, the trend in Chile is a growing arid zone, with more intense flood events. From Fig. 9, we see that especially in dry years, the attractiveness of BESS/RRR is higher than in other years. In other words, in a system of more fluctuating energy production (including river runoffs), flexibility (BESS/RRR) becomes more valuable.

For future work, there is room for improvement in implementing time-varying operational constraints. For example, in many watersheds, the need for environmental flows change throughout the year (Arthington et al., 2006). This may change the performance of the mitigation alternatives across the different hydrologic years considered. Finally, in our case study, we considered the minimum sizes of RRR and BESS that are able to reproduce the natural flow regime; larger sizes would exhibit an even smoother flow, but in a direct trade-off with the profitability.

5. Conclusions and future work

In this study, we determine whether battery energy storage systems (BESS) are an efficient mechanism to reduce the impacts of hydropeaking. We compare their techno-economic performance in reducing the impact of subdaily hydropeaking with a re-regulation reservoir (RRR).

For the comparison, we used a hydrothermal dispatch model applied to a hypothetical test system under different levels of renewable energy penetration. In all scenarios, the business-as-usual case (without any limits on downstream variations in flow) is compared to cases where environmental constraints (in the form of maximum ramping rates and minimum instream flows) are imposed on the hydropower plant. The enactment of environmental constraints leads to additional system-wide operational costs, due to increased reliance on more expensive fossil-fuel resources for peaking. We study how an RRR and a BESS can reduce that additional cost.

The considered scenarios of environmental constraints result in flashiness indexes close to the natural regime. Both RRR and BESS can help to restore the natural regime at lower costs than using environmental flows alone.

The techno-economic analysis shows that an RRR is extremely cost-effective for a very broad range of possible investment costs. However, we did not consider uncertainties arising from potential social opposition and interference with downstream hydropower operations (i.e. lower head). Current battery cost projections show them to be cost-effective for hydropeaking mitigation (internal rate of return >10%) from around 2025 onwards for power systems with medium and high shares of renewables. More stringent environmental constraints make both solutions significantly more attractive. After 2030, BESS can match the cost-efficiency of RRR, but only if the construction costs of the latter are high. We delivered the resulting profitability of BESS and RRR in curves, such that they can be applied elsewhere for any arbitrary cost projection.

As future work, we recommend focussing on dynamic (variable over the year) environmental constraints. Yet another direction is understanding how the profitability of BESS and RRR evolve in more complex systems, as many hydropower dams going through relicensing that gradually need to meet more demanding environmental constraints. In the end, both BESS and RRR are a viable option for making hydropower reservoirs more ecologically sound.

Overall, understanding how hydropower can deliver operational flexibility to support highly renewable systems, without deteriorating riverine ecosystems is a key challenge for cleaner power production. Our findings offer new insights for decision-makers in the areas of combined energy system, and watershed and ecosystem management.

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Appendix A. Supplementary data

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Attachment 8

Pacific Northwest
NATIONAL LABORATORY

PNNL-SA-157672

Deployment of Energy Storage to Improve Environmental Outcomes of Hydropower

White Paper

May 2021

B Bellgraph, T Douville,
A Somani, K DeSomber,
R O'Neil, R Harnish,
J Lessick, D Bhatnagar,
J Alam

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Deployment of Energy Storage to Improve Environmental Outcomes of Hydropower

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Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Summary

Hydropower operators have many reasons to integrate energy storage, either co-located onsite or located elsewhere, but co-optimized with facility operations. Storage systems can be configured to have complementary performance profiles to hydropower projects, opening a broad spectrum of operational patterns.

Integrating energy storage can allow hydropower operators to accomplish the following:

- Capture additional revenue by using more agile operational characteristics for fast-response ancillary services or by generating greater amounts of peak energy with expanded operational limits.
- Adapt to changing regulatory and market conditions, such as evolution of the Energy Imbalance Market in the western United States, without pushing equipment beyond design parameters or optimal hydraulic performance.
- Improve asset management conditions by minimizing equipment wear and tear using energy storage to support fast-response ancillary services or support demands beyond optimally efficient setpoints.

An important but unexamined opportunity is to integrate energy storage systems with hydropower facilities to improve environmental outcomes. Integrated operations support increased flexibility in the management of the underlying water system and the associated ecosystem. The connections are particularly clear in modifying power generation relative to water storage, release, and flow regimes. Such integrated operations support regulatory requirements, including maintaining upstream reservoir levels, ensuring adequate downstream flows to meet an ecological target, or for human uses of a river such as fishing or boating.

This document provides an organized discussion of the relationship between hydropower-storage integration and improved localized environmental outcomes. Which includes:

- An overview and survey of current uses of energy storage in the hydropower industry.
- A comprehensive framework describing the range and type of potential localized environmental benefits realized through integrating energy storage and hydropower.
- Case study examples comparing real conditions with environmental requirements.
- Methodological guidance to analyze potential benefits, technology characteristics, and tradeoffs.
- A discussion of co-optimizing versus co-locating storage within the facility footprint.
- A concluding summary of the steps necessary for industry to fully develop and implement this concept.

This paper is a fundamental exploration of local environmental outcomes that can be realized through integration of energy storage systems with hydropower facilities. It provides a methodological foundation for future analysis rooted in expert knowledge of both hydropower–environmental interactions and attributes of energy storage technologies.

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1.0 Problem Overview

Hydroelectric dams have been operating in the United States (U.S.) for more than 100 years, and throughout this time, the range of potential environmental effects from hydroelectric dams has become well-established. As part of the periodic authorization or review of these dams, environmental effects are studied, evaluated, and in some cases mitigated. Mitigation may require investing in habitat restoration, improving river connectivity for migratory species, monitoring water quality, engaging the public, developing and implementing new technologies (hardware or software), and directly adjusting dam operations.

As dam operators balance the management of environmental impacts with maintenance of their electricity resource, new storage technologies may help to meet both needs. Most federally operated hydropower projects, as well as those operating under licenses granted by the Federal Energy Regulatory Commission (FERC), have limits on their operations to reduce environmental impacts. These limitations include spilling water outside of generating turbines, or managing flow on daily, seasonal, or yearly time scales balanced around the needs of fish and other aquatic species, reservoir levels, or downstream ecological needs. These flow management practices affect the economic viability of a given hydroelectric project by limiting its full operational flexibility. Additionally, the increase in renewable energy production has challenged the contribution of hydropower to the grid, and maintaining environmental flows mandated by FERC license requirements will become increasingly challenging (Kern et al. 2014). As storage technologies advance and become commercially available at utility-grade, grid-scale, and cost-effective levels there is a new opportunity to imagine how they can integrate with hydroelectric operations to support the larger electrical grid, while maintaining financial stability and improving environmental outcomes.

This paper describes how the installation of energy storage systems, co-sited with hydroelectric projects, offer operational, economic, and environmental benefits by enabling a broader range of electricity performance, capitalizing on its flexibility and grid reliability, while mitigating critical environmental impacts or improving environmental outcomes across U.S. rivers and streams. The paper attempts to link environmental outcomes to energy storage utilization. It offers a comprehensive inventory of research-grade work, site-specific studies, policies, and pilot projects regarding energy storage and hydropower that show significant environmental implications. It provides an outline of methodologies given the known costs and attributes of storage technologies, with case study illustrations. It also outlines the key components of a methodology that could be applied within the context of specific projects to reveal the environmental benefits of energy storage paired with hydropower production to properly size the storage systems to capitalize on potential benefits.

This paper provides a framework for assessing the degree to which energy storage can support operational strategies to improve environmental objectives, including where flow releases or other operational changes are provided to match a water quality, fish, or other ecological objective. Factors driving the integration of hydropower and energy storage will be site-specific, and include combinations of operational, maintenance, economic, and environmental considerations. The focus of this paper will strongly support the validity of the environmental approach. A set of knowledge gaps to be addressed in future work is provided. To validate and support the information provided in this paper, further analysis will be required on a physical facility to serve as a test case.

2.0 Current Use of Energy Storage by the Hydropower Industry

Hydroelectric plants currently offer energy storage due to the presence of water reservoirs, but to increase storage, operators have at times considered batteries to be a competitive resource. Energy storage could be accomplished by expanding the impoundment and raising the height of a dam; however, raising dam height introduces a host of civil engineering requirements, costs, and timelines, as well as regulatory authorizations, and doing so would inundate new lands. Despite these challenges, dam-raising efforts are being considered.[1] In contrast, energy storage systems can be installed in as little as 6 months, when physical space, electrical infrastructure, and construction permits are readily available (Pyper 2017). Larger reservoirs offer similar characteristics of storage that are already available; energy storage systems can offer a complementary capability rather than an expansion of existing flexibility.

As batteries become more reliable and efficient, an emerging idea is to directly integrate batteries with hydroelectric plants and hybridize their operations for overall improved plant performance. To date this idea has been explored for power flexibility benefits or market participation eligibility, such as provision of ancillary services, market eligibility as a fast-responding resource, or improved operational integration across cascading plants. Many energy storage systems are sited at utility infrastructure based on reliability, or distribution or transmission requirements. The appropriateness of whether to co-site or to co-optimize storage systems with hydroelectric plants, given ownership model, revenue mechanism, and grid operation conditions, is discussed in a later section.

Examples of power flexibility achieved by incorporating different types of storage on-site at hydroelectric plants, either simulated or actual, are provided below.

- In Sweden, Fortum has connected a 5 MW battery system to a 44 MW hydropower plant to improve its quick response time and the precision of its regulation service, because wind power has created the need for increased flexibility. The site has also asserted that the battery helps to keep the market in balance and reduces wear on hydropower turbines, allowing for deferral of investment in maintenance or replacement (Hydro Review 2018).
- The Buck and Bullesby power plants owned by AEP in southwestern Virginia have installed a 4 MW battery system. The system is used to reduce peaking in the older hydropower plants and increase the value of frequency regulation in the PJM market. This allows AEP to leverage and enhance revenue by providing regulation services and offset the charges that customers incur.
- Idaho Falls Power has also implemented a black start field demonstration to show that run-of-river hydropower plants with energy storage can restore electric power without assistance from the transmission system. This capability is essential for small hydropower facilities to be able to operate a microgrid to power critical loads in the event of an outage.[2]

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[1] San Vincente Dam in San Diego was raised more than 100 ft in 2012. See https://www.water-technology.net/projects/san-vicente-dam-raise-san-diego-california-us/. The Bureau of Reclamation intends to raise Shasta Dam in California by 18.5 ft. The project is currently in pre-construction. See https://www.usbr.gov/mp/ncao/shasta-enlargement.html.

[2] See the "Integrated" project, which explores the energy benefits to hydropower when paired with energy storage technology: https://factsheets.inl.gov/FactSheets/Integrating%20Hydropower.pdf.

- Other examples include the Cordova Electric Cooperative 1 MW battery and Kodiak Electric Association's 3 MW batteries. Both sites coordinate battery operations with small-scale hydropower to support small grids in Alaska. In Cordova, the battery system is designed to support a microgrid in the event of an outage due to harsh weather and avoid spill during dynamic seasonal loads. Kodiak aims to achieve reliability from an increase in the use of wind generation to support their microgrid, while reducing rates for customers with their two-battery system.
- Douglas County Public Utility District announced their intention to construct a 5 MW hydrogen electrolysis pilot project at its Wells Dam on the Columbia River (Shumkov 2020).
- In January 2020, Brookfield Renewable proposed an energy storage project at two of their hydro facilities along the Penobscot River—the Penobscot Mills and Ripogenus projects. Each project consists of a 10 MW, 20 MWh on-site system, which would be permitted under existing interconnection agreements. The batteries would allow the continued operation of the hydroelectric facilities during periods of high congestion and would have no impact on the operation or maintenance of the projects.[1]

It is clear from the examples above and the direction of the international industry that operational flexibility and asset management are the driving factors for hybridization of storage and hydroelectric plants. Even emerging "clean peak" policies such as Massachusetts' new Clean Peak Standard require hybridization of storage on clean energy projects to qualify for special treatment and remuneration, based on the premise that this additional flexibility is necessary to meet reliable system operations and clean energy goals.[2] [3] Additional power benefits for energy storage installations are yet to be analyzed, to the authors' knowledge. For example, storage systems could replace end-of-life small hydropower turbines to support station service at large plants.

3.0 A Novel Energy Storage Use Case: Environmental Benefits

This white paper posits that an additional class of benefits is derived from co-siting storage systems with hydroelectric plants—environmental benefits. As noted above, storage can improve the range of operational flexibility. Regardless of the primary investment driver, local environmental management is an essential part of the operational equation. Once hydropower plant operators install storage systems, the projects may operate differently to manage environmental constraints. Whether optimization occurs as an investment, regulatory, or planning tool, or after the fact as a new operational regime implemented from storage-integrated operations, improved environmental outcomes are possible with the installation of expanded on-site storage. New techniques such as advancements in multi-objective optimization of hydropower funded by the National Science Foundation (Roy et al. 2018) and

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[1] FERC Project No. 2458-214 – Penobscot Mills Project, Great Lakes Hydro, LLC; FERC Project No. 2572 – Ripogenus Project, Great Lakes Hydro, LLC.

[2] Arizona, California, North Carolina, and New York have explored clean peak standards without success in implementation. Michigan has explored a "low-cost peak program," which would require renewable energy generation to be paired with energy storage.

[3] See the Low Impact Hydropower Institute's webinar with experts discussing how this standard may affect operational and economic outcomes for hydropower plants: https://lowimpacthydro.org/massachusetts-clean-peak-standard/.

data-rich demonstrations are needed to fully evaluate the flexibility and environmental opportunities.

The nexus between environmental objectives and operational flexibility is well-established, and research continues to define these relationships.[1] A short list of operational changes to improve environmental outcomes, depending on site-specific operational and structural configurations, includes discharge ramping rates, minimum flows, reservoir levels, downstream and upstream temperature, dissolved gases (too much or too little), turbine loading patterns, as well as recreational management, boating flows, fish passage, flood control, irrigation, and other uses of the river. How could batteries or comparable energy storage technologies permit a win-win opportunity—operational flexibility and environmental improvements?

Examples of direct advocacy for energy storage installation for environmental outcomes, under discussion in two open FERC proceedings exist, as indicated in the case studies highlighted below.

3.1 Case Study: Connecticut River Conservancy and Great River Hydro's Vernon Dam (White et al. 2020)

The Connecticut River Conservancy contracted a study with Synapse Energy Economics in February 2020 to analyze the potential for the Vernon Dam hydroelectric plant (P-1904), owned by Great River Hydro, to be re-operated in a run-of-river mode and paired with a 10 MW, 2 hr battery storage system. The researchers aimed to determine the energy market revenue impacts of transitioning Vernon Dam to run-of-river operations while quantifying the value of installing an integrated battery storage system to capture a portion of peak energy prices.

The researchers found that a transition to run-of-river operations would moderately affect energy market revenues by 3 to 10 percent, while the other revenue streams (capacity, ancillary services, and renewable energy credits) would have little to no impact. It may be necessary, however, to relax true run-of-river operations during peak-load hours to maintain capacity values (and thus capacity revenues). Energy price arbitrage can be leveraged by charging batteries from turbines during periods of low energy prices and discharging power during periods of high energy prices. As New England increases its renewable energy levels, price volatility may increase, increasing the value of energy arbitrage. The cost range of the 10 MW proposed storage system was determined to be $4.9 to $9.8 million—a cost-effective investment at the lower end of the range, but a loss at the higher end.

With five hydropower plants along the Connecticut River in Massachusetts, New Hampshire, and Vermont applying for new licenses, this case study illustrates the potential for battery storage to offset revenues if peak operating plants convert to run-of-river operations. The results of this case study have been provided to the applicants for their consideration and submitted to the FERC docket as an alternative scenario opportunity.

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[1] See U.S. DOE HydroWIRES grant to the Electric Power Research Institute to *Quantify Hydropower Capabilities for Operational Flexibility*: https://www.energy.gov/articles/doe-announces-249-million-funding-selections-advance-hydropower-and-water-technologies

3.2 Case Study: Alabama Rivers Alliance and Alabama Power's Harris Project[1]

One emerging case study with a goal of reducing hydropower peaking to reduce the impact of unnatural flows on the Tallapoosa River's ecosystem may begin to explain the potential environmental benefits of adding a battery and allowing greater flexibility to meet electrical demand. In June 2020, Alabama Rivers Alliance advocated for Alabama Power to conduct studies of downstream release alternatives and battery storage integration at the Harris Project (FERC #P-2628) on the Tallapoosa River. Current operations include discharge variations, occurring within a few hours' time, from zero to about 16,000 cubic feet per second (cfs) when both turbines are operating. FERC proceedings regarding downstream release alternatives included comments from FERC staff, Alabama Rivers Alliance, and the U.S. Environmental Protection Agency, each recommending specific study scenarios. Alabama Rivers Alliance requested a study to compare models simulating the release of the natural flow variability of the Tallapoosa River compared to several alternative operations scenarios. Simulation of "natural flows" will ultimately not occur, but the alternative scenarios to be studied will include (1) the current operation plan ("Green Plan," designed to reduce effects from peaking operations on the aquatic community), (2) the project's historical peaking operation, (3) a modified current operation plan, (4) a downstream continuous minimum flow of 150 cfs under the historical peaking operation scenario, and (5) six other operations scenarios including minimum flows of 300, 600, and 800 cfs; a derivation of the "Green Plan;" and two other scenarios resulting from an addition of a battery energy system.

Alabama Rivers Alliance requested that a new study be conducted by Alabama Power titled "Battery Storage Feasibility Study to Retain Full Peaking Capabilities While Mitigating Hydropeaking Impacts." This study would determine whether a battery storage system could be economically integrated at the Harris Project to provide power during peak demand periods—decreasing the need for peak generation flow released and reducing flow fluctuations downstream—by evaluating battery type, size, costs, ownership options, and barriers to implementation. In their response, FERC described the potential benefits of adding a battery energy system to include reducing the fluctuations in the reservoir by half, reducing peak flows from 16,000 to 8,000 cfs, and achieving the ability to release flows throughout the day and night versus only during peak demand hours. Alabama Power initially rejected the study, citing the high costs of battery storage systems and turbines that are not designed to operate gradually over an extended period. Using a 2018 National Renewable Energy Laboratory report (DOE 2018), Alabama Power estimated the cost of a 60 MW, 1 hr battery (the equivalent to power one turbine at the site) to be $36 million, with a combined cost for both turbines of $72 million. FERC further noted that a 4 hr 60 MW battery, costing $91 million may be needed because Harris Dam can generate for up to 4 hr. FERC recommended that the company conduct the battery storage feasibility study to include (1) a 50 percent reduction in peak releases associated with installing one 60 MW battery unit, and (2) a smaller reduction in peak releases associated with installing a smaller MW battery unit (i.e., 5, 10, 20 MW), including cost estimates. The study will be conducted through April 2021 and will be used to assess the project impacts on downstream resources including aquatic species, erosion, water quality, terrestrial resources, and recreation.

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[1] Project No. 2628-065 – Alabama R.L Harris Hydroelectric Project, Alabama Power Company.

4.0 Environmental Benefits Associated with Increased Operational Flexibility

An initial framework of relationships between storage and environmental outcomes is provided in Table 1. Although the issue categories in the table are not mutually exclusive, they begin to elucidate the potential environmental improvements that pairing energy storage with hydropower may provide. Future work would further characterize these examples and conduct a more thorough review of potential environmental gains derived from augmenting hydropower with energy storage technologies.

Adding a storage system to a facility would allow owners flexibility in generation, by breaking the tie between river flows and fluctuating power demands. Site-specific conditions, location, and regulations will dictate the magnitude and type of environmental outcome that may be realized. Table 1 discusses the potential improvements and is not intended to be all-inclusive, nor are all benefits applicable to every unique case.

Table 1. Taxonomy of potential environmental benefits from pairing hydropower with energy storage.

Issue Category	Desired Positive Environmental Outcome	Change in Operation with Energy Storage	Knowledge Gaps
Fisheries	Release flows that are more similar to the historic hydrograph (e.g., run-of-river) that includes cues used by fish for spawning, rearing, migration, etc.; reduce fish-stranding mortality.	Maintain operations and absorption of energy to permit a higher (or lower) release of flows.	Characterize the duration and intensity of flows and turbine operations/energy generation in relation to fish behavioral cues and survival relationships.
	Allow historical seasonal peak flows to enable fish spawning.	Reduce wear-and-tear on components through steady operation during fluctuating generation and release requirements.	Determine sizing and controls between energy storage and turbine units to integrate operations.
	Foster safe passage through hydropower infrastructure.	Allow spill for downstream passage to maintain the same electricity production; offset efficiency losses from fish screens.	Optimize storage capacity, state-of-charge, duration, degradation, and efficiency.
Water Quality	Reduce supersaturated total dissolved gas (TDG) levels.	Support more advantageous release schedules and reservoir management, absorption of energy if released through turbines under oversupply conditions.	Potentially improve TDG throughout a cascading hydropower system with new operations and energy storage flexibility?

Issue Category	Desired Positive Environmental Outcome	Change in Operation with Energy Storage	Knowledge Gaps
	Optimize dissolved oxygen.	Allow oxygen injection to be combined with turbine operation and releases through absorption of energy or support more advantageous release schedules.	Potentially improve dissolved oxygen with new operations and storage flexibility?
	Allow for improved temperature regimes.	Enable temperature control via locally powered reservoir control structure to manage downstream temperatures where seasonally stratified reservoirs are present.	Explore added flexibility of batteries and hydro operations to control temperature.
	Reduce unwanted nitrogen/phosphorous contributions to algal blooms.	Use energy storage system to allow spill variation in reservoir levels; local energy could be used for removing nutrients from water.	Understand the impacts of alternative operations on the ability to control nutrient levels.
Flows	Reduce intensity of peaking flows and up and/or down ramping rates.	Charge energy device in advance of peak flows to increase the responsiveness of the project to signal and shave flow releases to lower ramp rates.	Measurably improve environmental resources through changes in intensity and ramping that are possible with storage integration?
	Maintain minimum flows (varied by season or otherwise as specified).	Permit cost-effective decrement in flows and generation with releases not timed to match electricity demand.	Acquire new environmental benefits when minimum flows are more easily obtained as well as make valuation possible to allow new environmental markets?
	Enable bypass reach flows.	Allow maintenance of revenues during flow releases in the bypass.	Support releases for non-power flows?

4.1 Reducing Hydro Peaking

Hydropeaking and load following operation modes, whereby pulses of water are released in rapid response to meet changes in electrical demand, can alter the quantity, quality, and accessibility of downstream aquatic habitats (Clarke et al. 2008; Fisk et al. 2013). Depending on their timing, frequency, duration, and magnitude, discharge fluctuations can have adverse effects on stream fishes and other aquatic life (Young et al. 2011). Discharge fluctuations during the period of fish spawning may cause adult fish to abandon nests or alter spawning site selection (Chapman et al. 1986; Auer 1996; Zhong and Power 1996; Geist et al. 2008). Fluctuations in discharge that occur shortly after the spawning period can dewater nests, resulting in mortality of eggs and larval fish (Becker et al. 1982; McMichael et al. 2005; Fisk et al. 2013). Discharge fluctuations that occur during the early rearing stage can strand fish along changing channel margins or entrap them in isolated pockets of water (Cushman 1985; Halleraker et al. 2003; Connor and Pflug 2004; Nagrodski et al. 2012). Repeated, rapid fluctuations in discharge may also negatively affect downstream fishes indirectly by altering the density, biomass, and diversity of their food supply (Cushman 1985; Gislason 1985; Bunn and Arthington 2002), which can reduce fish growth as well as the biological productivity of the ecosystem. Reductions in spawning success, survival, and growth have the potential to reduce the productivity of populations that reside downstream of hydroelectric projects (Harnish et al. 2014).

Co-sited energy storage may enable a hydropower facility to meet system peaking needs, provided that state-of-charge control is aligned with the peaks, without releasing such significant water volumes downriver. Thus, energy storage systems would decrease peak generation flow releases, thereby reducing flow fluctuations downstream of the hydroelectric project—and ultimately, lowering the potential impacts on threatened fish and other organisms using the river habitat. Response times are also much faster when using batteries and power factors of 0.0 are supported, so more than just maintained but *improved* power system benefits (i.e., energy and ancillary services) may be achievable along with environmental improvements.

4.2 Securing Safe Fish Passage through Hydro Infrastructure

In addition to fish populations experiencing the effects of hydropower operations downstream of dams, fish migrating in a downstream direction may sustain injury or death while passing hydroelectric dams. At many hydroelectric dams, downstream migrants can pass via several different routes (e.g., spillways, turbines); however, passage through turbines is generally associated with the highest mortality rate (Muir et al. 2001). At some hydroelectric projects, operations have been altered to deliberately release water through spillways to direct downstream migrants from the turbines to the spillway to increase dam passage survival. Many species display differences in depth distribution and/or migratory activity throughout the daily cycle, which can alter their probability of turbine or spillway passage (Haro et al. 2000; Li et al. 2015). Therefore, energy storage systems, instead of the hydropower turbine, could be used to provide power when needed, allowing more water to be spilled during periods of peak fish passage or times when turbine passage rates are expected to be high. For example, salmon and steelhead smolts are more likely to pass through the powerhouses of Snake River dams at night than during the day due to a diel shift in depth distribution. Approximately 60 MW of stored power exported for 4 hr nightly could reduce powerhouse passage of Snake River Chinook salmon smolts by 12 to 23 percent over the entire summer passage season, thereby increasing survival significantly. Added flexibility of spill operations, and in turn, improved fish survival, may help hydropower operators further improve fish survival and reduce mitigation costs (e.g., mid-Columbia River No-Net-Impact funds).

Fish passage is not limited to spillways or downstream travel. Spill for upstream migration (i.e., fish ladders) can account for 10 percent of the flow rate, resulting in lost power generation potential. Noting that attraction flows to fish ladders need not spill constantly, the seasonality and perhaps even time of day of fish migration activity can allow for banking of energy benefits through energy storage, which can then be exported when spills do need to flow in correlation with fish activity.

A facility may also operate under specific flow rates for fish spawning benefits, which may require spilling water that cannot be used to generate electricity and may lower the annual energy production of a hydropower facility. However, just as spawning does not happen through all seasons and at all hours of the day, water can be released when needed for environmental benefit and the restriction may be relaxed at other times, thereby allowing a net energy production increase. When the timing of energy increases does not align with power system needs, there is an opportunity for energy storage systems to shift the available energy and make use of the surplus.

4.3 Operational Shifts and Requirements for Fish in the Eastern U.S.

In addition to operational shifts and flow management for western U.S. fish (in particular salmon) as indicated above, eastern U.S. hydropower plants also adjust operations for fisheries including resident, anadromous (e.g., American shad), and catadromous (e.g., American eel) fish. We discuss examples below related to fish specifically, because fish are often the driving factor of dam operational changes; however, we understand that many other aquatic species (e.g., mussels) as well as aquatic ecosystem health benefits are gained from these operational changes.

Operational shifts to ensure safe fish passage through hydropower plants is a precedented activity dating back to the early 1900s—particularly in the northeastern U.S., where migratory anadromous and catadromous fish use rivers highly developed with hydropower projects. For example:

- The Holtwood Hydroelectric Project on the Susquehanna River in Pennsylvania uses a tailrace lift with two entrances and a spillway lift for upstream fish passage and a pipe system for downstream fish passage.
- The York Haven Dam, also on the Susquehanna, uses a vertical slot fishway to support upstream passage of anadromous fish, primarily American Shad.
- In Maine, along the Penobscot River, the Milford Hydroelectric Project uses a 4 ft by 4 ft bottom entrance for American eels to pass through the dams slowed to 70 cfs into the plunge pool and an upstream fish lift capable of passing up to 300 cfs.
- The Orono Hydroelectric Project uses a similar system with an 8 ft wide downstream diadromous fish-passage floor screen chamber into the plunge pool and a lower-level 4 ft by 4 ft entrance designed to pass at 150 cfs.
- The Holyoke Dam, on the Connecticut River, uses two elevator fish lifts that carry migrating fish, including American Shad, Sea Lamprey, Atlantic Salmon, and American eel, up and over the dam.

In these cases, operational flows are altered to meet fish-passage needs. Storage augmentation at these facilities could allow increased flexibility to meet both the electrical demands of the grid as well as the site-specific fish-passage requirements.

4.4 Managing Spill for Habitat Benefit

Habitat benefits for the aquatic ecosystem as a whole may also extend to spill. Many river ecosystems rely on sediment that passes downstream in the absence of dams. Sandbars have been depleted by long-term dam presence, to the detriment of endangered species on the Colorado and Missouri Rivers. The Department of the Interior has shown success in rebuilding sandbars through controlled flood operations through the Glen Canyon Dam since 2012 (USGS 2015). Energy storage may enable a means for making up for some of the lost energy value associated with controlled flood events, or even increase their frequency to maximize the habitat benefit.

4.5 Preserving River Flows to Improve Water Temperature and Dissolved Gases

River water temperatures directly affect aquatic ecosystem health, and energy storage may allow more flexible operation to control downstream temperatures for environmental benefits. Extreme high temperatures, such as those that occurred in 2015 in the Columbia River, were associated with significant salmon and sturgeon fatalities;[1] in these situations, water temperatures may be able to be cooled by further operational flexibility at hydropower dams to release deeper and cooler hypolimnetic waters. Conversely, unnaturally cold water temperatures, such as in a dam tailrace when a thermally stratified reservoir releases the colder/deeper water through deep-draw turbines or spill, can also have detrimental effects such as creating unnatural temperatures that may allow, for example, an invasive species to increase predation on native warmwater fishes (Ward and Bonar 2003). To keep temperatures within acceptable ranges, the added operational flexibility that batteries paired with hydropower may provide could allow hydropower operators to be more selective about mixing upper warmer waters (using surface spillways) with deeper cooler waters (using deep-draw turbines or deep spill).

Similarly, oxygen and/or total dissolved gas (TDG) levels can be directly affected by hydropower operations to the detriment of fish and the larger ecosystem. For example, in the Coosa River in Alabama, low oxygen levels in tailrace waters are directly linked to operation of the turbines drawing low-oxygen water from deep water, which ultimately negatively affected ecosystem health and resulted in the operator’s FERC licenses being vacated.[2] High dissolved gas levels above 100 percent also have detrimental effects on aquatic organisms. Dissolved gas levels above 110 percent can cause fish to lose their ability to sense (hear) encroaching predators (Weber and Schiewe 1976), and increasing gas concentrations up to 130 percent result in high mortality of some species (Mesa et al. 2000). An energy storage device may provide additional flexibility for hydropower generators to adjust operations as a function of oxygen/TDG level, or to allow some degree of spill from a considerable elevation to restore oxygen content. Operations to control dissolved oxygen and/or TDGs occur throughout the U.S., but, to our knowledge, the ability of batteries to improve the environmental outcomes has not yet been evaluated.

5.0 Considerations for Studying Storage Applications for Environmental Outcomes

Given the potential benefits, what is the best approach to determining whether a storage device could allow for operational changes that offer environmental benefits at hydropower projects?

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[1] https://www.nwcouncil.org/news/warm-water-wreaks-havoc-columbia-river-fish

[2] https://www.gadsdentimes.com/news/20180827/alabama-power-loses-coosa-river-dam-licenses

This paper highlights key components of a *conceptual* methodology to evaluate potential environmental benefits of deploying storage systems in cooperation with hydropower facilities. The following example shows how the deployment of energy storage at a peaking hydropower facility can yield win-win outcomes, i.e., maintain the power generation requirement, while simultaneously allowing for less severe changes in water flows.

5.1 Conceptual Example to Illustrate How Storage May Be Used to Enhance Environmental Benefits for a Peaking Hydropower Plant

Figure 1 presents a stylized example of a utility that operates its hydropower plant to maximize generation during the morning and afternoon peaking periods. In this example, it is assumed that plant operations reach the upper limit of available water (ramp up in water flow – cubic feet per second per hour [cfs/hr]), which is required to ramp up power generation. With the addition of a storage system, plant operators can employ alternative operational strategies, in general charging the storage system when fuel (water) is available and operations are more flexible, and discharging electricity during peak hours or when operational and water (storage) limitations have been reached. Such a strategy could allow the hydropower plant to operate above normal operating levels during off-peak hours and operate at a lower level during peak periods. Water flow to support such an operational strategy would change as well (i.e., increase during off-peak periods and decrease during peak periods). The implied benefits of a less severe ramp up and ramp down of water would include less severe variations in tailwater elevations, and reduced time of running with water flows close to the maximum limit. Depending on the plant configuration and operating conditions, such an operational strategy might also enable coincident benefits, such as longer periods of operating the turbines near their peak efficiencies. It should be noted that the primary benefit associated with market-facing operations—either revenue capture or more efficient generation portfolio stack—is not adversely impacted, because the effective power supply is identical to the baseline.

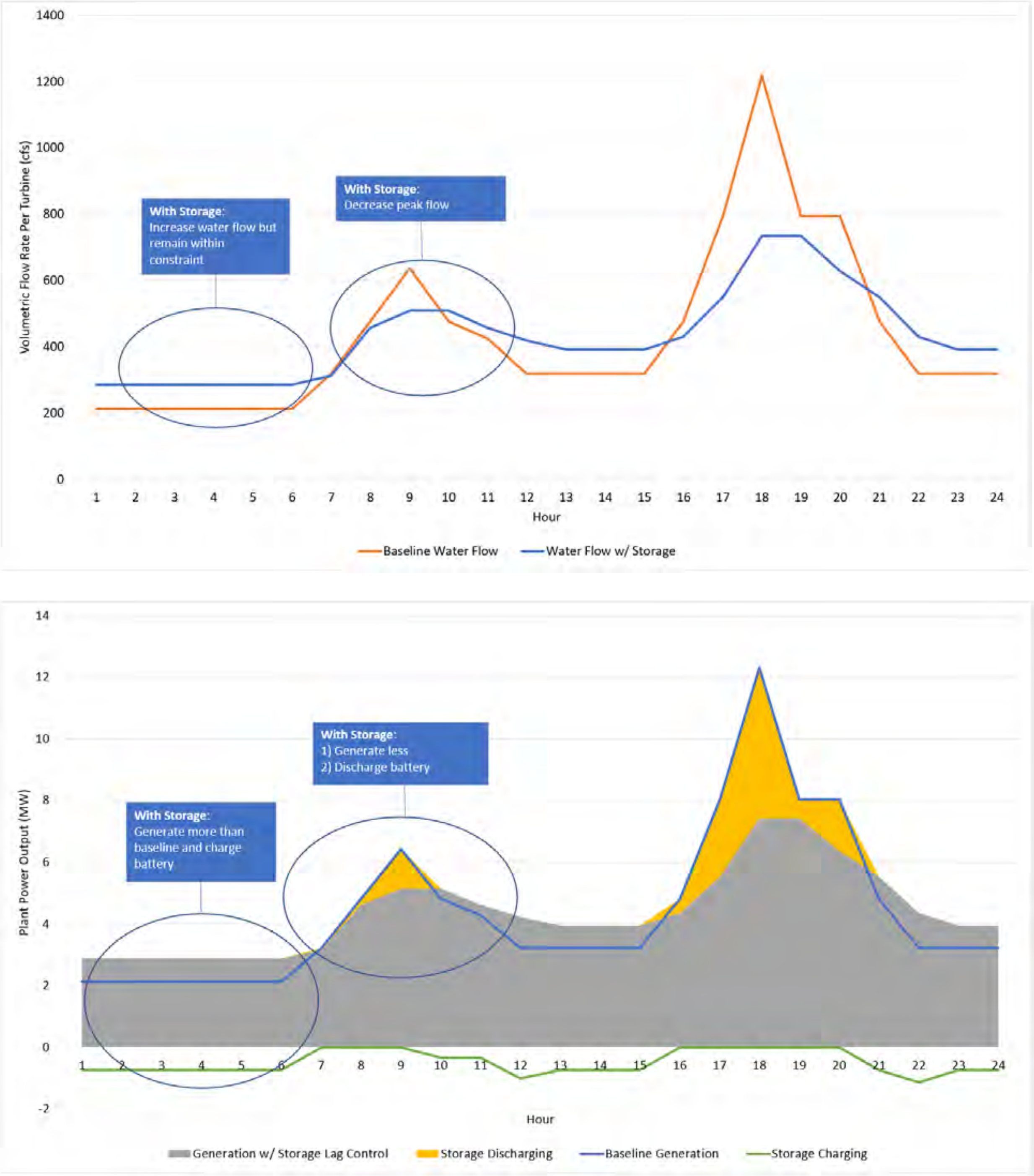

Figure 1. Conceptual example to illustrate alternative water flow regimes (top) and plant operations (bottom) based on deployment and use of energy storage technology.

5.2 General Process of Studying Storage Solutions for Environmental Outcomes

The hydropeaking example can be used to generalize the process one might use to study storage applications for environmental benefits. As highlighted in the example, the decision process requires an understanding of the relationship between environmental and power generation outcomes at a given location. Fundamentally, these outcomes are connected through water flow regimes at that location. Water flow regimes, characterized by min/max flow rates in units of cubic feet per second, daily fluctuations (cfs/24 hr), flow ramp rates (cfs/hr), and duration of sustained flows at increased or decreased levels, directly affect power generation possibilities at the location as well as the health of associated aquatic and riparian ecosystems. These regimes may need to be controlled in time, on hourly or seasonal bases, to balance positive environmental outcomes with power production. Any changes in water flow decisions, due to environmental or other objectives, will directly affect the power generation capabilities at that facility,[1] and hence, affect the choice of whether to install storage technology and if so what size. Figure 2 depicts the decision-making process that is encapsulated in the ensuing numbered steps.

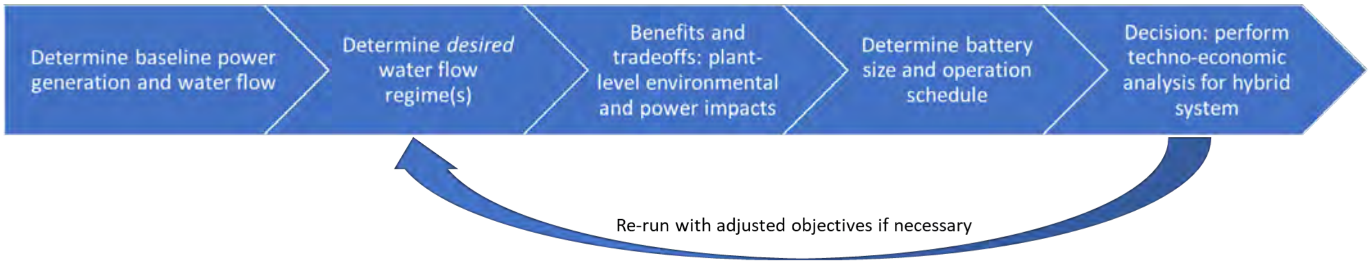

Figure 2. Energy storage sizing methodology.

1. Baseline: Ascertain the existing operational baseline regime (i.e., generation and water flow patterns at a given location) by considering baseload, load following, and peaking.
2. Determine desired water flow regime(s):
    a. Flexibility: Identify the operational flexibility, in both power generation and flow patterns, relative to the baseline operational regime.
    b. Alternatives: Identify the alternative set of water flow regimes that help enhance environmental outcomes at the location based on the flexibility assessment.
3. Benefits and tradeoffs: Assess the environmental benefits, changes in power generation outcomes and other tradeoffs, if any, due to the alternative flow regime(s) (e.g., hydropeaking can limit the opportunities for whitewater recreation).
4. Determine the energy storage size and operation schedule: Perform analysis to optimize energy storage size, including identifying a suitable location, and identify an operational schedule for the hybrid system.

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[1] A current, ongoing research project stewarded by the U.S. Department of Energy's Water Power Technology Office, called "HydroWIRES Topic A," will provide a comprehensive mapping of environmental objectives and power operations at a facility, which could be used to supplement the proposed methodology.

5. Decision: Perform techno-economic analysis to ascertain economic outcomes of the optimization.
6. Adjust objectives, if needed, and repeat Steps 2 through 6.

While knowledge of the baseline operational regime—generation and water flow profiles and the inherent flexibility therein—may be known, the identification of alternative flow regimes requires thorough understanding of local environmental needs. These needs will inform how and when hydropower operations must be restricted, and when they can be relaxed, to achieve desirable environmental outcomes.

5.3 Alternative Water Flow Regimes to Enable Environmental Benefits

In the hydropeaking example, a threshold analytical understanding of the relationship between flow rates, power outcomes, and environmental outcomes must first be established. Data related to water elevations in locations of potential fish spawning habitat, flow rates at various river locations, and correlations of these data with flow rates through hydropower facilities must be collected to determine more precisely where and when maximum flow rates should be reduced. Additional measurements will be needed in various locations within a specific river to understand the efficacy of specific restrictions on ramp rate and successive ramping events in attaining meaningful environmental benefits of hydropeaking reduction. These requirements reach beyond hydropeaking reduction; the same can be said for any environmental gain associated with modifications of hydropower operations. The changes in operations, such as minimum and maximum flow limits, etc., will require precise determination of enhanced environmental benefits.

Table 2 presents a *hypothetical* set of values for maximum flow rates, ramp rates, and successive ramps per day that (1) are standard in baseline operations, before hydropeaking avoidance, and (2) will be required to achieve the environmental benefits associated with eliminating or reducing hydropeaking. The additional restrictions on power operations that come with changes in the values of these constraints directly correlate with either reduced or increased power generation potential. In the case of hydropeaking reduction, maximum flows must be reduced within time periods spanning several hours. In the consideration of whether energy storage can yield environmental benefits while maintaining power benefits, it is equally important to know where and when power operations can exceed the baseline. Minimum flow rates at off-peak times serve to limit the ramps associated with hydropeaking as well as provide a means for additional power generation to charge the energy storage asset. In this way, the information pertaining to the new flow regime, as well as the trade-off in power generation timing and scale, can be used to approximate the size, type, and location of a useful energy storage technology application.

Dispatch of the energy storage asset to shave hydropeaking is conceptually demonstrated in Figure 1, which demonstrates how flows can be reduced while energy is exported from the storage asset to maintain power system benefits. In this way, energy storage dispatch is directly linked to benefits to downstream fish populations during various life stages, as described in Table 2. To provide greater precision, an optimization problem can be formulated that treats the new flow regimes as constraints to ascertain the appropriate size, location, and type of storage technology. Hydropeaking avoidance is just one conceptual example. Appendix A presents two tables that repeat this methodology for the potential benefits associated with spill for safe fish passage downstream and upstream, and water quality benefits.

Table 2. Operational shift requirements to enable environmental benefits of hydropeaking reduction (hypothetical metrics).

Operational Constraint	Baseline	Flows to Meet Environmental Objectives (limit impacts from hydropeaking)	Potential Benefit	What data are needed?
Spawning flow range (cfs)	No limit	2,500–5,000	Conducive to spawning activity for spawning fish. Species and river dependent.	Habitat use – including water elevation of spawning habitats and larval fish behavior and habitat use. Life stage phenology.
Minimum flow release (cfs)	1,000	1,500–2,600	Protect larval fish incubating in gravel or developing during larval drift phase.	
Downramp amplitude limit (cfs)	None	4,000	Limit fish from getting trapped in pools that are disconnected from the main channel.	
Maximum downramp rate (cfs/hr)	No limit	3,000	Limit fish from getting trapped in pools that are disconnected from the main channel.	
Daytime downramping	Allowed	Not allowed	Limit fish being trapped; site- and species-specific differences	

5.3.1 Case Study: Glen Canyon Dam

Prior to 1991, Glen Canyon Dam (GCD) operated under fewer environmental restrictions. Table 3 shows that power plant water releases could range from 1,000 cfs to 30,500 cfs, with no limit regarding the daily fluctuations or ramp rates. Such flexibility caused significant environmental damage, such as the endangered species listing of native fishes and changes in the overall ecosystem due to changes in downstream water temperatures and decreased sediment load. From August 1991 to January 1997, temporary restrictions called “Interim Flow Restrictions” were put in place before the release of a final environmental impact statement. Since 1997, the water release range has been reduced to a range from 5,000 to 25,000 cfs, and daily fluctuations and ramp rates have been limited. More recently, in January 2017, a new Record of Decision (ROD, DOI 2016) mandating the preferred alternative prescribed by the Long-Term Experimental and Management Plan has been adopted and was first implemented in October 2017.

Table 3. Evolution of Glen Canyon Dam operating constraints.

Operational Constraint	Historical Flows (before 1991)	1996 ROD Flows (from 1997 to 2017)	2016 ROD Flows (after 2017)
Minimum flows (cfs)	3,000 (summer) 1,000 (rest of year)	8,000 (7 a.m. - 7 p.m.) 5,000 (at night)	8,000 (7 a.m. - 7 p.m.) 5,000 (at night)
Maximum non-experimental flows (cfs)(a)	31,500	25,000	25,000
Daily fluctuations (cfs/24 hr)	28,500 (summer) 30,500 (rest of year)	5,000, 6,000, or 8,000 depending on release volume	Equal to 10 X monthly water release (in thousands of acre-feet) during June-August, and equal to 9 X monthly water release the rest of the year, but never exceeding 8,000 cfs
Ramp rate (cfs/hr)	Unrestricted	4,000 up 1,500 down	4,000 up 2,500 down

(a) Except during experimental releases.

Because water flow rate and power are closely related, peaking capability at GCD has been also significantly reduced (Figure 3). Power generation is dependent on available head and flowrates. Before the environmental restrictions, during the week from July 19 to July 25, 1987, GCD was able to produce a peak power of 1,164 MW, that is, 89 percent of the potential peaking capacity of this period. After the 1996 ROD, during the same week of year 2015, this peak generation dropped to 746 MW, that is, only 68 percent of its potential available capacity. The limitation on the peak capacity is due to the maximum daily fluctuations imposed above.

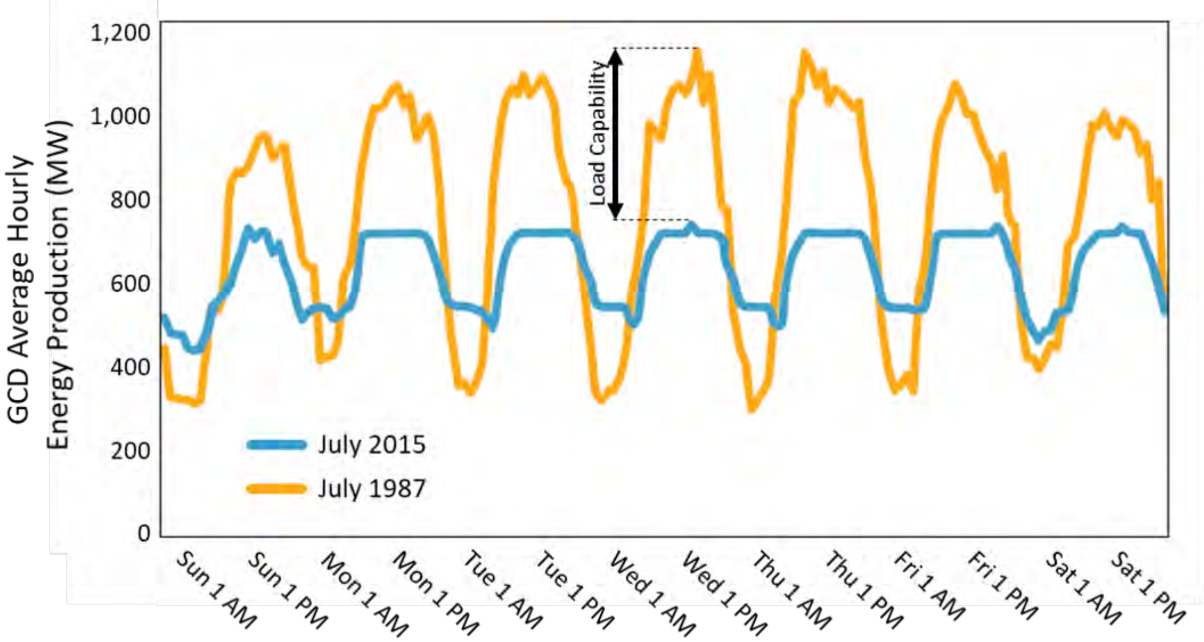

Figure 3. Hourly energy production at the GCD powerplant during a July week in 1987 and 2015.

5.3.2 Case Study: GCD Potential Improvements

The GCD case illustrates the potential benefits of implementing energy storage to improve environmental outcomes. Though the peaks vary significantly due to flow restrictions, the overall power generated relative to potential available power during the case periods is quite similar. Potential available power considers differences in head and assumes the maximum flowrate of 31,500 cfs can be achieved at the differing heads. If 31,500 cfs cannot be achieved during the lower head period of 2015, the convergence is increased. The July 1987 flow data generated at approximately 58 percent of the potential available power, whereas the July 2015 performance is approximately 54 percent of the potential available power. The convergence of these values is due to minimum flows being required during the night for 2015, increasing the generation over this period.

The imposed flow requirements resulting in night generation occur during a period of low demand. Increased power demands begin in the morning, taper through the day, then peak in the evening. Demand drops significantly at night. Implementing an energy storage system to capture the generation at night and discharge during the day would allow the average hourly energy productions from the environmentally restricted 2015 period to behave similarly to the less regulated 1987 period.

5.4 Process of Deciding the Storage Size, Type, and Location

Industry,[1] academia, and national labs have developed several tools and methodologies to assist with the sizing of energy storage for site-specific installations. Most of these tools and methodologies (Wu et al. 2017) focus primarily on maximizing revenues or cost-savings from power operations, either for the stand-alone storage technology or for a hybrid solution, such as a traditional solar or wind facility with the integrated addition of a storage system. To the best of our knowledge, currently there are no tools and methodologies that can assist with making decisions about the sizing of storage technologies for environmental benefits. However, existing methodologies can be adapted for this purpose. All that the methodologies require is a sufficiently precise characterization of the technical attributes of the resource being analyzed—whether a stand-alone storage system or a hybrid solution—and its intended functions. In the case of energy storage for environmental benefits, the technical characteristics of a hybrid hydropower resource with integrated storage will likely be based on the flow regimes, both baseline and alternative ones.

The changes in flow regimes may be required for a variety of reasons:

- FERC licensing or relicensing process, where the federal authorization for the facility requires a new flow regime or alternate water budget, such as maintaining upstream reservoir levels, or flow requirements to meet a downstream objective including human uses such as fishing or boating;
- operational strategies for asset management purposes, where the facility must adjust the hydraulic capacity of the system in order to maintain useful equipment life;
- new market opportunities, such as a change in the price of ancillary services, or changes in underlying regulatory and policy constructs, and market designs; and

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[1] Det Norske Vitas (DNV)-GL's ES-Select tool compares energy storage technologies for different use cases; Pason Power Inc., and Energy Toolbase LLC., have designed a tool called Energy Toolbase to assist with sizing and controlling residential solar PV plus battery systems.

- mitigation of environmental issues, where water flows must be adjusted ~~provided~~ to match a water quality, fish, or other ecological objective.

In all but the last case, environmental benefits are not likely to be the primary drivers when making decisions about deploying an energy storage technology. Even so, the deployment of energy storage, whether for operational flexibility or asset management, will provide options for alternative operating practices and, by extension, alternative water flow regimes. The choice of storage technology in such cases will need to consider the appropriate combination of power generation and environmental outcomes, weighed against the cost of the storage technology itself. This process could be designed as a multi-objective optimization problem consisting of an appropriately weighted combination of objectives—(maximize) power generation responsiveness, operating limit, and flexibility, (minimize) asset management costs, (maximize) environmental compliance, and (minimize) technology costs. This process, essentially, uses a range of water flow regimes to construct the *pareto frontier* to analyze tradeoffs between different objectives.

Alternatively, one or more of the objectives may be treated as constraints in the design process. For instance, to avoid lost generation opportunity and attributes in the hydropeaking example, the baseline generation profile may be treated as a fixed requirement that the combination of storage and hydropower generation (with altered flow regime) must attain. Hence, the first step in the decision-making process is to determine the attributes of lost generation capacity—energy and power ranges, ramp rates, and so forth. The required set of attributes will help determine the choice of energy storage technologies. The next step in the process is to conduct techno-economic analyses based on understanding and knowledge of market conditions, water availability, and other critical considerations. The techno-economic analysis can be based on detailed time-series simulations and optimization of the hybrid resource, modeling its operations and dispatch in an actual market. Pacific Northwest National Laboratory's (PNNL's) energy storage evaluation tool (ESET), for instance, has been used extensively to create a sizing space for storage, based on known or assumed use cases (such as hydropeaking), deterministic or stochastic information on market conditions (prices, demand, and so forth), and storage technology specific considerations.

5.4.1 Storage Sizing Methodology for Maximizing Revenue of a Storage Hybrid System

The ESET tool formulates a linear programming problem to maximize the annual economic benefits of the energy storage or hybrid system. In this case, the benefits would include any identified hydropower use cases as well as any other market services that could be provided. The tool co-optimizes identified services to be provided subject to energy storage power and energy constraints, state-of-charge dynamics, and the coupling of different use cases. The ESET formulation dispatches the system on an hourly basis, first formulating a look-ahead optimization to determine a system operating point, and then dispatching the system on an hourly (or more granular) basis, to determine the number of hours the system would be actively engaged in the provision of each service. In addition, a storage system cost formulation can be added to the objective function to optimally size the storage system within the model. This cost formulation includes the equivalent system capital cost as a function of power and energy, which consists of investment, installation, and operations and maintenance costs for the storage device and associated inverter. The optimal sizing approach maximizes investment return for a given time frame. ESET then provides the maximized benefit, optimal size, and dispatch for the system under the given use cases and subject to the other variables (Wu et al. 2016). A *Monte Carlo type* analysis can then be conducted, varying one or more input variables of the formulation, including use case requirements, market prices, and storage technology types and costs, to generate a decision space. Within this space, present-value benefits and costs can be calculated to find optimal energy storage parameters that return the largest net-benefit.

The following sequence of steps presents a simplified version of the methodology:

1. Determine initial energy storage size.
2. Maximize revenue from hybrid plant operations subject to:
    - Plant electro-mechanical constraints,
    - Energy storage capacity limits.
3. Adjust energy storage size and re-initiate Step 2.

Figure 4 below, borrowed from Wu et al. (2016), presents an example decision space generated by the ESET tool across energy storage capacity and energy for different locations (i.e., San Francisco [SF], Chicago [CHI], Houston [HOU], and New York City [NYC]) and technology price points (i.e., high, medium, and low).

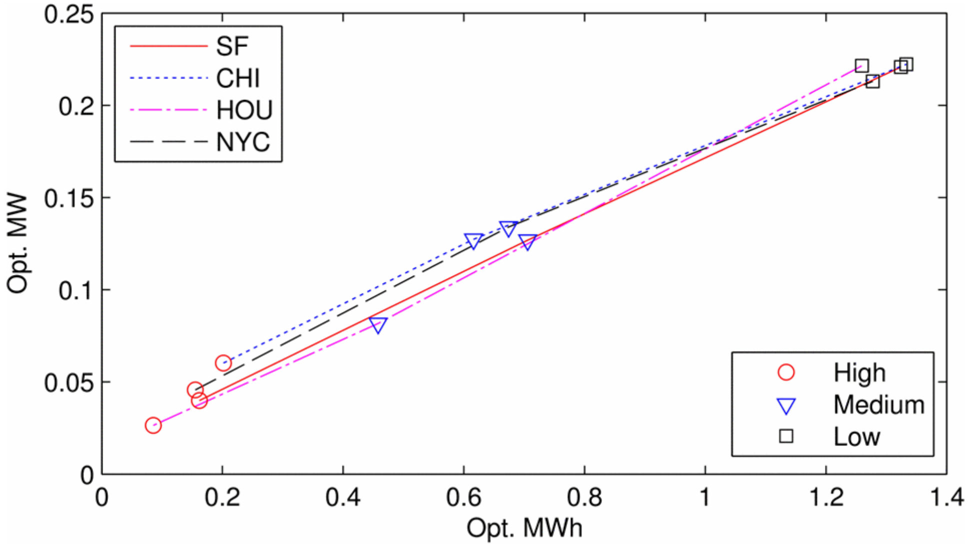

Figure 4. Optimal (Opt.) energy and power capacity in different battery cost scenarios and energy markets (San Francisco [SF], Chicago [CHI], Houston [HOU], New York City [NYC]).

Such tools and methodologies can be extended to study the suitability of different storage technologies for environmental benefits. The above methodology can be adapted to include desired environmental outcomes as additional constraints in the optimization problem. For instance,

1. Determine initial energy storage size.
2. Maximize revenue from hybrid plant operations subject to
    - Plant electro-mechanical constraints,
    - Energy storage capacity limits,
    - Environmental objectives:

   - Flow >= Min flow limit
   - Flow <= Max flow limit.
3. Adjust energy storage size and/or environmental objectives and rerun Step 2.

The min and max flow limits are derived from alternative flow regimes that correspond to desired environmental outcomes. In this way, the sensitivity of energy storage sizing relative to desired environmental outcomes can be determined by adjusting the water flow constraints.

6.0 Co-optimization vs. Co-location of Storage

There is a useful distinction here for when a storage system should be directly interconnected and integrated with a hydropower facility ("co-location") and when it should be operated in a coordinated fashion ("co-optimization"). Generating resources are already coordinated to operate as a portfolio, to serve load, to transmit energy, to balance control boundaries. Advanced control and communication can allow networked operation of electricity system assets across multiple systems. So, when does it make sense to site a storage system within a hydropower facility footprint? This section explores the contextual conditions that lean toward co-location or co-optimization of storage and hydropower assets.

6.1.1 Why Co-optimize?

Hydropower plants operate within a system context and their operation is coordinated with other resources to assure that load and generation are matched. In vertically integrated utilities or system-level coordination, the power tradeoffs for managing environmental objectives may be most cost-effectively dealt with by adjusting the merit order or dispatch of other plants, rather than co-siting storage at a specific project. For example, if a hydropower plant is limited in how fast it may ramp flows up and down, then the faster ramping requirement could be replaced by a gas unit or by other ramping resources already available elsewhere in the system.

For utility-owned plants, operating in organized markets, there may be locational considerations for siting energy storage systems based on geographical patterns of energy and ancillary service prices. One technique for identifying optimal siting of storage systems is to run a system-wide analysis using production cost models. These models enable co-optimization of the entire fleet of resources under a utility's ownership, with explicit consideration of certain locational aspects of its resources.

6.1.2 Why Co-locate?

Co-location of storage at the hydropower plant may allow additional local benefits. To achieve these locational benefits, utility-owned projects may be motivated to enhance the resource eligibility of a larger plant, or to maintain operational simplicity in response to a signal.

The case for co-location is notably broader for merchant (contracted resources) or market-facing plants. These plants are remunerated and environmentally governed independently from other resources, so there is greater motivation to demonstrate higher performance at the facility to be eligible for higher contractual rates, market products, or greater compensation.

Where avoiding harm to facility and unit components is a priority, integration of on-site storage solutions may help avoid detrimental use of existing equipment, such as low-loading units or frequent or sudden movement across hydraulic and efficiency ranges. Hydroelectric projects are uniquely capable of a suite of flexibility characteristics, including motoring units[1] and dispatchability using on-site water (energy) storage in reservoirs. Augmenting or preserving this flexibility with batteries could be very useful, because their characteristics are highly complementary to the flexibility of hydropower. Storage systems can increase the instantaneous responsiveness of units or avoid unit start-stop or rough zone utilization, thereby bolstering the case for on-site power value. They can also support local power needs, such as managing reactive power for voltage control, or assisting in the automatic generation control function for the management of area control error. Another factor is the speed of interconnecting a storage system to the grid, which is substantially more straightforward within the footprint of a large power plant (Kougias 2019).

In addition to the proximity benefits, it is typical for hydropower facilities to own a large parcel of land, or have overarching real-estate agreements for the surrounding land and its use, that may provide a suitable footprint for the location of the energy storage system. Locating energy storage on-site at the hydropower facility may eliminate the need for additional land acquisitions.

Aside from interconnection of the energy storage system, co-location is supported by existing transmission rights. The purpose of the energy storage being proposed provides operational flexibility rather than increased capacity beyond current peak demands. This allows the rights of the existing transmission system, sized for the existing generation, to be suitable for continued load transmission with the added energy storage system.

Many hydroelectric projects are located within a cascading operation, meaning that there are plants upstream or downstream between which there is a hydrologic link. Under these conditions, the project owner may operate the plants in a coordinated fashion, sequencing flows to an optimal outcome. Or if ownership is varied, there may be a coordination agreement regarding flow schedules or communication between plants to assure operational parameters are met at each plant. In these cases, energy storage, when integrated with a particular facility, such as a facility that acts as a hydrologic constraint, may permit additional flexibility to accrue to other plants in the same cascading system.

There also may be instances in which storage co-location is motivated by load tied directly to the water source, and the timing of the load does not align with hydropower production. Examples of this load include environmental restoration through active water treatment, oxygenation or cooling processes, hydrogen production, desalination, sensing, communications, and control and power backup. Loads of these types could be served by merchant resources as well as utilities under various arrangements. To the extent that these loads can be deferred in time and follow business-as-usual hydropower production patterns, the need for on-site storage to serve these loads and thus the requirement for co-location of energy storage assets may be reduced.

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[1] Motoring of hydroelectric generators corresponds to an extreme idle state of running the turbines with insufficient pressure head to run the (interconnected) generator at synchronous speed. Under this condition, electrical generators act as synchronous motors and pull power from the grid to drive the turbines.

7.0 Next Steps

This paper outlines the potential for deriving improved environmental outcomes by integrating energy storage systems with hydropower plants. This idea is an exciting one, because it suggests that through technology investments, improvements in both river health and the financial future of hydropower plants can be achieved. Quantifying the mutual benefits is an important step in realizing storage adoption by privately and publicly owned hydropower projects.

Throughout this paper, existing knowledge and practical gaps in data, controls, and methodologies for evaluating this potential are indicated. The next steps, summarized below in order of action and scale, will help inform the industry and shape the discussion:

- Determine the full taxonomy and prioritization of the opportunity space for environmental benefits.
- Specify the practical considerations for retrofitting dams with energy storage, related to physical size, electrical interconnection, and charging mechanisms.
- Develop new techniques, based on multi-objective optimization, to support and evaluate the feasibility of hybridization for environmental benefits.
- Adapt or design a decision-support process to evaluate and inform the size, location, and type of energy storage technology.
- Simulate real hydropower plants and energy storage-informed operational models to design hybrid system controls and interactions of mutual benefit.
- Perform data-rich demonstrations of the relationships between environmental benefits and energy storage-augmented operations, in partnership with dam operators.

Several avenues are being explored to realize the data gaps listed above and to enable a demonstration project to serve as a foundation for integrating energy storage with hydropower projects for environmental benefits. Other use cases including the integration of energy storage with other electricity-dependent water infrastructure, such as water conveyance pumps, may offer similar potential for environmental benefits and will be additionally explored. Once a foundational use-case project is identified and implemented, the ultimate goal is to leverage this environmental use-case framework and apply it across the U.S. to other hydropower projects where energy storage could enable more cost-effective ecosystem improvements.

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Appendix A – Methodology Crosswalk

Table A.1. Operational shift requirements to enable environmental benefits of spill for safe fish passage (*hypothetical* metrics).

Operational Constraint	Baseline	Flows to Meet Environmental Objectives (limit impacts from not spilling)	Potential Benefit	What data are needed?
Minimum spill discharge (cfs)	7,000 (late summer) 30,000 (spring) Unrestricted (rest of year)	17,000 (summer smolt passage season) 100,000 for 16 hours daily (spring)	Route downstream-migrating fish from the powerhouse to the spillway to improve passage survival	Hourly passage routing of downstream-migrating fish
Passage flow rate (cfs)	Unrestricted	500 (upstream fish-passage season)	Provide adequate flow rate to attract for upstream fish passage	Seasonal and diel timing of upstream fish passage

Table A.2. Operational shift requirements to enable environmental benefits of Spill for Water Quality (*hypothetical* metrics).

Operational Constraint	Baseline	Flows to Meet Environmental Objectives (limit impacts on water quality)	Potential Benefit	What data are needed?
Minimum flows (cfs)	3,000 (summer) 1,000 (rest of year)	3,000 (summer) 1,000 (rest of year)	Reduce dissolved oxygen and total dissolved gas to at/near 100% for aquatic organism health	Water elevations near spawning habitat, correlation of elevations with flow rates as a function of river hydrology
Maximum non-experimental flows (cfs)[a]	31,500	31,500	Increase dissolved oxygen and/or total dissolved gas to increase under-saturated (<100%) water to avoid fish kills.	
Daily fluctuations (cfs/24 hr)	28,500 (summer) 30,500 (rest of year)	28,500 (summer) 30,500 (rest of year)	Manage spill to optimize oxygen and gas levels for aquatic system health.	
Spill flow rate (cfs)	No requirement	1000 (3-7am)	Spilling warmer surface water downstream may warm the river. Spill from higher elevations re-oxygenates the river but can be too much. Must be carefully planned.	

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