JAWRA Journal of the American Water Resources Association

AMERICAN WATER RESOURCES ASSOCIATION

RESEARCH ARTICLE OPEN ACCESS

From Planning to Action: Advancing Sustainable Water Resources Management in the Potomac Basin

Heidi L. N. Moltz

Interstate Commission on the Potomac River Basin, Rockville, Maryland, USA

Correspondence: Heidi L. N. Moltz (hmoltz@icprb.org)

Received: 15 October 2025 | **Revised:** 23 January 2026 | **Accepted:** 5 February 2026

Keywords: adaptive management | comprehensive planning | integrated water resources management | Potomac basin | water resources

ABSTRACT

The Potomac River basin, a critical source of drinking water and home to the U.S. capital, provides a case study in sustainable water resources management. This paper traces the history of planning in the basin, examines the opportunities and challenges of water resources management in a complex, multi-jurisdictional setting, and analyzes the integrated, adaptive process used to develop and implement the Potomac Basin Comprehensive Water Resources Plan. Using a review of planning documents and stakeholder engagement outcomes, the analysis identifies key mechanisms through which adaptive, collaborative planning is operationalized across four analytic dimensions: stakeholder engagement, facilitation, plan components, and planning process. The Potomac case demonstrates how integrative principles can be implemented pragmatically through voluntary, science-based, and locally grounded collaboration—rather than applying Integrated Water Resources Management (IWRM) as a formal or prescriptive framework. The findings highlight how institutional capacity, iterative learning, and cross-jurisdictional coordination enable basin-scale planning to evolve over time. Unlike previous Potomac scientific and planning reports, this paper offers a systematic, reflective analysis of the long-term planning process in the Potomac basin, providing empirically grounded insights and a conceptual framework for others pursuing integrated, sustainable water resources management.

1 | Introduction

The need to plan and manage water resources holistically is well established (e.g., Al-Jawad et al. 2019; Boinet et al. 2024; Hülsmann et al. 2019; Nagata et al. 2022). Integrated Water Resources Management (IWRM) has been widely adopted as a guiding framework in global water governance since the early 1990s. The Global Water Partnership defines IWRM as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP 2000, 22). Initial adoption emerged in 1992 from the Dublin Statement on Water and Sustainable Development and the United Nation's Agenda 21, Chapter 18 (1992), followed by commitments in the 2002 Johannesburg Summit and the 2015 Sustainable Development Goal 6.5, Target 6.5, and Indicator 6.5.1.

While the overarching concept of IWRM provides a useful framework, it has been critiqued for its breadth, complexity, and tendency toward slow, top-down planning processes (Woodhouse and Muller 2017). Critics have also noted that IWRM often lacks clear operational guidance, making implementation difficult and uneven across institutional and political contexts (Biswas 2004; Molle 2008). In practice, efforts to operationalize IWRM have sometimes struggled to account for local governance arrangements, political realities, and implementation capacity, underscoring the importance of context-specific and adaptive approaches (Grigg 2008). The water resources management approach described in this paper builds on the spirit of integration with collaborative,

localized planning in the Potomac basin. The approach generally aligns with an integrated framework while drawing on the basin's long history of cooperation, its established organizational infrastructure, and the practical needs and priorities of local stakeholders.

River basin commissions in the mid-Atlantic United States—including the Interstate Commission on the Potomac River Basin (ICPRB), the Delaware River Basin Commission, and the Susquehanna River Basin Commission (listed in order of formation)—embody the principles of holistic, proactive resource management. In fact, these river basin commissions were built around the idea of managing water resources at the basin scale, across jurisdictions, to effectively address issues at the scale in which they occur. Each has developed basin-wide water resources plans (DRBC 1962, 2001; ICPRB 2018, 2023; SRBC 1987, 2008, 2021)—engaging stakeholders, coordinating management, and addressing cross-sectoral impacts at the basin scale.

In the Potomac basin, home to the U.S. capital, water resources planning has deep roots. George Washington himself "planned its [the Potomac River's] use as an integral part of a great city" (Potomac Planning Task Force 1967). Early comprehensive efforts included the establishment of ICPRB. Congress first authorized the basin states to negotiate a compact in 1940 (S.J. Res. 222, Pub. Res. No. 93, ch. 579, 54 Stat. 748) and later approved ICPRB in 1949 (Pub. L. No. 81-91, 63 Stat. 12, codified at 33 U.S.C. § 568 note), formally establishing the Commission. In 1963, the U.S. Army Corps of Engineers (USACE) issued a Comprehensive Plan for Development of the Water Resources of the Potomac River Basin, which recommended constructing 16 major reservoirs and numerous smaller impoundments for multiple purposes, including water supply storage (USACE 1963). These structural solutions did not gain traction. Soon thereafter, the Potomac Planning Task Force (1967) articulated a vision for the river as a "national model of river basin development," emphasizing the need for careful study and stakeholder collaboration. The following year, the U.S. Department of Interior issued *The Nation's River*, providing recommendations on water resources problems like public accessibility to the river, meeting state water quality standards, and encouraging continued planning efforts to name a few (US DOI 1968).

Subsequent decades saw important milestones: water quality improvements under the 1972 Clean Water Act, a collaborative approach to solving the Chesapeake Bay's water quality problems through the Chesapeake Bay Agreement of 1983, and cooperative management of Potomac water supply through the 1978 Low Flow Allocation Agreement and 1982 Water Supply Coordination Agreement. As described in Sheer (1983), the latter two agreements served as collaborative alternatives to the previously proposed structural water supply solutions of USACE (1963). Subsequent ICPRB efforts, including the Potomac River Watershed Visions Project (Cummins 1994), reflect the persistence of a basin-wide, collaborative planning tradition into the late twentieth century. While some issues like point source pollution were largely addressed, some challenges have persisted and new challenges have emerged, including population growth, urbanization, microplastics, per- and polyfluoroalkyl substances (PFAS), pharmaceuticals, extreme weather, and the water–energy demands of data centers to name a few.

To address these evolving challenges systematically, the ICPRB catalyzed development of the Potomac Basin Comprehensive Water Resources Plan (ICPRB 2018), guided by an adaptive IWRM framework. Building on the holistic, integrative, and participatory strengths of IWRM, the Potomac basin's unique context (e.g., long-standing interstate cooperation, an established convening body, and active stakeholder engagement) provides an in situ case study of water resources planning that is integrated, adaptive, and locally grounded. This specific context has enabled the planning process to overcome common criticisms of IWRM, including its tendency to be overly broad and difficult to implement (Nesheim et al. 2010).

The purpose of this paper is to document and analyze the Potomac's integrated, adaptive planning process, to identify lessons learned around stakeholder engagement, facilitation, plan components, and planning process, and to outline next steps for basin-wide water resources planning. Further, this paper examines how long-standing institutional arrangements and collaborative planning processes enable adaptive, basin-scale water resources management in a complex interstate context. Using the Potomac Basin Comprehensive Water Resources Plan as an explanatory case study, practical mechanisms are identified through which integrative planning emerges and persists over time, illustrating how integrative planning principles can be operationalized through locally grounded planning and collaboration. The findings offer analytic insights applicable to other basin-scale planning efforts.

2 | Study Area

The Potomac River, often called "The Nation's River" for its historical and cultural significance, drains a 14,670 square mile basin encompassing portions of Maryland, Pennsylvania, Virginia, West Virginia, and the entire District of Columbia (Figure 1). Approximately 6.89 million people reside in the basin (U.S. Census Bureau 2020). The basin is geographically and ecologically diverse, spanning five physiographic provinces—the Appalachian Plateau, Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain (Fenneman et al. 1946)—which together create a complex landscape ranging from mountains to coastal plains, supporting a wide variety of ecosystems and human activities.

Land cover is now predominantly forested, with over 50% forest cover (USGS 2023). Agriculture occupies roughly one-quarter of the basin, producing crops including corn, soybeans, wheat, vegetables, and fruits. Agriculture is an important economic driver (e.g., The Chesapeake Group 2016), though it is also the primary source of phosphorus, nitrogen, and sediment to the Chesapeake Bay (Leyva Ollivier et al. 2023). Urban and suburban development increasingly threatens the basin's pervious landscapes, highlighting ongoing land use pressures (Buchanan et al. 2013; Leyva Ollivier et al. 2023).

Hydrologically, the Potomac River is relatively unregulated (i.e., unimpounded) compared to other major mid-Atlantic rivers (Buchanan et al. 2013), resulting in a flashy system with high and low flows that can vary by orders of magnitude at different streamgage locations (ICPRB 2018). The river supplies nearly 75% of the Washington, D.C., metropolitan area's drinking water (Ahmed et al. 2025), creating critical management

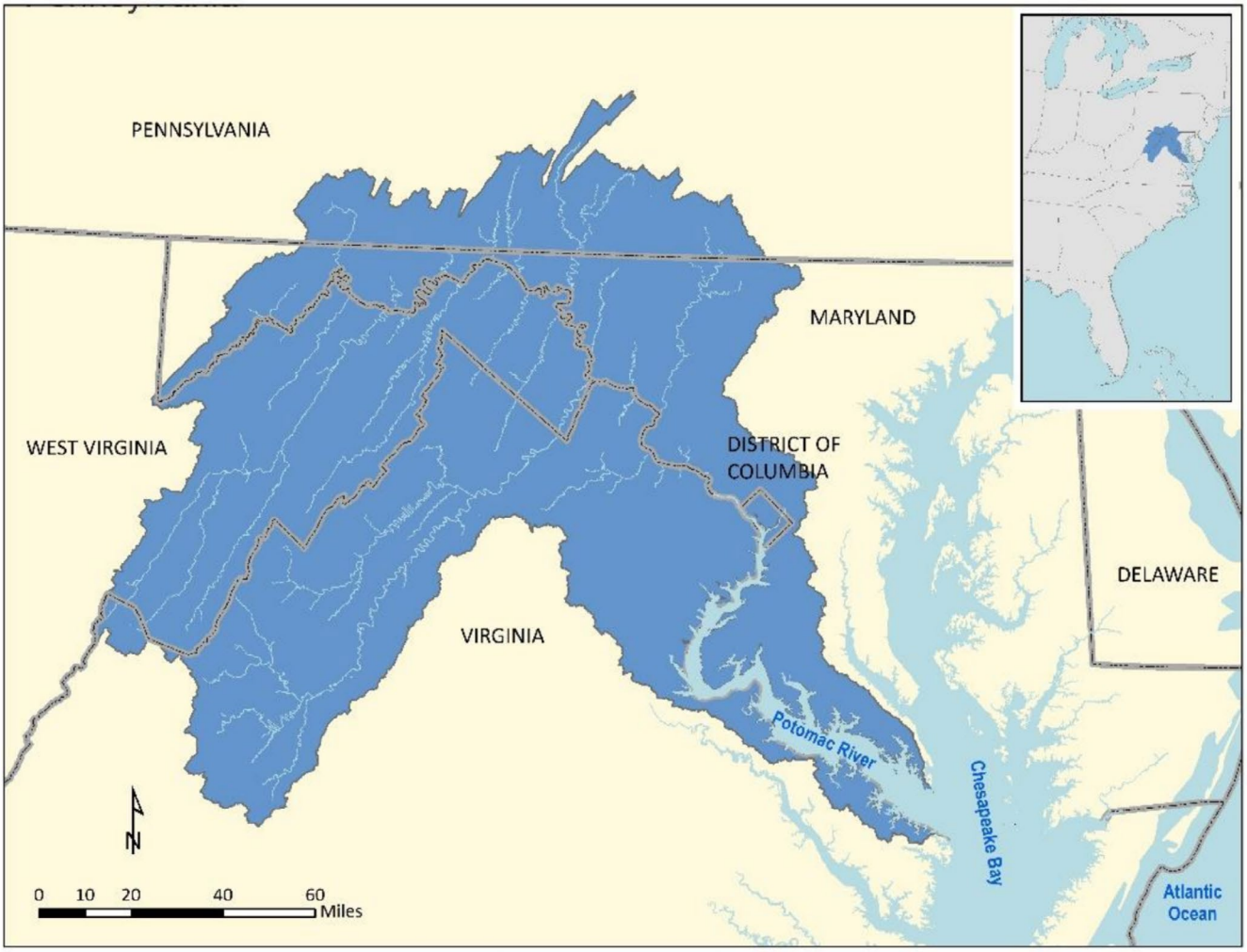

FIGURE 1 | Potomac River basin in the larger U.S. mid-Atlantic region. The basin is shown in dark blue with the intersecting state boundaries in gray. The inset map shows the location of the basin, again dark blue, in the U.S. mid-Atlantic region.

considerations for maintaining human and ecological water needs under both high-flow and low-flow conditions.

2.1 | Water Resources Challenges

As in other large interstate basins worldwide, the Potomac faces numerous interjurisdictional challenges that extend beyond the authority of individual local and state governments. While local jurisdictions address issues within their regulatory purview such as zoning, many water resources challenges occur at basin scale and cross political boundaries. During a 2016 stakeholder meeting (ICPRB 2016), participants identified more than 50 basin-wide issues that would benefit from collaborative solutions. These included ecological concerns, information gaps, and emerging threats to name a few. For example, the relatively few impoundments on the basin's rivers have disrupted the historic range of the American Eel, with cascading effects on native mussel populations (Aldridge et al. 2023; CBP 2018; Vaughn and Hoellein 2018). Small water withdrawals, which often fall below state reporting thresholds, were poorly quantified in the basin until recently (Wallace et al. 2024). Local decision-makers frequently lack access to integrated information on sustainable water management when land-use decisions are made (Moltz et al. 2020). In particular, readily available, scientifically backed information is often missing on how proposed land use changes may affect local water quality and quantity. Two illustrative examples include the impacts of new impervious cover on stormwater and of new data centers on water availability for other uses. Emerging pressures include rapid data center development in northern Virginia and elsewhere in the basin (Ahmed et al. 2025) and new federal regulation of per- and polyfluoroalkyl substances (EPA 2024). These issues are further interconnected with social, economic, regulatory, and infrastructure sectors. Addressing such complexity requires an adaptive planning framework that allows for ongoing reassessment of both the science and societal priorities and fosters nimble, coordinated responses. In the Potomac basin, this need was addressed in part by the basin-wide comprehensive plan, providing a case study of successes and challenges that can inform planning efforts elsewhere.

2.2 | Planning in the Basin

Water resources planning in the Potomac basin occurs at multiple levels. At the federal scale, the Chesapeake Bay Program coordinates efforts to restore and protect the Bay, to which the Potomac is the second largest freshwater contributor (Du et al. 2017). The

Chesapeake Bay Program is a regional partnership led by the U.S. Environmental Protection Agency, the six watershed states, the District of Columbia, the Chesapeake Bay Commission, in collaboration with numerous local governments, nonprofits, and academic institutions. The program's interjurisdictional structure enables coordinated action across political boundaries to address the Bay's complex environmental challenges.

The U.S. Army Corps of Engineers has also advanced Bay-wide efforts through its *Chesapeake Bay Comprehensive Water Resources and Restoration Plan* (USACE 2019). The purpose of the plan is to identify opportunities where the Corps can provide technical expertise, planning, and implementation support in coordination with partners, ensuring that the Corps' restoration and resilience projects are strategically aligned with regional goals. Goals of the USACE plan are to target resources efficiently, avoid duplication, and advance long-term ecological health, economic vitality, and community resilience across jurisdictional boundaries.

Regionally, the Metropolitan Washington Council of Governments (MWCOG) addresses topics related to the environment, transportation, economy, and safety. MWCOG brings together local governments, utilities, and state and federal partners to address timely regional issues of significance.

At the state level in the Potomac basin, each jurisdiction maintains its own water resources planning requirements, including Section 4(a) of the National Capital Planning Act of 1952, Maryland House Bill 1141, West Virginia Senate Bill No. 641, Pennsylvania Act 220, and Virginia's Title 9 Local and Regional Water Supply Planning Regulation. The Comprehensive Plan for the National Capital includes a Federal Elements component and a District Elements component, developed by the National Capital Planning Commission and the District of Columbia, respectively. Maryland's 2006 House Bill 1141 mandates a state water resources program and local Water Resources Elements in comprehensive plans, supported by the Wolman Report (Wolman 2008). Virginia's 2005 Local and Regional Water Supply Planning Regulation requires local or regional plans to ensure safe drinking water, promote conservation, and protect beneficial uses, leading to the development of the Virginia State Water Resources Plan (VA DEQ 2015; 2020). Pennsylvania's Act 220 (2002) created a State Water Plan and Water Atlas and identified Critical Water Planning Areas. West Virginia's Senate Bill 641 of 2004 established the Water Resources Protection and Management Act, resulting in a statewide plan and mapping tool (WV DEP 2013). Collectively, these state initiatives provide a foundation of planning within their jurisdictional boundaries.

These efforts advance sustainable management within their respective domains and operate either within smaller or larger geographic scales than the Potomac basin. A key element was missing: an integrated, holistic framework for managing water and land resources specifically for the basin and spanning the entire basin. The Potomac basin comprehensive water resources plan supports, complements, and integrates with existing federal, regional, state, and local plans by emphasizing cross-jurisdictional Potomac challenges. This approach identifies opportunities to leverage resources to achieve common goals while providing scientific assessments and stakeholder-derived solutions.

The Interstate Commission on the Potomac River Basin (ICPRB) was created by the five jurisdictions in the Potomac River basin (the District of Columbia, Maryland, Pennsylvania, Virginia, and West Virginia) and was approved by an Act of Congress in 1940. The Commission is composed of three Commissioners and three Alternate Commissioners from each of the five jurisdictions. As a non-regulatory agency with expertise in science, communication, and education, ICPRB was ideally positioned to catalyze the development of a voluntary, basin-wide, comprehensive plan. The next section outlines the methods applied to design, implement, and evaluate this integrated, adaptive approach.

3 | Methods

The development of the Potomac Basin Comprehensive Water Resources Plan followed nearly a decade of preparation that included building stakeholder support, drafting a framework, securing funding, and initiating the process. Presentations to the full Commission in December 2010 emphasized the need for such a plan (ICPRB 2010). In 2011, a draft framework was prepared and presented at local, regional, and national venues for feedback and to learn from other efforts (Moltz et al. 2011; Moltz 2012). The *Middle Potomac River Watershed Assessment* (USACE et al. 2014, appendix K) subsequently formalized the proposed process, and that same year the ICPRB Commissioners authorized plan development. Work in 2015 focused on information gathering and scientific analysis, followed by stakeholder engagement beginning in 2016.

Following the process articulated in USACE et al. (2014) and after extensive watershed characterization and stakeholder engagement, the ICPRB formally adopted the comprehensive plan in June 2018 (ICPRB 2018). Since then, the Commissioners and basin stakeholders, assisted by ICPRB's technical staff, have implemented recommended actions and completed the first 5-year review of implementation (ICPRB 2023). The process is structured around a cyclical framework coined here as P-I-R-R: *Plan, Implement, Review, Repeat* (Figure 2). Overall, the process is similar to that applied in other water resources planning and management contexts (e.g., Bilalova et al. 2023; Kalogiannidis et al. 2023; Lim et al. 2022).

3.1 | P-lan

The adopted plan (ICPRB 2018) begins with a purpose statement and a shared vision. It includes a watershed characterization describing physiography, hydrology, population, land use, water use, water quality, and aquatic life. The plan identifies four stakeholder-derived primary challenge areas—(1) ensuring sustainable water supplies, (2) protecting and improving water quality, (3) managing land use for sustainability, and (4) protecting ecological health—along with several cross-cutting issues such as source water protection.

For each challenge area, the plan outlines the nature of the challenge, desired environmental outcomes, guiding principles, and

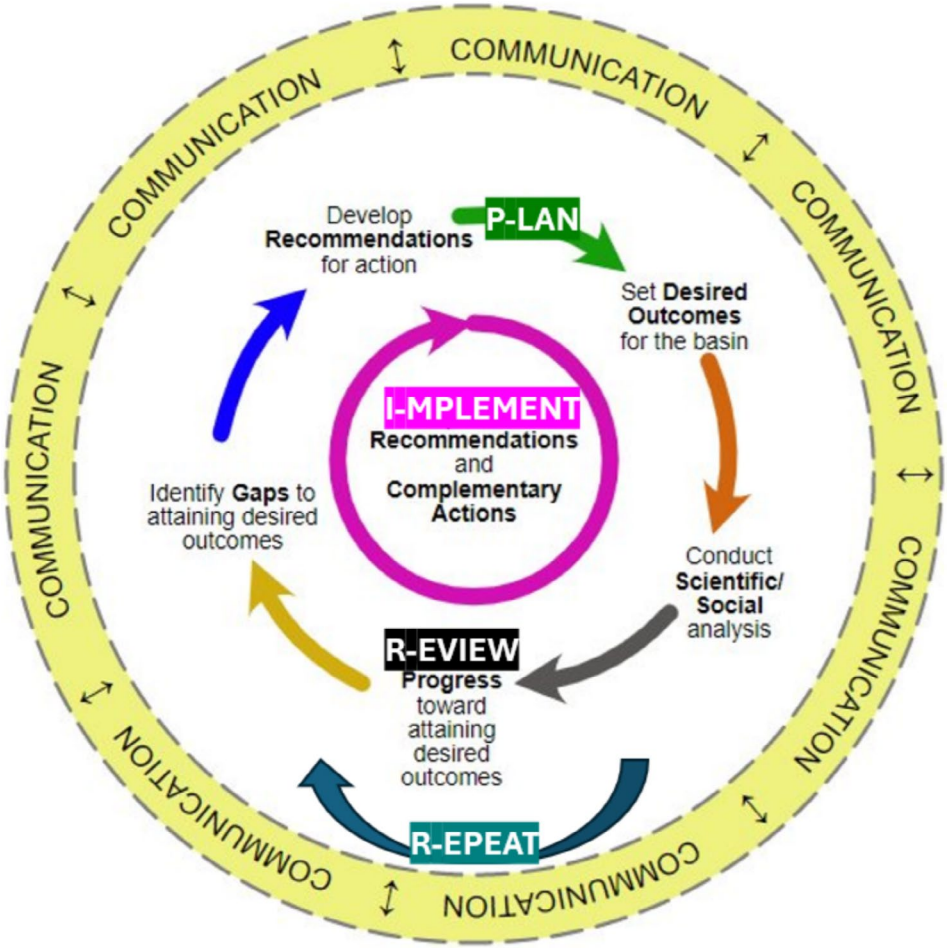

FIGURE 2 | Synthesis of the Potomac planning process. *Source:* Adapted from Rowles (2020).

a set of recommendations. It also specifies milestones (actions to be completed) and measures of success (products or outcomes expected from those actions). A communications plan describes strategies for making information accessible to basin residents and stakeholders.

The plan establishes an adaptive framework that calls for updates to milestones, measures of success, and the communications plan every 5 years, with a full-plan update every 15 years. Consistent with this framework, the 2023 update report (ICPRB 2023) documented revisions to these components. The next 5-year update is scheduled for 2028, and the next full update for 2033.

3.2 | I-mplement

Implementation of milestones is carried out by the ICPRB in collaboration with partner agencies and organizations. Products generated through implementation are disseminated via multiple platforms, including peer-reviewed publications, publicly available data sets, interactive online tools such as ArcGIS StoryMaps, and in-person or virtual events. The technical outputs span the full scope of comprehensive water resources management and are grounded in the best available science, as emphasized in both the literature (e.g., Stackpoole et al. 2023) and the plan's Vision statement (ICPRB 2018).

3.3 | R-eview

Evaluating implementation progress is a central component of effective water resources planning and management (Dirwai et al. 2021; Grison et al. 2023; Stackpoole et al. 2023). Potomac progress is evaluated along two dimensions:

- Programmatic progress: This dimension assesses whether milestones and measures of success identified in the plan have been carried out and how activities by the ICPRB and partners contribute toward desired outcomes. Information is collected annually through implementation summaries, every 5 years through advisory committee and stakeholder discussions, and every 15 years through a full plan review.
- Environmental progress: This dimension evaluates the status of environmental conditions relative to desired outcomes. Metrics are selected based on data availability, reproducibility over time, and alignment with the plan's challenge areas (Table 1). Results are communicated to stakeholders and the public through an interactive website.

3.4 | R-epeat

Findings from programmatic and environmental evaluations directly inform subsequent revisions to the plan. Discussions

TABLE 1 | Challenge areas, desired outcomes, and associated environmental metrics.

Challenge area	Desired outcome	Environmental metrics
Ensure sustainable water uses and supplies	The diverse users of the basin's water resources have clean, reliable, and resilient water resources for current and future generations.	Water supply storage based on the National Inventory of Dams (USACE 2022)
		Reported and unreported water use (Wallace et al. 2024)
Protect and improve water quality	The waters of the basin achieve or exceed water quality standards established by the states in accordance with the Clean Water Act. New and emerging threats are proactively addressed.	Chesapeake Bay Program tidal water quality indicators (Cordero Hernandez et al. 2020)
Manage human land use for sustainability	Human land use in the basin supports sustainable water resource management.	Hydrologic flashiness as the Richard-Baker flashiness index (Baker et al. 2004)
		Land use (USGS 2021)
		Population (U.S. Census Bureau 2023)
Protect ecological health	The propagation and growth of balanced, desirable populations of aquatic life are ensured.	Chesapeake basin-wide index of biotic integrity for stream macroinvertebrates ("Chessie BIBI") for non-tidal streams (Buchanan et al. 2023, 2025; Smith et al. 2017)
		Submerged aquatic vegetation in tidal waters (VIMS 2017)

focus on progress achieved, resource management gaps, obstacles encountered, and emerging issues requiring attention. These insights shape updates to milestones, measures of success, and communication strategies within each 5-year cycle, ensuring that the plan remains adaptive and responsive to changing conditions.

3.5 | Stakeholder Engagement

Transparent, early, and frequent stakeholder engagement is widely recognized as essential for holistic, proactive water resources management (Chaffin et al. 2016; Godinez-Madrigal et al. 2019; Lee et al. 2021; Lim et al. 2022; McCool 2018; Roestamy and Fulazzaky 2022; Seigerman et al. 2023). The stakeholder process for developing and updating the Potomac basin comprehensive plan has been long and active, employing advisory committees, public review of drafts, workshops, information sessions, and digital communication through websites and social media. This broad and sustained approach provided opportunities for both general public participation and targeted engagement.

3.5.1 | 2018 Plan Development

3.5.1.1 | **Advisory Committee.** The 2018 planning process was guided by an advisory committee of 25 members representing state and local agencies, drinking water suppliers, nonprofit organizations, academic institutions, and consulting firms. All basin jurisdictions were represented by various stakeholder groups as appropriate. Members contributed expertise spanning water resources management, source water protection, environmental policy and regulation, and fisheries protection (to name a few) from the perspectives of drinking water utilities, agriculture, industry, development, and academia.

The committee met seven times between September 2016 and March 2018 (five in person, two by conference call). An independent facilitator guided unbiased discussion, while ICPRB staff provided technical expertise and prepared plan documents. Key outputs included a shared vision statement, identification of challenge areas (sustainable water use, water quality, land use management, ecological health, and cross-cutting issues), milestones for the first 5 years, and measures of success (ICPRB 2018).

3.5.1.2 | **Email Distribution List.** An email list of approximately 200 individuals was developed using existing contacts, professional networks, and referrals. Stakeholders represented government agencies, agriculture, watershed organizations, academia, the power sector, recreation, consulting, industry, and science organizations. Between 2016 and 2018, the list was used to:

- Introduce the planning process (October 2016).
- Solicit comments on the draft vision and challenge categories (January 2017).
- Request feedback on research, monitoring, and implementation needs (April 2017).
- Seek input on draft recommended actions (July 2017).
- Announce plan adoption (August 2018).

3.5.1.3 | Federal Engagement. Federal agency perspectives were incorporated through a fiscal year 2017 U.S. Army Corps of Engineers Planning Assistance to States grant. Ten federal agencies provided feedback on priority issues and collaboration opportunities, documented in the plan (ICPRB 2018, appendix D).

3.5.2 | 2020 Virtual Event Series

Two years into plan implementation, a basin-wide workshop was held to identify entities with a role to play in sustainable water resources management in the Potomac basin, describe how to measure programmatic and environmental progress, and identify subsequent planning efforts as called for in the 2018 plan. Originally scheduled as an in-person event in April 2020, the workshop was shifted to a three-part virtual series due to the global COVID-19 pandemic. Sessions were held on August 14, August 21, and September 11, 2020, covering topics including water use and supply, water quality, ecological health, land use management, and cross-cutting challenges.

Average attendance was approximately 40 participants per session (range: 28–56). Outputs included poll results, findings charts, and synthesized feedback that directly informed implementation priorities.

3.5.3 | 2023 Plan Update

3.5.3.1 | Advisory Committee. For the first 5-year review, a reconstituted advisory committee of 22 members met seven times in 2023, including two full-day workshops and five virtual sessions. Participants again represented diverse sectors and geographies across the basin. Products of the committee included updated milestones, measures of success, and a communications plan for the next 5 years (ICPRB 2023).

3.5.3.2 | Federal Government. In June 2024, ICPRB hosted a 1-day workshop in Washington, D.C., titled *Partnering for the Potomac*. Nine federal agencies participated, identifying and discussing opportunities for collaboration on contamination response, long-term stream gaging, conservation land prioritization, and basin-wide water use evaluation among others.

3.5.4 | Evaluating Stakeholder Engagement

Engagement effectiveness has been measured through:

1. Participation counts (attendance at meetings and workshops).
2. Digital engagement (website analytics and distribution list activity).
3. Direct feedback (responses to questionnaires and comment periods).

Together, these metrics provide quantitative indicators of participation and qualitative insights into stakeholder priorities, supporting adaptive improvement of engagement strategies over time.

4 | Results

The stakeholder-intensive P-I-R-R planning process produced results across four areas: scientific advances, adaptive refinements, collaborative engagement, and authoritative influence. Each of these (scientific, adaptive, collaborative, and authoritative) is discussed in the sections below. The results illustrate how the Potomac comprehensive, basin-wide planning approach integrated data, stakeholder input, and iterative learning to guide sustainable water resources management.

4.1 | Scientific

Science is central to ICPRB's organizational mission, to "protect and enhance the waters and related resources of the Potomac River basin through science, regional cooperation, and education." The plan reflects this, explicitly stating in the Vision statement that "The plan will be based on the best available science and data" (ICPRB 2018). As part of its overall mission and to execute the actions identified in the basin-wide plan, ICPRB has collaborated with basin partners to generate and disseminate technical information that informs both planning and implementation, resulting in outputs ranging from water availability assessments to ecological indicators. Several recent ICPRB products illustrate these efforts:

- Water supply reliability: Every 5 years, ICPRB's Section for Cooperative Water Supply Operations on the Potomac publishes a demand and availability study (Ahmed et al. 2015, 2020, 2025). These assessments evaluate the reliability of metropolitan Washington's drinking water supply and analyze emerging pressures such as upstream consumptive uses.
- Water use assessment: Although water use is regulated at the state level, the Potomac is a shared water resource. ICPRB has compiled state-reported basin-wide withdrawal and consumptive use data (Ducnuigeen et al. 2015) and conducted trend analyses of reported and estimated unreported water uses to understand how water use is changing over time (Moltz et al. 2021, 2022; Nummer et al. 2024; Wallace et al. 2024).
- Integration with land use planning: Moltz et al. (2020) proposed an approach to incorporate water resources management into local land-use decisions, drawing on Potomac basin characteristics and global case studies. This work launched a webinar series for land use decision-makers, which has reached more than 1850 participants through live and archived events.
- Ecological indicators: Buchanan et al. (2023) evaluated 26,752 macroinvertebrate samples collected by federal, state, local, and other organizations to estimate with a common index the percentage of stream miles supporting healthy biological communities in the Potomac as well as other Chesapeake watersheds.

- Long-term water quality trends: Hunter et al. (2021) analyzed more than 80 years of data from the Washington Aqueduct's Great Falls intake and Dalecarlia Reservoir, documenting significant increases in Potomac River temperature, chlorides, and total solids associated with urbanization and population growth upstream of Washington, D.C.

Collectively, these (and other) technical studies, stimulated or supported by the comprehensive planning process, provide critical pieces of the puzzle needed to address the complex, multi-jurisdictional challenges of sustainable water management in the Potomac basin. Building on this foundation of scientific evidence, the plan's adaptive framework allows for iterative refinement of priorities and strategies based on both environmental monitoring and programmatic progress.

4.2 | Adaptive

Adaptive management is central to the P-I-R-R process. During the 2023 plan update, the advisory committee reviewed programmatic progress through presentations and discussions, identifying new activities for the next 5-year cycle. Implementation from 2019 to 2023 was judged successful, with all milestones categorized as "completed," "ongoing," or "always ongoing." Complementary activities—those advancing the plan's objectives but not designated as milestones—were also documented in meeting records and appended to the 2023 plan.

With 7 years of implementation complete, environmental evaluation has focused on snapshots of selected indicators. The next cycle of monitoring will enable trend analysis to determine how conditions are changing over time.

The adaptive process has yielded three key benefits: (1) adjusting or reinforcing priority focus areas—the 2023 plan update, for example, reaffirmed the commitment to reach all basin communities, particularly those disproportionately affected by water resources issues; (2) refreshing the list of implementation activities at the start of each 5-year period, allowing timely adjustments for emerging challenges; and (3) continuously refining written and interactive materials based on stakeholder feedback. The success of this framework is reinforced by extensive collaboration and communication, ensuring that stakeholders remain actively engaged throughout planning and implementation.

4.3 | Collaborative

Collaboration and communication have been defining features of the planning process. Nearly 20,000 instances of engagement were recorded (Table 2), reflecting participation across planning forums, outreach activities, and implementation events. Table 2 represents engagement counts rather than a number of unique individuals, as many participants contributed in multiple ways.

Digital communications accounted for the largest share of engagements, particularly website views, downloads, and social media interactions. In-person and live virtual events also drew substantial participation, with nearly 900 attending the land use webinar series and more than 400 participating in Potomac River conferences.

ICPRB sought feedback throughout the process. An email questionnaire to the broad distribution list in 2017 generated 20 comments, while a 2020 virtual series yielded 102 questionnaire responses. The land use webinar series continues to collect feedback on topics, speakers, and timing, with more than 46 responses received to date. This iterative input has been invaluable for refining outreach and ensuring that products remain relevant and useful.

Finally, the combination of science, adaptive processes, and collaboration has enhanced the plan's authority, allowing it to guide policy and management decisions across the basin.

4.4 | Authoritative

Although voluntary, a plan grounded in sound science and developed collaboratively across jurisdictions can acquire authoritative influence. Since adoption, the Potomac plan has been cited as a guiding authority in the basin.

For example, the U.S. Army Corps of Engineers North Atlantic Division identified the basin-wide comprehensive plan as an authority as part of drought contingency planning for Jennings Randolph Lake (USACE, n.d.). In addition, Pennsylvania's Municipalities Planning Code requires that local water surveys and comprehensive plans align with "any applicable water resources plan adopted by a river basin commission" (1968, Article 3). By providing a shared rationale for action, the Potomac plan has gained traction as an authoritative resource across the region.

5 | Discussion

This paper examines how basin-scale water resources planning can emerge and persist in complex, multi-jurisdictional contexts. The Potomac Basin Comprehensive Water Resources Plan is used as an explanatory case study to identify mechanisms through which integrative, adaptive planning is operationalized in practice. The analysis highlights how institutional capacity, collaborative processes, and iterative learning enable effective planning at the basin scale, while recognizing that specific strategies and structures are shaped by historical, social, and legal context. These insights provide a conceptual framework for understanding and evaluating similar adaptive planning processes in other basins, illustrating both opportunities and limitations for transferability.

More than a decade of planning and implementation through the Potomac Basin Comprehensive Water Resources Plan has advanced integration across disciplines, strengthened stakeholder collaboration, generated new science, and yielded early measures of environmental progress. Numerous organizations contribute to sustainable water management in the basin—from local and state governments to regional entities such as the Chesapeake Bay Program and the Metropolitan Washington Council of Governments, and federal agencies

TABLE 2 | Instances of engagement by type.

Engagement type	Name	Years	Count (#)
Planning	Advisory Committee	2016–2018	25
		2023	22
	Email Distribution List	2016–2018	200
	ICPRB Commissioners	2018–2025	36
	ICPRB Staff	2018–2025	20
	Federal Agencies	2017	10
		2024	9
Communications	Potomac News Reservoir	2018–2025	1545
	Facebook	2018–2025	1700
	YouTube	2018–2025	70
	Twitter	2018–2025	1200
	Instagram	2018–2025	1200
	Plan Introductory Videos	2018	100
		2024	100
	Plan Website Views	2018–2025	7000
	Plan File Downloads	2018–2025	2310
	StoryMap Views	2018–2025	2100
Implementation	Land use Webinar Series, Live	2021–2025	890
	Land use Webinar Series, YouTube	2021–2025	960
	Potomac River Conference	2022–2024	435
Total			19,932

including EPA and USACE—but ICPRB occupies a distinct role as a non-regulatory, science-based body focused exclusively on the Potomac. Although its small size limits funding and staffing capacity, the Commission serves as an effective "catalyst and partner" (as the plan defines its role) by convening stakeholders and advancing science-based collaboration.

Several mechanisms through which adaptive, collaborative planning is operationalized in the Potomac basin are summarized in Table 3. These examples illustrate explanatory insights into how institutional capacity, stakeholder engagement, and iterative processes support effective basin-scale planning.

Stakeholders: For a truly collaborative process, stakeholders need to collectively bring a diverse set of skills and relevant geographies and to remain engaged throughout the process. Sustained engagement requires strategically timed and planned meetings to keep participants feeling that their time is valued and to keep the group feeling energized over time. Virtual meetings improved efficiency, but periodic in-person sessions proved essential for relationship-building and consensus. Turnover remains a challenge, underscoring the need to retain institutional memory and bring new participants up to speed.

TABLE 3 | Illustrations of explanatory insights.

1. Stakeholders
   a. Engaged
   b. Diverse (skills, expertise, geographies)
2. Facilitators
   a. Independent
   b. Knowledgeable (water resources, thematic contents)
3. Plan components
   a. Best available science (data, models, interpretation)
   b. Easily understood products
   c. Readily available, accessible
   d. Engaging (StoryMaps, videos, styled text)
4. Plan process
   a. Adaptive (revisited regularly)
   b. Collaborative, open
   c. Evaluate progress (metrics)

Facilitators: Independent, knowledgeable facilitators proved critical for maintaining neutrality and guiding constructive dialogue. This helped ensure no single perspective dominated outcomes.

Plan components: Credibility depends on the best available science, but accessibility determines usefulness. Stakeholders emphasized that dense, text-heavy reports are insufficient. Interactive maps, styled reports, StoryMaps, and webinars have proven more effective at engaging decision-makers and other users. Simple, memorable slogans—such as "The Potomac Belongs to All"—can also help promote engagement and inspire action.

Plan process: Adaptation has been central. The 5-year review introduced milestones and measures of success for cross-cutting challenges, while virtual formats were refined to enhance participation. Iterative adjustments to meetings and products helped sustain engagement.

It is important to note that the Potomac basin had several enabling conditions prior to this effort, including a history of interjurisdictional cooperation and a basin-wide organization (ICPRB) with both technical expertise and convening ability. In basins lacking these foundations, significant effort may be required to build relationships and identify or establish a trusted coordinating entity. The Potomac plan also gains strength from its position within a broader network of integrated planning efforts, spanning local to federal scales, as well as supportive funding for planning and implementation by state and federal partners.

Adaptations to the approach will certainly be needed to address conditions in other basins. For example, if applied in a basin where the interstate agency has regulatory authority, the role of convener may need to be delegated to a voluntary organization to encourage open dialogue. Or, in a basin with considerable industrial water use, integrating theirs with other considerations may take priority. Adapting to basin-specific conditions will be a key factor in applying these lessons elsewhere.

6 | Conclusions

Although holistic water resources management is widely endorsed, the effectiveness of current approaches and areas for improvement remain under debate (Armas Vargas et al. 2023; Benson et al. 2020; Bilalova et al. 2023; Boinet et al. 2024; Hussein et al. 2018; Al-Jawad et al. 2019). The IWRM literature regularly calls for approaches that are locally-grounded, context-specific, and explicit about implementation pathways rather than broad normative prescriptions (e.g., Lim et al. 2022; Nagata et al. 2022). The Potomac basin experience responds to these calls by not applying IWRM as a formal or comprehensive model, but by operationalizing integrative principles. This happens through a voluntary, science-based, and collaborative planning process tailored to basin-specific needs and institutional realities.

Like many large interstate basins, the Potomac faces challenges that extend beyond the authority of any single jurisdiction or entity. Ecological disruptions, fragmented data and governance structures, and emerging pressures such as data center growth and PFAS regulation illustrate the complexity of contemporary basin-scale water management. These interconnected issues highlight the need for an approach that emphasizes coordination, shared learning, and adaptability.

The Potomac Basin Comprehensive Water Resources Plan demonstrates how long-standing cooperative relationships, an established convening institution, and sustained stakeholder engagement can enable integrative planning in practice. The approach has increased transparency, leveraged resources, and fostered dialogue among agencies, organizations, and communities to address complex water challenges at the basin scale. Ongoing evaluation of progress (e.g., 5-year updates), combined with continued stakeholder engagement (e.g., the Advisory Committee), will be essential to sustain momentum.

While significant challenges remain, the Potomac planning process demonstrates how voluntary, science-based, and locally grounded approaches, underpinned by adaptive and collaborative mechanisms, can enable stakeholders to respond effectively to emerging threats and opportunities, cultivate institutional capacity and trust, and provide a potentially transferable pathway for other watersheds seeking resilient and sustainable water management. This case suggests that effective basin-scale water resources planning may be less about adopting comprehensive management paradigms and more about building the organizational, social, and informational capacities that allow integrated planning to emerge and evolve over time.

These findings highlight a set of criteria and mechanisms that other basin planning efforts can consider when designing or evaluating adaptive, collaborative approaches. Key elements include long-standing institutional arrangements that facilitate coordination across jurisdictions, iterative planning cycles that allow for learning and course correction, structured mechanisms for stakeholder engagement that balance diverse interests, and access to integrated scientific and management information to support decision-making. While the specific solutions and processes in the Potomac basin are unique to its historical, social, and legal context, these elements provide a conceptual framework for evaluating the presence and effectiveness of similar capacities in other basins. Applying these criteria can help other water management efforts assess their readiness for integrated, adaptive planning and identify opportunities for strengthening collaborative governance, even where institutional structures, legal frameworks, or ecological challenges differ.

Author Contributions

Heidi L. N. Moltz: conceptualization, writing – original draft, investigation, writing – review and editing, methodology.

Acknowledgments

The collaborative planning process in the Potomac basin has been made possible through the commitment and contributions of countless stakeholders. The author gratefully acknowledges the Commissioners and staff of the Interstate Commission on the Potomac River Basin, whose dedication has enabled both timely planning and implementation. This paper reflects a collective story shaped by many voices. Special thanks

are extended to Daniel Bloedow for his thorough review of the IWRM literature and to Dr. Willem Brakel, Dr. Claire Buchanan, and Karin Bencala for their thoughtful and constructive reviews. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does the Environmental Protection Agency endorse trade names or recommend the use of commercial products mentioned in this document, as well as any images, video, text, or other content created by generative artificial intelligence tools, nor does any such content necessarily reflect the views and policies of the Environmental Protection Agency.

Funding

Preparation of this manuscript has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement 98339418 to the Interstate Commission on the Potomac River Basin.

Conflicts of Interest

The author declares no conflicts of interest.

Data Availability Statement

The author has nothing to report.

References

Ahmed, S. N., K. R. Bencala, S. Nummer, C. Schultz, and A. Seck. 2025. "2025 Washington Metropolitan Area Water Supply Study: Demand and Resource Availability Forecast for the Year 2050." In Review.

Ahmed, S. N., K. R. Bencala, C. L. Schultz, and A. Seck. 2015. "2015 Washington Metropolitan Area Water Supply Study: Demand and Resource Availability for the Year 2040." ICPRCB Report No. 15-4.

Ahmed, S. N., H. L. N. Moltz, C. L. Schultz, and A. Seck. 2020. "2020 Washington Metropolitan Area Water Supply Study: Demand and Resource Availability for the Year 2050." ICPRB Report No. 20-3.

Aldridge, D. C., I. S. Ollard, Y. V. Bespalaya, et al. 2023. "Freshwater Mussel Conservation: A Global Horizon Scan of Emerging Threats and Opportunities." *Global Change Biology* 29: 575–589.

Al-Jawad, J. Y., H. M. Alsaffar, D. Bertram, and R. M. Kalin. 2019. "A Comprehensive Optimum Integrated Water Resources Management Approach for Multidisciplinary Water Resources Management Problems." *Journal of Environmental Management* 239: 211–224, ISSN 0301-4797. https://doi.org/10.1016/j.jenvman.2019.03.045.

Armas Vargas, F., L. F. Nava, E. Gómez Reyes, et al. 2023. "Water and Environmental Resources: A Multi-Criteria Assessment of Management Approaches." *Water* 15, no. 16: 2991. https://doi.org/10.3390/w15162991.

Baker, D. B., R. P. Richards, T. T. Loftus, and J. W. Kramer. 2004. "A New Flashiness Index: Characteristics and Applications to Midwestern Rivers and Streams." *Journal of the American Water Resources Association* 40, no. 2: 503–522. https://doi.org/10.1111/j.1752-1688.2004.tb01046.x.

Benson, D., A. K. Gain, and C. Giupponi. 2020. "Moving Beyond Water Centricity? Conceptualizing Integrated Water Resources Management for Implementing Sustainable Development Goals." *Sustainability Science* 15: 671–681. https://doi.org/10.1007/s11625-019-00733-5.

Bilalova, S., J. Newig, L. C. Tremblay-Lévesque, J. Roux, C. Herron, and S. Crane. 2023. "Pathways to Water Sustainability? A Global Study Assessing the Benefits of Integrated Water Resources Management." *Journal of Environmental Management* 343: 118179. https://doi.org/10.1016/j.jenvman.2023.118179.

Biswas, A. K. 2004. "Integrated Water Resources Management: A Reassessment." *Water International* 29, no. 2: 248–256. https://doi.org/10.1080/02508060408691775.

Boinet, E., E. Tardieu, C. Brachet, and A. Bernard. 2024. "Lessons From the Last 30 Years for Future Water Resource Management in National and Transboundary Basins." *Water International* 49, no. 3–4: 255–266. https://doi.org/10.1080/02508060.2024.2343176.

Buchanan, C., R. D. Jepsen, and M. E. Mallonee. 2023. "Stream Biological Health in the Chesapeake Bay Watershed." ICPRB Report ICP23-1. Report Prepared for the Chesapeake Bay Program Stream Health Workgroup. https://www.potomacriver.org/wp-content/uploads/2023/02/ChesWatershed-Percent-Healthy-Streams_FINAL_02-10-2023-1.pdf.

Buchanan, C., R. D. Jepsen, and E. Young. 2025. "Stream Biological Health in the Chesapeake Bay Watershed, 2018–2023 Update." ICPRB Report ICP25-1. Report Prepared for the Chesapeake Bay Program Stream Health Workgroup. https://www.potomacriver.org/wp-content/uploads/2022/02/Stream-Health-in-the-Chesapeake-Bay-Watershed-2018-2023-Update.pdf.

Buchanan, C., H. L. N. Moltz, H. C. Haywood, J. B. Palmer, and A. Griggs. 2013. "A Test of the Ecological Limits of Hydrologic Alteration (ELOHA) Method for Determining Environmental Flows." *Journal of Freshwater Biology* 58: 2632–2647. https://doi.org/10.1111/fwb.12240.

CBP. 2018. "Fish Passage Outcome, Management Strategy 2015–2025, v.2." https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/2018-2019_fish_passage_management_strategy.pdf.

Chaffin, B. C., A. S. Garmestani, H. Gosnell, and R. K. Craig. 2016. "Institutional Networks and Adaptive Water Governance in the Klamath River Basin, USA." *Environmental Science & Policy* 57: 112–121. https://doi.org/10.1016/j.envsci.2015.11.008.

Cordero Hernandez, A. L., P. J. Tango, and R. A. Batiuk. 2020. "Development of a Multimetric Water Quality Indicator for Tracking Progress Towards the Achievement of Chesapeake Bay Water Quality Standards." *Environmental Monitoring and Assessment* 192: 94. https://doi.org/10.1007/s10661-019-7969-z.

Cummins, J. D. 1994. *Potomac River Watershed Visions Project* ICPRB Report 94-6. Interstate Commission on the Potomac River Basin (ICPRB). https://www.potomacriver.org/wp-content/uploads/2014/12/ICP94-6_Cummins.pdf.

Dirwai, T. L., E. K. Kanda, A. Senzanje, and T. I. Busari. 2021. "Water Resource Management: IWRM Strategies for Improved Water Management. A Systematic Review of Case Studies of East, West and Southern Africa." *PLoS One* 16, no. 5: e0236903. https://doi.org/10.1371/journal.pone.0236903.

DRBC. 1962. "Comprehensive Plan." https://www.nj.gov/drbc/library/documents/comprehensive_plan1962.pdf.

DRBC. 2001. "Comprehensive Plan." https://www.nj.gov/drbc/library/documents/comprehensive_plan.pdf.

Du, J., D. Wang, and J. Shen. 2017. "Transport of Riverine Material From Multiple Rivers in the Chesapeake Bay: Important Control of Estuarine Circulation on the Material Distribution." *Journal of Geophysical Research – Biogeosciences* 122, no. 3: 770–785. https://doi.org/10.1002/2016JG003707.

Ducnuigeen, J., S. N. Ahmed, K. R. Bencala, H. L. N. Moltz, A. Nagel, and C. L. Schultz. 2015. "Geospatial Analysis Tool for Estimating Watershed-Scale Consumptive Use: Potomac River Basin Case Study." In *Advances in Watershed Science and Assessment*, edited by T. Younos and T. E. Parece, 141–169. Springer International Publishing Switzerland.

EPA. 2024. "PFAS National Primary Drinking Water Regulation [Final Rule]." *Federal Register* 89, no. 80: 32532–32757.

Fenneman, A., M. Nevin, and D. W. Johnson. 1946. *Physiographic Divisions of the U.S.* USGS.

Godinez-Madrigal, J., N. Van Cauwenbergh, and P. van der Zaag. 2019. "Production of Competing Water Knowledge in the Face of Water Crises: Revisiting the IWRM Success Story of the Lerma-Chapala

Basin, Mexico." *Geoforum* 103: 3–15. https://doi.org/10.1016/j.geoforum.2019.02.002.

Grigg, N. S. 2008. "Integrated Water Resources Management: Balancing Views and Improving Practice." *Water International* 33, no. 3: 279–292. https://doi.org/10.1080/02508060802272820.

Grison, C., S. Koop, S. Eisenreich, et al. 2023. "Integrated Water Resources Management in Cities in the World: Global Challenges." *Water Resources Management* 37: 2787–2803. https://doi.org/10.1007/s11269-023-03475-3.

GWP. 2000. *Integrated Water Resources Management*. Global Water Partnership Technical Advisory Committee. TAC Background Papers No. 4.

Hülsmann, S., J. Sušnik, K. Rinke, et al. 2019. "Integrated Modelling and Management of Water Resources: The Ecosystem Perspective on the Nexus Approach." *Current Opinion in Environmental Sustainability* 40: 14–20. https://doi.org/10.1016/j.cosust.2019.07.003.

Hunter, D., R. D. Jepsen, C. C. Davis, and C. Buchanan. 2021. "Potomac River Water Quality at Great Falls: 1940–2019." ICPRB Report ICP21-5. https://www.potomacriver.org/wp-content/uploads/2021/11/PRWQ_Final.pdf.

Hussein, H., F. Menga, and F. Greco. 2018. "Monitoring Transboundary Water Cooperation in SDG 6.5.2: How a Critical Hydropolitics Approach Can Spot Inequitable Outcomes." *Sustainability* 10, no. 10: 3640. https://doi.org/10.3390/su10103640.

ICPRB. 2010. "Interstate Commission on the Potomac River Basin, First Quarter Business Meeting Minutes, December 7, 2010." https://www.potomacriver.org/wp-content/uploads/2014/12/2011-1Q.pdf.

ICPRB. 2016. "Advisory Committee for the Comprehensive Water Resources Plan, September 26, 2016 Meeting Minutes." https://www.potomacriver.org/wp-content/uploads/2016/09/2016-09-26-Potomac-Advisory-Committee-Meeting-Summary-final-1.pdf.

ICPRB. 2018. "Potomac River Basin Comprehensive Water Resources Plan." https://www.potomacriver.org/wp-content/uploads/2018/06/Potomac_Comprehensive_Plan.pdf.

ICPRB. 2023. "2023 Updates, Potomac River Basin Comprehensive Water Resources Plan." https://www.potomacriver.org/wp-content/uploads/2024/03/CompPlanUpdates_2023Report_Final.pdf.

Kalogiannidis, S., D. Kalfas, G. Giannarakis, and M. Paschalidou. 2023. "Integration of Water Resources Management Strategies in Land Use Planning Towards Environmental Conservation." *Sustainability* 15, no. 21: 15242. https://doi.org/10.3390/su152115242.

Lee, C.-C., K.-C. Huang, S.-Y. Kuo, C.-K. Cheng, C.-P. Tung, and T.-M. Liu. 2021. "Development of a Social Impact Assessment for the Water Environment: A Professional Perspective." *Water* 13: 3355. https://doi.org/10.3390/w13233355.

Leyva Ollivier, M. E., A. Newton, and H. Kelsey. 2023. "Socio-Ecological Analysis of the Eutrophication in Chesapeake Bay, USA." *Frontiers in Marine Science* 10: 1237493. https://doi.org/10.3389/fmars.2023.1237493.

Lim, C. H., H. L. Wong, R. Elfithri, and F. Y. Teo. 2022. "A Review of Stakeholder Engagement in Integrated River Basin Management." *Water* 14, no. 19: 2973. https://doi.org/10.3390/w14192973.

McCool, D. 2018. "Integrated Water Resources Management and Collaboration: The Failure of the Klamath River Agreements." *Journal of Policy History* 30, no. 1: 83–104. https://doi.org/10.1017/S0898030617000392.

Molle, F. 2008. "Nirvana Concepts, Narratives and Policy Models: Insights From the Water Sector." *Water Alternatives* 1, no. 1: 131–156.

Moltz, H. L. N. 2012. "Integrated Water Resources Management, Potomac River Basin." Presentation to AWRA National Capital Region Section. January 12, 2012, Rockville, Maryland.

Moltz, H. L. N., C. Haywood, and J. Hoffman. 2011. "Integrated Water Resources Management in the Potomac River Basin." AWRA 2011 Summer Specialty Conference, June 27–29, 2011, Snowbird, Utah.

Moltz, H. L. N., A. Nagel, and S. Nummer. 2022. "Potomac Basin Reported Water Uses." ICPRB Report No. 22-8. https://www.potomacriver.org/wp-content/uploads/2022/08/Reported-Water-Use_090222.pdf.

Moltz, H. L. N., A. Nagel, E. Sharifi, and C. Wallace. 2021. "Potomac Basin Unreported Water Use." ICPRB Report No. 21-3. https://www.potomacriver.org/wp-content/uploads/2021/03/UnreportedWaterUse-FINAL2.pdf.

Moltz, H. L. N., C. W. Wallace, E. Sharifi, and K. Bencala. 2020. "Integrating Sustainable Water Resource Management and Land Use Decision-Making." *Water* 12, no. 8: 2282. https://doi.org/10.3390/w12082282.

Nagata, K., I. Shoji, T. Arima, et al. 2022. "Practicality of Integrated Water Resources Management (IWRM) in Different Contexts." *International Journal of Water Resources Development* 38, no. 5: 897–919. https://doi.org/10.1080/07900627.2021.1921709.

Nesheim, I., D. McNeill, K. J. Joy, et al. 2010. "The Challenge and Status of IWRM in Four River Basins in Europe and Asia." *Irrigation and Drainage Systems* 24: 205–221. https://doi.org/10.1007/s10795-010-9103-9.

Nummer, S., H. L. N. Moltz, and A. Nagel. 2024. "Potomac Basin Trends in Water Use." ICPRB Report No. 24-3. https://www.potomacriver.org/wp-content/uploads/2024/03/ReportedWaterTrendsPamphlet_V4_03132024.pdf.

Potomac Planning Task Force. 1967. *The Potomac: A Report on Its Imperiled Future and a Guide for Its Orderly Development*, 103. U.S. Government Printing Office.

Roestamy, M., and M. A. Fulazzaky. 2022. "A Review of the Water Resources Management for the Brantas River Basin: Challenges in the Transition to an Integrated Water Resources Management." *Environment, Development and Sustainability* 24: 11514–11529. https://doi.org/10.1007/s10668-021-01933-9.

Rowles, K. 2020. *2020 Virtual Event Series. Facilitator Presentation to Participants, August 14, 2020*. Policy Works LLC.

Seigerman, C. K., S. K. McKay, R. Basilio, et al. 2023. "Operationalizing Equity for Integrated Water Resources Management." *Journal of the American Water Resources Association* 59, no. 2: 281–298. https://doi.org/10.1111/1752-1688.13086.

Sheer, D. P. 1983. *Assured Water Supply for the Washington Metropolitan Area*. ICPRB. https://www.potomacriver.org/wp-content/uploads/2014/12/water_supply_19831.pdf.

Smith, Z. M., C. Buchanan, and A. Nagel. 2017. "Refinement of the Basin-Wide Index of Biotic Integrity for Non-Tidal Streams and Wadeable Rivers in the Chesapeake Bay Watershed." ICPRB Report 17.2. https://www.potomacriver.org/wp-content/uploads/2017/05/ChessieBIBI_Report_Final_5-25-2017.pdf.

SRBC. 1987. "Comprehensive Plan for the Water Resources of the Susquehanna River Basin." https://digitalcollections.statelibrary.pa.gov/Documents/Detail/comprehensive-plan-for-management-development-of-the-water-resources-of-the-susquehanna-river-basin/1361021.

SRBC. 2008. "Comprehensive Plan for the Water Resources of the Susquehanna River Basin."

SRBC. 2021. "Comprehensive Plan for the Water Resources of the Susquehanna River Basin (2021–2041)." Pub. No. 325. https://www.srbc.gov/our-work/planning/comprehensive-plan.html.

Stackpoole, S. M., G. P. Oelsner, E. G. Stets, et al. 2023. "Integrated Water Resources Trend Assessments: State of the Science, Challenges, and Opportunities for Advancement." *Journal of the American Water*

Resources Association 59, no. 6: 1181–1197. https://doi.org/10.1111/1752-1688.13137.

The Chesapeake Group. 2016. "Economic Impact Model for the Historic South Mountain Fruit Belt in Adams County Pennsylvania." https://www.adamscountypa.gov/getmedia/90208199-6918-42b1-bfba-f9b18fb70444/Adams_Co_Fruit_Belt_Model-91916_Final.pdf.

United States Army Corps of Engineers (USACE). 2022. *National Inventory of Dams (NID)*. 2022nd ed. U.S. Army Corps of Engineers. https://nid.sec.usace.army.mil.

United States Department of Interior (US DOI). 1968. "The Nation's River." https://www.gutenberg.org/files/20503/20503-h/20503-h.htm.

United States Geological Survey (USGS). 2023. *Annual National Land Cover Database (NLCD) Collection 1 Land Cover Conterminous United States*. U.S. Geological Survey. https://doi.org/10.5066/P94UXNTS.

U.S. Census Bureau. 2020. "2020 Census, Summary File 1, Table P1: Total Population." https://data.census.gov/.

U.S. Census Bureau, U.S. Department of Commerce. 2023. "ACS Demographic and Housing Estimates. American Community Survey, ACS 5-Year Estimates Data Profiles, Table DP05, 2023." https://data.census.gov/table/ACSDP5Y2023.DP05.

USACE. 1963. *Potomac River Basin Report 1-2*. Baltimore District, North Atlantic Division. https://catalog.hathitrust.org/Record/006215926.

USACE. 2019. *Chesapeake Bay Comprehensive Water Resources and Restoration Plan (CBCP): Final Report*. U.S. Army Corps of Engineers. https://www.nab.usace.army.mil/Missions/Civil-Works/Chesapeake-Bay-Comprehensive-Plan/.

USACE. n.d. *Memorandum for the Record, Drought Contingency Plan for Jennings Randolph Lake*. USACE North Atlantic Division.

USACE, TNC, and ICPRB. 2014. "Middle Potomac River Watershed Assessment: Potomac River Sustainable Flow and Water Resources Analysis." Final Report. 10 Appendices. https://www.potomacriver.org/focus-areas/water-quality/middle-potomac-sustainable-flow-and-water-resources-analysis/middle-potomac-river-watershed-assessment-products/.

USGS. 2021. *National Land Cover Database (NLCD) 2019 [Raster Dataset]*. U.S. Department of the Interior. https://www.mrlc.gov.

Vaughn, C., and T. Hoellein. 2018. "Bivalve Impacts in Freshwater and Marine Ecosystems." *Annual Review of Ecology, Evolution, and Systematics* 49: 183–208. https://doi.org/10.1146/annurev-ecolsys-110617-062703.

VIMS. 2017. "Submerged Aquatic Vegetation Program." https://www.vims.edu/research/units/programs/sav/.

Virginia Department of Environmental Quality (VA DEQ). 2015. "Commonwealth of Virginia: State Water Resources Plan." https://www.deq.virginia.gov/home/showpublisheddocument/8227/637534969441500000.

Virginia Department of Environmental Quality (VA DEQ). 2020. "Commonwealth of Virginia: State Water Resources Plan." https://www.deq.virginia.gov/home/showpublisheddocument/16134/637991887436000000.

Wallace, C., H. L. N. Moltz, A. Nagel, S. Nummer, and K. R. Bencala. 2024. "Evaluation of Reported and Unreported Water Uses in Various Sectors of the Potomac Basin for the Year 2017." *Journal of the American Water Resources Association* 60, no. 5: 1008–1028. https://doi.org/10.1111/1752-1688.13223.

West Virginia Department of Environmental Protection (WV DEP). 2013. "West Virginia Water Resources Management Plan." http://www.dep.wv.gov/WWE/wateruse/WVWaterPlan/Pages/default.aspx.

Wolman, M. G. 2008. "Water for Maryland's Future: What We Must Do Today." Final Report of the Advisory Committee on the Management and Protection of the State's Water Resources. https://mde.maryland.gov/programs/water/water_supply/Pages/wolman_fullreport.aspx.

Woodhouse, P., and M. Muller. 2017. "Water Governance-An Historical Perspective on Current Debates." *World Development* 92: 225–241. https://doi.org/10.1016/j.worlddev.2016.11.014.