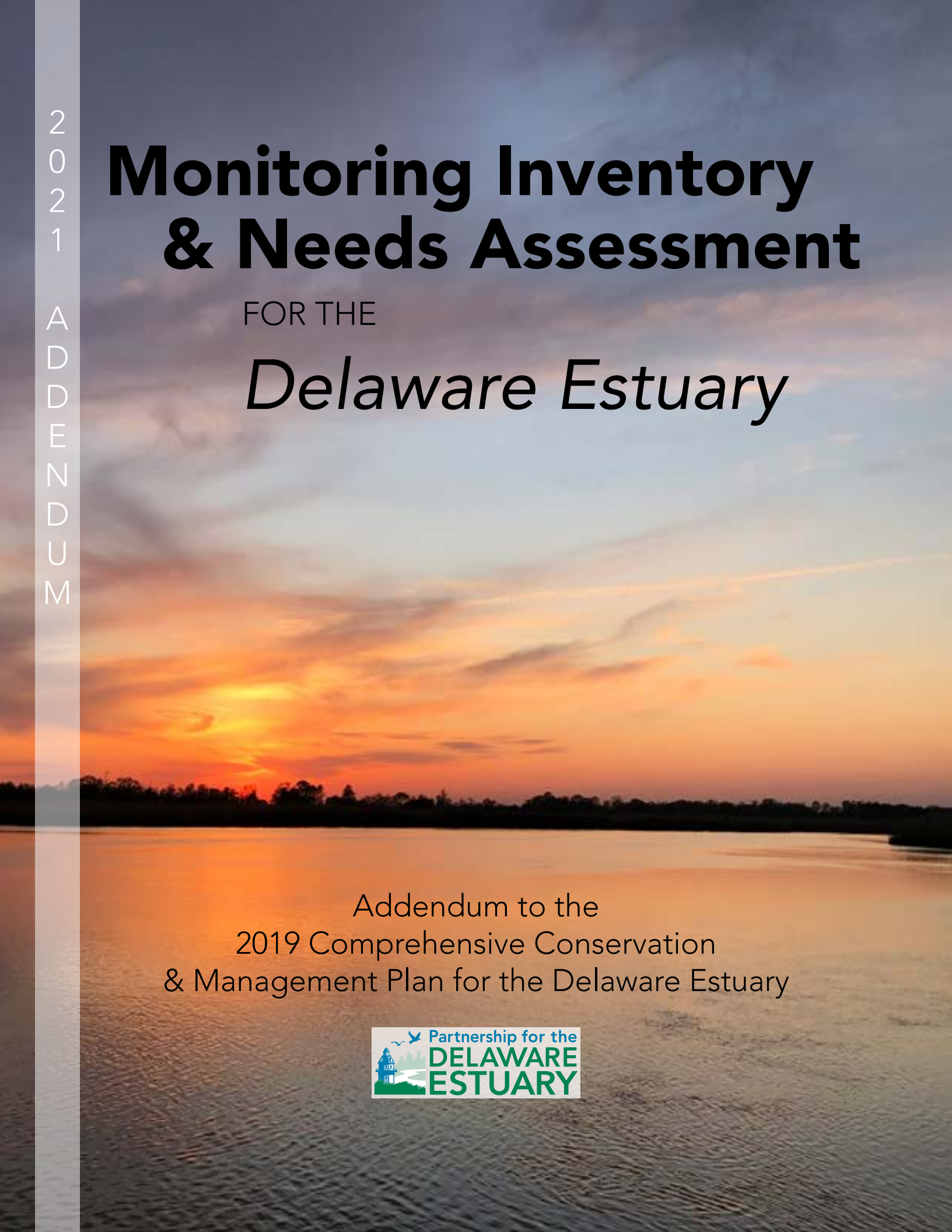
2021 ADDENDUM

Monitoring Inventory & Needs Assessment

FOR THE

Delaware Estuary



Addendum to the
2019 Comprehensive Conservation
& Management Plan for the Delaware Estuary

Partnership for the DELAWARE ESTUARY

Monitoring Inventory and Needs Assessment for the Delaware Estuary

Addendum to the 2019 Comprehensive Conservation and Management Plan for the Delaware Estuary

Final report for
U. S. Environmental Protection Agency

The Partnership for the Delaware Estuary brings together people, businesses, and governments to restore and protect the Delaware River and Bay. We are the only organization that focuses on the entire environment affecting the river and bay—beginning at Trenton, including the greater Philadelphia metropolitan area, and ending in Cape May, New Jersey and Lewes, Delaware. We focus on science, encourage collaboration, and implement programs that help restore the natural vitality of the river and bay, benefiting the plants, wildlife, people, and businesses that rely on a healthy estuary.

Suggested Citation

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Table of Contents

EXECUTIVE SUMMARY

The 2019 Revised Comprehensive Conservation and Management Plan (CCMP) for the Delaware Estuary is a 10- year plan created to guide the work of partners across the region for watershed improvements. The Monitoring Approach section of the revised CCMP outlines activities that facilitate coordination of monitoring of diverse natural resources such as: water quantity, water quality, living resources, and habitats. Tracking of monitoring programs helps to assess CCMP implementation and supports periodic State of the Estuary indicator reporting.

Three strategies outlined in the Monitoring Approach include: 1) joint meetings of the Science & Technical Advisory Committee (STAC) and the Monitoring Advisory and Coordination Committee (MACC) every year, 2) State of the Estuary Reporting every 4-5 years, and 3) inventorying and assessing needs for watershed-wide environmental monitoring activities every 5 years. To address the third monitoring strategy above, this report, the Monitoring Inventory and Needs Assessment (MINA) for the Delaware Estuary, summarizes the results from the first attempt of inventorying and assessing relevant monitoring activities. This inventory of monitoring activities lent itself to the development of this report, and is accessible via the PDE website should constituents want to find more detail regarding involved entities, methodologies, applicable CCMP strategies, and data accessibility.

The Delaware Estuary and River Basin is a large and complex coastal watershed with a unique environmental history, which will encounter diverse challenges in the future. There are many environmental monitoring and assessment programs, being performed by state, regional, and federal agencies, academic and non-profit organizations at widely variable spatial and temporal scales. Due to funding and capacity constraints, the purpose of this MINA report was to identify the major monitoring activities that have the greatest spatial and temporal coverage and which are aligned with the most important environmental challenges and CCMP strategies. With the inclusion of summarizing future monitoring priorities, this report also aims to assist with CCMP implementation and future indicator reporting across the watershed.

To develop the MINA, the Partnership for the Delaware Estuary (PDE) engaged the STAC, MACC, and other monitoring experts to participate in a monitoring workshop, providing an opportunity to identify gaps or redundancies in the overall monitoring infrastructure. An ad hoc MINA workgroup reviewed methods for tracking various monitoring programs across the Delaware River Basin, including results of the 2017 Technical Report for the Delaware Estuary and Basin (TREB), which assesses the overall environmental condition of the watershed by examining the status and trends of key indicators every 5 years. The MINA workgroup also reviewed performance measures and key deliverables for strategies in the 2019 CCMP. The MINA workgroup developed an inventory of current monitoring and tracking efforts across the watershed, and with dozens of additional monitoring experts, were then asked to perform a gap analysis and prioritize the top ten future monitoring needs. The following current top ten monitoring needs list represents a synthesis of survey responses and workshop results:

1. Water chemistry and its effects on key living resources
2. Nutrient pollution and its effects on dissolved oxygen and estuary-dependent living resources
3. Occurrence of endangered, invasive or other ecologically important species
4. Climate change, with a focus on extreme events and ecological effects
5. Sediment quantity, quality and beneficial management in the tidal estuary
6. Sources of water quality impairment and management efforts to reduce pollutants
7. Distribution and abundance of non-commercial bivalve shellfish
8. Tidal wetland condition, and efforts to sustainably manage and restore tidal wetlands
9. Critical habitat availability for fish, blue crabs, horseshoe crabs, freshwater mussels and submerged aquatic vegetation (SAV)
10. Restoration progress, especially regarding natural and nature-based techniques

Given these priorities, we highlight main monitoring activities found in the CCMP Tracking Database, Baseline Monitoring Inventory database, and list lead experts on the subject. Each priority also has key action(s), as well as possible mechanisms for implementing these actions, which serve as recommendations for priority implementation. We further expand on these by outlining the connection of monitoring priorities to CCMP strategies and TREB chapters in accordance with their associated data metrics, partner(s), and funding sources.

For next steps, we propose routine synthesis and assessment of monitoring activities and partner needs. Reporting on the synthesis of monitoring activities, through this report and other follow-up efforts, ensures that DELEP partners can support projects addressing monitoring gaps. Further, we propose to continue with three main strategies to enhance communication among DELEP partners to support CCMP actions, which include 1) joint meeting of the Science & Technical Advisory Committee (STAC) and the Monitoring Advisory & Coordination Committee (MACC), 2) TREB reporting every 4-5 years, and 3) inventory monitoring activities and needs every 5 years. In additional support of these main strategies, we also develop a framework to help DELEP partners continue to make connections between their ongoing work and CCMP implementation. Lastly, this MINA report, and its associated products (i.e. CCMP Tracking databases, NEPORT, Baseline Monitoring Inventory), will serve as a foundation for future CCMP monitoring needs assessments.

INTRODUCTION

Overview of the Delaware Estuary Program

The Delaware Estuary Program (DELEP) is one of 28 National Estuary Programs (NEP) across the coastal United States dedicated to protecting and enhancing estuaries of significance to achieve clean water goals. NEPs were created by amendments to the Clean Water Act (section 320) in 1987 to provide resources for stakeholders to work together to help protect and enhance the nation's estuaries. These programs focus on using collaboration, science, research, outreach, and education to keep estuarine waterways clean and healthy.

In 1988, the governors of the states of Delaware, New Jersey, and Pennsylvania nominated DELEP for inclusion into the NEP, and the DELEP Management Conference was officially convened in July 1989. The Partnership for the Delaware Estuary (PDE), founded in 1996 and host of DELEP, coordinates several DELEP committees, including the Steering Committee (SC), the Estuary Implementation Committee (EIC), and the Science and Technical Advisory Committee (STAC). PDE also has a Board of Directors that governs its operations and engages additional private and local sectors. The SC is comprised of regulatory or non-regulatory decision makers with leadership responsibility in environmental management. The EIC includes additional environmental managers or other professionals, elected by the SC, responsible for implementing regulatory or non-regulatory management or planning decisions. Members of the STAC represent a diverse body of elected or appointed scientists and resource managers with technical expertise. Core Partners of DELEP have standing representation on the STAC, EIC, and SC. The STAC also includes representatives from additional entities, including academia, non-profit, industry, and other government sectors. The Delaware River Basin Commission (DRBC) coordinates the Monitoring Advisory Coordination Committee (MACC) as well as the Toxics Advisory Committee (TAC). Together, these entities – the SC, EIC, STAC, MACC, TAC, and PDE Board – comprise the DELEP Management Conference (Fig 1).

The Core Partners of DELEP include PDE, Philadelphia Water Department (PWD), DRBC, United States Environmental Protection Agency (EPA) Regions 2 and 3, Delaware Department of Natural Resources and Environmental Control (DNREC), New Jersey Department of Environmental Protection (NJDEP), and Pennsylvania Department of Environmental Protection (PADEP).

Comprehensive Conservation and Management Plan for the Delaware Estuary

The Comprehensive Conservation and Management Plan (CCMP) was created to guide the efforts of environmental agencies and organizations in the region to protect the tidal Delaware River and Bay (i.e., the Delaware Estuary). The original plan was written in 1996 included 77 actions and served the Delaware Estuary well for over 20 years. From 2016 to 2018, the DELEP partners worked together with input from hundreds of local stakeholders and experts to revise the CCMP for the Delaware Estuary. The revised 2019 plan lays out goals and strategies for

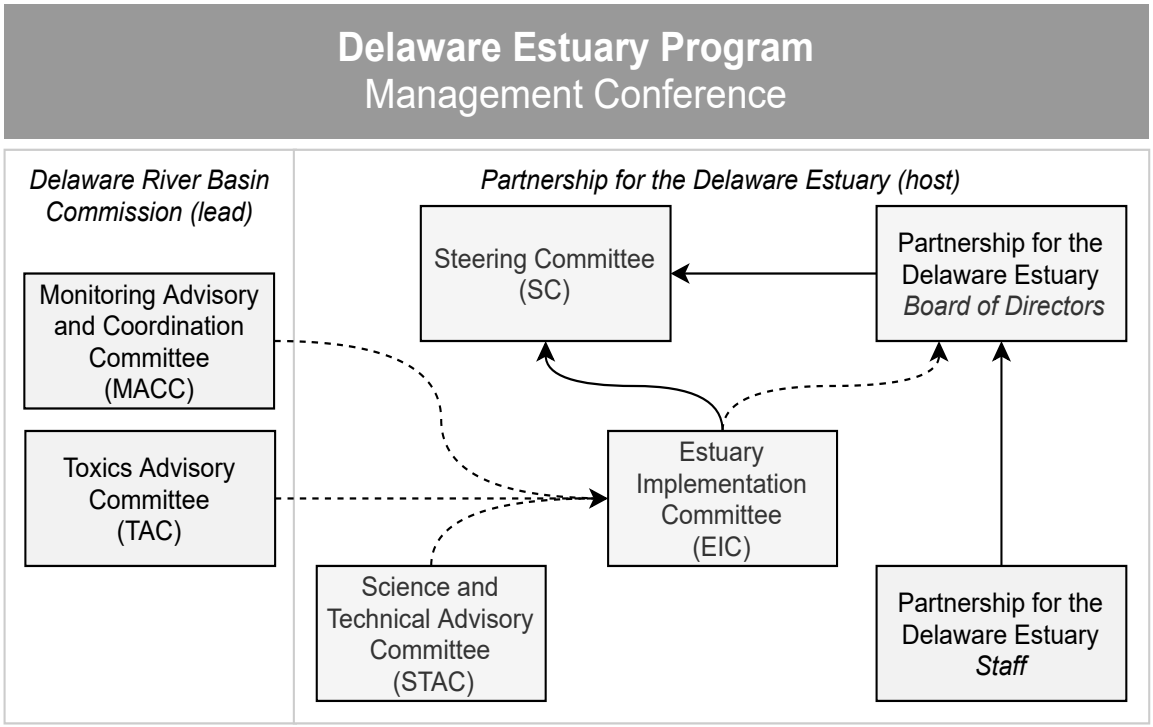

Figure 1. Delaware Estuary Program Management Conference organizational chart. Arrows illustrate relationships among committees, where dashed arrows represent advice or information solicitation and solid arrows are direct reports.

continuing to restore, sustain, and protect the Delaware Estuary over the next 10 years. The revised CCMP is streamlined into eight goals with 39 strategies that are organized into three themes: Clean Waters, Strong Communities, and Healthy Habitats (Appendix A).

Delaware River Basin and Estuary Focus Area

The geographic area for the revised CCMP includes the full extent of the Delaware River Basin, with the Delaware Estuary as a focus area for future protection and restoration efforts. The Estuary Focus Area includes the Delaware Bay, the tidal Delaware River up to the Trenton Falls, and up to the headwaters of the Schuylkill River (Fig 2). The Estuary Focus Area is the priority area of DELEP partners and their work together. Incorporating the entire Delaware River Basin in addition to the Estuary Focus Area, however, acknowledges the need to consider upstream locations that affect downstream Delaware Estuary resources. Driven by these needs, work by PDE and the DELEP partners has expanded beyond the Estuary Focus Area in cases where Estuary priorities require it, and where there are partners and resources to support activities.

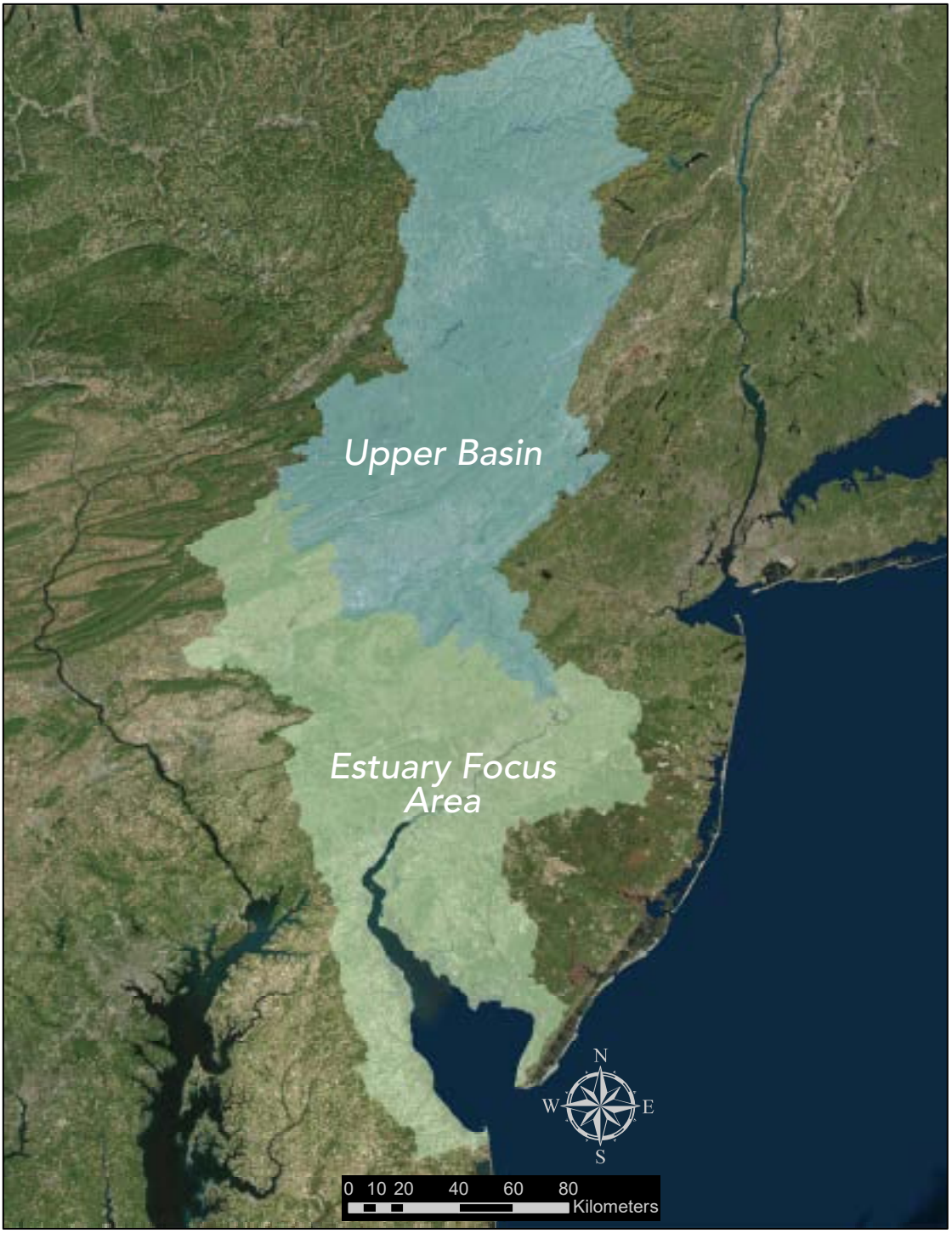

Figure 2. Extent of Delaware Estuary and Basin, with the upper reaches of the Delaware River (Upper Basin, light blue area) and the downstream Estuary Focus Area (light green area), which includes tributaries of the Delaware River and Bay, such as the Schuylkill River.

ASSESSMENT AND REPORTING

Technical Report for the Delaware Estuary and Basin

Overview

The Technical Report for the Delaware Estuary and Basin (TREB) analyzes the best possible current data on the status and trends of 62 environmental indicators, including a diverse suite of water, habitat, and living resources. The purpose of the TREB is to assess the overall environmental condition of the watershed by examining the status and trends of key indicators that reflect the health of its natural systems. The TREB is produced every five years by PDE with input from dozens of partners, representing diverse agencies, academic institutions, companies, and non-profit entities. This report serves as the technical foundation for the State of the Estuary report that shares key findings with the public. The TREB describes future actions and needs that can strengthen indicator reporting and potentially improve environmental conditions.

Environmental Indicators

Environmental indicators are aspects of the environment that can be quantified and are representative of prevailing local conditions. The approach used in the TREB is to gather, analyze, and interpret the best and most recent data for indicators that represent different facets of the Delaware Estuary and Basin's ecosystem. There are eight key indicator categories in the TREB: watersheds and landscape, water quantity, water quality, sediments, aquatic habitats, living resources, climate change, and restoration. Each of these categories includes specific environmental indicators in the corresponding TREB chapters (Appendix B).

Scientists and managers examined historic, current, and predicted future changes of each indicator to develop an understanding of trends. For each indicator in the TREB, there is also a section that summarizes any actions or needs that could strengthen future indicator reporting, which could lead to improved environmental conditions.

Results and Recommendations

The results from the last assessment of indicators in the 2017 TREB suggest that the current health of the Delaware Estuary and River Basin was "fair," reflecting a mix of positive and negative trends (Appendix B). The overall assessment of "fair" health is unchanged from 2012 TREB and the less comprehensive State of the Estuary Report in 2008. Changes in some indicators do not necessarily reflect declining or improving conditions, but rather natural variability. Impact scores are qualitative and based on 1) novelty of the finding for the 2017 reporting period, 2) relative overall impact to estuary and basin-wide health, and 3) immediacy of action need. Impact scores of 1 for positives are very good, whereas a score of 6 for a negative is near detrimental. Averaging all impact scores yields a total score of 3.66, or an overall "fair" for the reporting period's estuary and basin health. Although the "fair" overall health assessment is unchanged since 2008, it reflects substantial improvement compared to earlier decades for many key indicators.

The TREB includes many examples of past successes, ecological interactions, and emerging threats. Since the cumulative impacts to natural resources from both anthropogenic alterations and shifting climate conditions are difficult to predict, continued monitoring of the indicators will be critical for environmental managers to make informed decisions to sustain crucial life-sustaining ecosystem services. To address future environmental challenges, the TREB recommends that agencies, scientists, and others must work together to:

- Sustain and strengthen the effectiveness of monitoring, protection and restoration efforts by focusing on a set of shared, strategic priorities;
- Set science-based goals that plan for change as part of the natural landscape;
- Adopt realistic environmental targets that focus on preserving and enhancing key life-sustaining features;
- Apply an ecosystem-based approach to management that considers cumulative impacts;
- Facilitate collaboration among states and sectors to implement the Comprehensive Conservation Management Plan of the Delaware Estuary Program, through the congressionally designated National Estuary Program for the Delaware River and Bay.

TREB results are also vital for measuring the progress made toward implementing the Comprehensive Conservation and Management Plan (CCMP) for the Delaware Estuary. By tracking indicators and assessing their status and trends every 5 years, periodic revisions and updates to CCMP goals and strategies can be responsive to changing conditions.

Delaware Estuary Comprehensive Conservation and Management Plan Tracking

Tracking Process and Participating Organizations

On an annual basis, PDE collects feedback from organizations across the estuary on CCMP progress and implementation. Each year in June, an initial email request goes out to a listserv of 500+ partners that represent organizations listed in the CCMP as Core, Key, or Contributing Partners for specific CCMP strategies. Core Partners are those that are part of the DELEP Management Conference. Key Partners are those working closely with Core Partner organizations and include work that's essential to CCMP implementation. Contributing Partners are those organizations that help to achieve CCMP goals even though they may not work directly with PDE or DELEP partners.

After the initial request for CCMP activities is sent in June, partners have a 2-month reporting window (June-August) to report back to PDE on their respective strategies as well as any other information on their organizations that relates to CCMP progress. During the reporting period, the opportunity to provide CCMP tracking feedback is shared through various platforms, including PDE's newsletter Estuary News, the Coalition for the Delaware River Watershed's monthly Member Update, and other partner websites, blogs, and email blasts.

CCMP tracking data are collected from partners through an online Google Form distributed to PDE's partner organization database and is also posted on PDE's website. To assist partners with the tracking process, reference documents including instructions for reporting, a map of the Focus Area, an overview of CCMP strategies and project activities, as well as project examples from previous reporting years are provided. The online tracking form collects general project information, spatial data, project metrics, funding and partners involved, and additional project information including contact information for each CCMP project or activity submitted (Appendix C).

Annually, 20 partners directly provide activities as part of the CCMP tracking process. Together, these partners report on projects reflective of the work of more than 70 organizations leading watershed improvement work across the Delaware Estuary.

Performance Measures and Key Deliverables

Progress made on specific CCMP strategies can be measured by reviewing the specific project metrics and associated values submitted to each project or activity (e.g., 50 acres of forested habitat restored). Projects are also evaluated by reviewing how each project entry meets associated performance measures and key deliverables in the respective CCMP strategy. Each CCMP strategy has 2-5 associated performance measures and key deliverables (Appendix A).

Since the completion of the revised CCMP in 2019, two years of CCMP tracking data have been collected and compiled (2019 and 2020). This includes a total of 672 activities (241 Clean Waters, 200 Strong Communities, 234 Healthy Habitats) (Table 1). Each specific CCMP activity submitted can be viewed on the online CCMP Tracking Database (also available as an Excel workbook). All CCMP tracking entries received in 2019 and 2020 were then summarized relative to their corresponding strategy performance measures and key deliverables in the CCMP Strategy and Performance Measures and Key Deliverables report.

Table 1. Number of tracking activities received by the CCMP theme and associated goals between 2019 – 2020.

CCMP theme or goal	# of Activities
Theme 1 | Clean Waters	241
Nutrient pollution	113
Other pollutants	72
Sustain flow	56
Theme 2 | Strong Communities	200
Resilience and access	47
Engagement	153
Theme 3 | Healthy Habitats	234
Wetlands	105
Forests	55
Fish and shellfish	77

CCMP tracking results are shared during the joint meetings of the EIC and the STAC which take place annually in September or October. Highlights from annual CCMP tracking results are shared in a section of PDE's newsletter Estuary News with other current projects and activities associated CCMP implementation labelled throughout each issue of the newsletter. PDE also creates a public-friendly CCMP Summary Brochure to help promote implementation of the CCMP, which is distributed during outreach and education events and emailed to partners.

CCMP tracking presentations, the CCMP tracking database, and the associated CCMP tracking resources are posted on PDE's Our Plan webpage. There is also an online, interactive map through Carto posted on this page with locations and details of activities reported through CCMP tracking (Fig 3A). The Carto map includes locations for activities where spatial data (i.e., latitude and longitude coordinates) were provided in the project entry submitted to PDE. There are more than 200 points represented on the map of the 600+ total projects submitted over the past two years. Each project listed on the map provides a clickable point that displays project details.

The CCMP reporting process will continue to take place on an annual basis, but may be subject to change. For instance, after DELEP committee member review, the frequency or timing of data collection, as well as the methodology used to capture data, may change based on future discussions and lessons learned.

National Estuary Program Annual Work Plan

Annually, PDE proposes outputs and deliverables to EPA for PDE-led activities as part of the work plan reporting process. Twice annually, PDE prepares and reports its accomplishments on these deliverables to EPA using the data and parameters established in the Work Plan, with copies provided to the PDE Board and EIC (part of the DELEP Management Conference). Each of the PDE-related activities listed in the work plan reference the supporting CCMP strategies.

Governmental Performance and Results Act Reporting

The Governmental Performance and Results Act (GPRA) process requires annual data collection and reporting of DELEP partner habitat and restoration projects. Each summer, PDE collects and compiles data from the Core Partners and their agencies on dollars leveraged and habitat acres protected or restored. PDE collects this information from partners through spreadsheets. After receiving completed spreadsheets, PDE compiles and reviews results and then submits the data to EPA for review and approval through EPA's National Estuary Program Online Reporting Tool (NEPORT). Projects that are approved on NEPORT are posted on EPA's NEP map application that allows viewers to explore habitat projects in each of the NEPs across the coastal United States (Fig 3B-C). The PDE CCMP tracking timeline runs concurrently with the NEPORT reporting timeframe so that projects reported to NEPORT can also be reviewed and count towards specific strategies related to CCMP implementation progress.

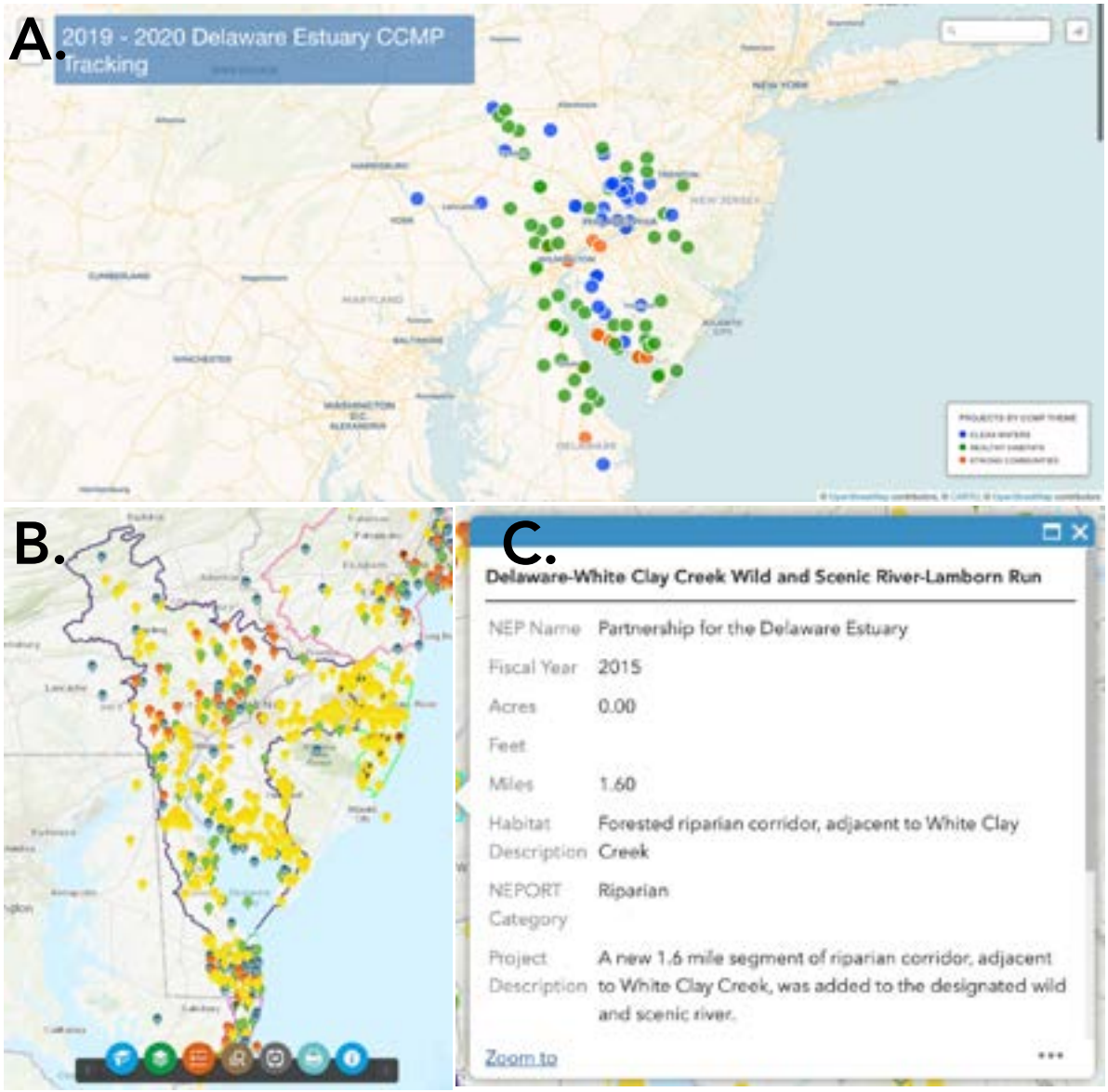

Figure 3. Map of CCMP activities where spatial data were provided in CCMP tracking submission (A), as well as the NEP map of NEPORT-approved projects with view of DELEP-approved habitat projects (B) and details available for each project (C).

MONITORING APPROACH

A Monitoring Approach section was required as part of the 2019 revision of the CCMP to outline how DELEP will assess critical monitoring activities across the region. Goals of the Monitoring Approach are to establish a baseline monitoring inventory for periodic reassessment and create a list of future monitoring priorities.

The three key activities in the CCMP Monitoring Approach include joint STAC-MACC meetings, state of the estuary reporting, and the Monitoring Inventory and Needs Assessment (Table 2).

Key activities outlined in the CCMP Monitoring Approach (joint annual STAC-MACC meeting, SOE report, TREB, monitoring workshop) as well as the CCMP, PDE's Strategic Plan, and other priorities led by DELEP committees, all contribute to directing strategic planning and priorities for PDE and DELEP (Fig 4). PDE and DELEP partners are actively working to align these current and future efforts to streamline DELEP planning and science priorities in the Delaware Estuary.

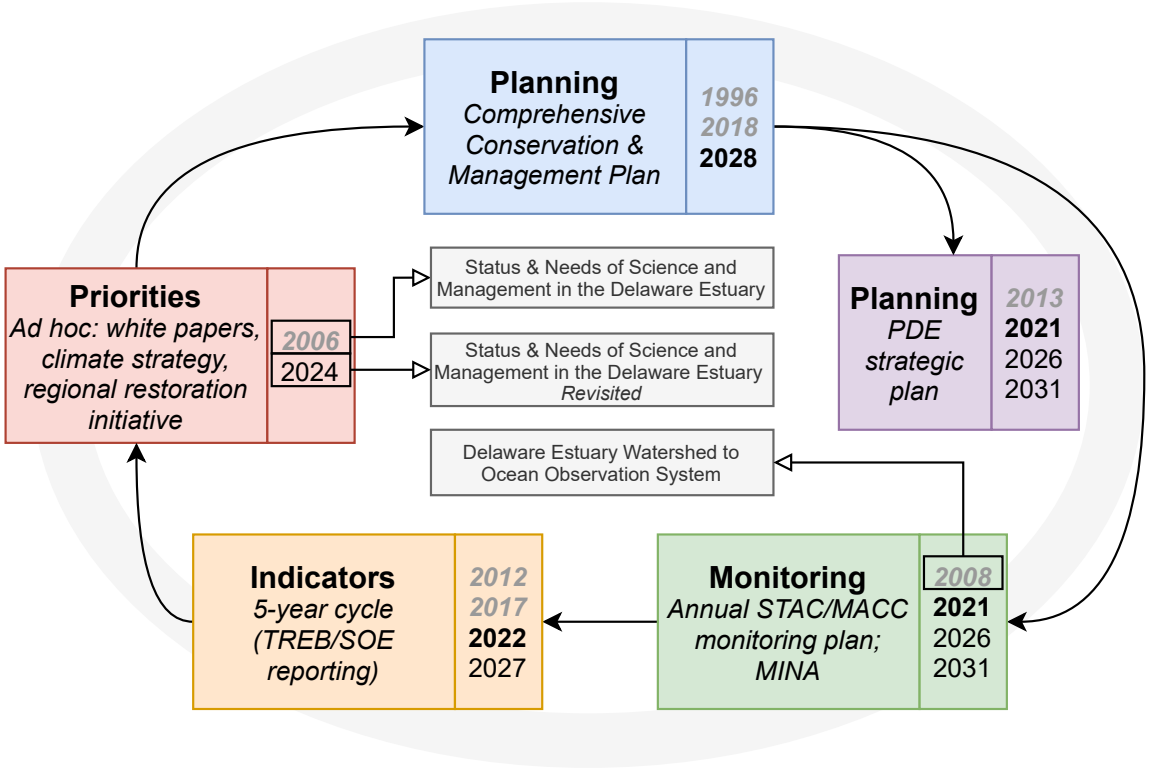

Figure 4. DELEP future planning and science task framework that shows continuous, yet stepwise, implementation of key DELEP activities. Each box represents a key activity with descriptions of the anticipated product (e.g., Planning for the CCMP). Past (grey, bold text) or anticipated implementation years (black text, with bold text highlighting upcoming products) are attached to the right of each planning step. Additional product examples, with production years highlighted, are provided in grey boxes in the workflow center.

Table 2. Three key activities that constitute the CCMP Monitoring Approach.

Activity		Frequency	Description
1. Joint meeting of the Science & Technical Advisory Committee (STAC) and the Monitoring Advisory & Coordination Committee (MACC)		Annually	The annual joint STAC-MACC meeting provides an opportunity to report out on current monitoring activities and coordinate plans for future monitoring efforts. Results from this meeting are shared with the EIC to be considered in DELEP-related decision-making related to research and monitoring.
2. State of the Estuary Reporting	Technical Report for the Delaware Estuary & Basin (TREB)	Every 4-5 years	PDE coordinates production of a basin-wide indicator report that assesses the status, trends and future needs for 57 environmental indicators, which provides the technical basis for the public-friendly State of the Estuary report which is developed after the TREB report is completed. The most recent TREB reports were completed in 2012 and 2017, and the next TREB report is expected to be completed in 2022.
	State of the Estuary (SOE) Report	Every 4-5 years	PDE translates ~20 environmental indicators for the public as a means to summarize the status and trends for the environmental health of the Delaware Estuary watershed. SOE reports were created in 2002, 2008, and 2012. The next SOE is scheduled to be completed in 2022 and will use the 2022 TREB as the technical foundation for this summary report (***Note:*** *A SOE was not produced in 2018 since PDE and DELEP partner resources were heavily allocated to the revision of the CCMP from 2016 - 2018*).
3. Delaware Estuary Monitoring Inventory and Needs Assessment		Every 5 years	A monitoring workshop is held to review current monitoring programs, identify gaps, and help prioritize future efforts. Outcomes are used to develop an inventory of monitoring programs and consensus views on top of monitoring priorities, leading to a synthesis report (i.e., this report). The initial monitoring workshop took place in October 2018, followed by additional data collection efforts, inventory analyses and development of the Monitoring Inventory and Needs Assessment (MINA) report during 2019-2020. The next workshop is scheduled to take place in 2023, following completion of the 2022 TREB which facilitates the MINA effort.

Inventory of Current Long-Term Monitoring Programs

Baseline Monitoring Inventory

To facilitate implementation of the monitoring approach, DELEP partners intend to inventory monitoring programs every five years to facilitate coordination, gap analyses and prioritization of monitoring activities and needs. In September 2018, 300 regional scientists and monitoring experts were invited to provide information on past and present monitoring efforts to be incorporated into a baseline monitoring inventory for the Delaware Estuary (Appendix D). The geographic focus for this inventory was the full extent of the Delaware River Basin, with special emphasis on the lower half of the watershed that comprises the Delaware Estuary Focus Area, as outlined in the revised CCMP. Special attention was given to monitoring programs that were geospatially broad and conducted over longer time periods.

The Delaware Estuary Baseline Monitoring Inventory includes 634 monitoring activities from over 35 different organizations across the watershed (Table 3). The monitoring inventory contains information on metric type, temporal and spatial coverage, sampling method, data availability and access, and general project information. The complete Delaware Estuary Baseline Monitoring Inventory workbook with details of each of the 600+ activities reported and their associated CCMP strategies is available for download from the PDE webpage.

Environmental Response Management Application and the Delaware Estuary Monitoring Inventory

Coordinating with the Partnership for the Delaware Estuary (PDE), the National Oceanic and Atmospheric Administration (NOAA) added parameters from the Delaware Estuary Baseline Monitoring Inventory as an area of interest layer on NOAA's Environmental Response Management Application (ERMA). This application is a web-based Geographic Information System (GIS) tool that assists both emergency responders and environmental resource managers in dealing with incidents that may adversely impact the environment. Inclusion of monitoring inventory data into ERMA facilitates broader awareness and use of the inventory as well as provides a geospatial tool for analyzing past and current monitoring activities in the watershed.

ERMA layers from the Delaware Estuary Baseline Monitoring Inventory outline the Delaware Estuary Focus Area and the secondary upper portion of the Delaware River Basin and include monitoring inventory layers separated by characteristic group (e.g., chemical, physical) (Fig 5).

As PDE works with regional partners to provide periodic inventory updates, NOAA will update the Delaware Estuary Baseline Monitoring Inventory layer on ERMA to be reflective of the most up-to-date monitoring data for the region. The next review of the Delaware Estuary Baseline Monitoring Inventory is planned for 2023-2024 (updated every 5 years).

Table 3. Long-term monitoring activities in the Delaware Estuary by characteristic group, associated CCMP strategies, and a total number of reported activities.

Monitoring Category	# of Participating Institutions	Characteristic Group	Associated CCMP Strategies	# of Long-Term Monitoring Activities
WATER	38	Nutrients	W1.5	124
		Water Quality	W1.5, W3.2, H1.1, H3.2	111
		Organics	W2.4, W1.5	79
		Inorganics (Non-metals)	W1.5	59
		Chemical/Chemistry	W1.5, W2.4, H1.1	31
		Inorganics (Metals)	W1.5	22
		Toxicity	W1.5, W2.4, H1.1	6
		PCBs	W2.3	2
		Pesticides	W2.4, W2.5	2
LIVING RESOURCES	23	Vegetation	W2.4, H1.1, H1.2, H1.3	24
		Animals (Invertebrate)	W1.5, W3.2, H3.2, H3.3, H3.5	21
		Animals (Vertebrates)	H3.1, H3.5	9
		Microbiological	W1.5	16
		Other Biological	W1.5, H1.1	7
HABITATS	25	Physical	H1.1, H1.2, W1.5, W2.4	39
		Sediment	W1.5, W2.4, W3.5, H1.1	30
		Spatial	W1.2, W1.3, H3.1, C1.1, C1.3	11
		Hydrology	W1.5, H1.1	10
		Habitat	W3.2, H3.1	7
		Geology	Other*	6
		Buffer	H1.1	5
		Atmospheric	H1.1	2

*e.g., surface and bedrock geology, earthquake catalogue

A.

B.

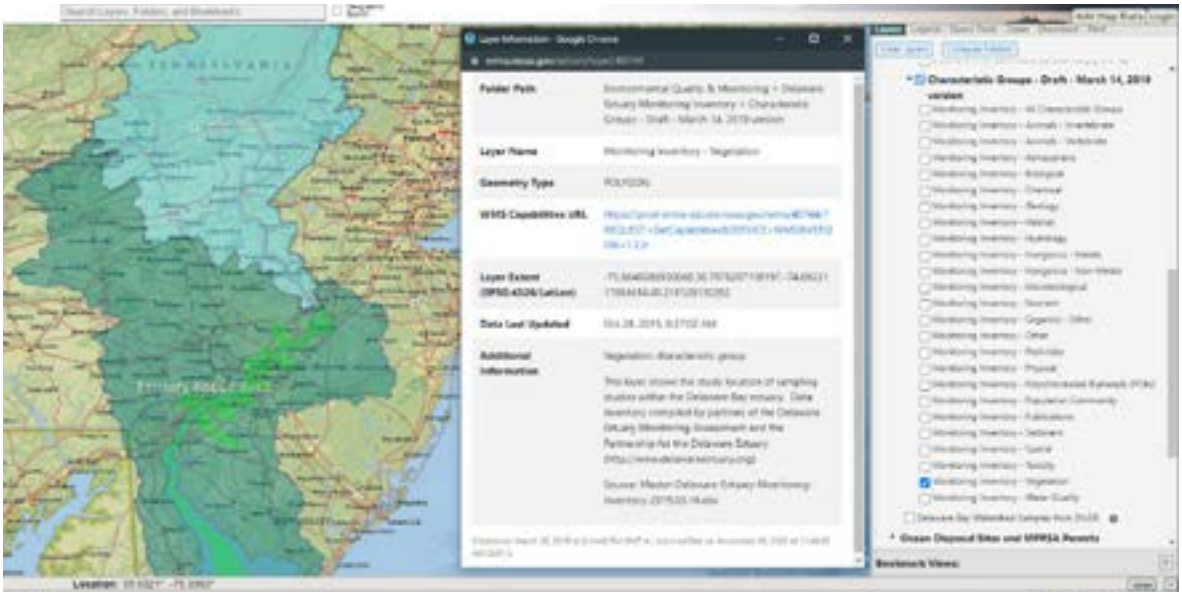

Figure 5. Delaware Estuary Baseline Monitoring Inventory activities by characteristic group layers in ERMA via polygon AOI query (A) and map click query (B).

Monitoring Priorities

Engagement of Monitoring Experts for Gap Analysis

Monitoring Workshop Summary

A monitoring workshop was convened in October 2018 to review the draft inventory of monitoring parameters, identify gaps in data collection, and gather input to help prioritize future monitoring efforts. A total of 36 individuals from Delaware River watershed organizations such as the Delaware Department of Natural Resources and Environmental Control (DNREC), New Jersey Department of Environmental Protection (NJDEP), and the Philadelphia Water Department, among others, participated in the monitoring workshop (Appendix D).

Monitoring workshop participants also suggested evaluating the level of effort that would be required to create a geospatial representation of the monitoring inventory entries. Participants also recommended ensuring that there are sufficient habitat and wildlife representatives involved in, or contributing to, the monitoring inventory review process (e.g., collect additional monitoring data from regional forestry experts) (Appendix D).

Prioritization and Ranking of Monitoring Parameters

A monitoring survey was sent to a list of 300 regional scientists and monitoring experts in December 2018 to examine results from the October 2018 monitoring workshop, aid in prioritizing and ranking results from the workshop, and gather additional missing information from the draft Delaware Estuary Baseline Monitoring Inventory. The survey sub-divided monitoring inventory activities into four sets of parameters: non-plant living resources, plants and habitat, water quality in the Delaware River and Bay, and water quality in tributaries (see workshop results above). For each of the four sets of parameters, respondents were asked to rank the importance of various parameters in a list that were identified at the workshop as not yet being robustly monitored in their respected study area (Table 4). Fifty-five people from 34 organizations, companies, and universities representing a diverse spread of expertise participated in the monitoring survey (Appendix D). Monitoring workshop participants, as well as monitoring survey recipients, were provided a second opportunity to peer review the draft Delaware Estuary Baseline Monitoring Inventory following the monitoring workshop and post-workshop survey. This allowed for further review findings and submit any missing activities that should be included in the monitoring inventory.

Table 4. Parameters that survey respondents suggested were high priority, with columns denoting categories and rows listing the top two prioritized parameters within each category.

Non-plant living resources	Plant and habitat	Water quality in the Delaware River and Bay	Water quality in tributaries
• Invasive species • Freshwater bivalves	• Cumulative impacts • Submerged habitat	• Endocrine disruptors • Fish tissue analysis for bioaccumulating compounds	• Wet weather (storm flow) monitoring • Flow measurements

Climate Vulnerability Assessment

The Climate Vulnerability Assessment (CVA) is an assessment of the vulnerability of DELEP's CCMP strategies to climate change stressors. The CVA is a companion to the CCMP process. For this assessment, input was solicited from approximately 300 scientists and experts on topics related to the CCMP themes of Clean Waters, Healthy Habitats, and Strong Communities. In 2016, over 150 of these experts provided responses to a series of open-ended survey questions on actions underway and actions needed to address these topics. All surveyed experts were invited to participate in a series of workshops to further refine the ideas to modify goals, strategies, and actions of the CCMP. PDE compiled over 1,700 ideas from these surveys and listening sessions along with additional feedback collected from its STAC and EIC. This information was then used to create a "Core Elements" document, which helped identify whether CCMP strategies were vulnerable to climate change.

Below, the greatest climate risks to CCMP strategies are detailed. While these strategies were ranked as most vulnerable, no strategies were deemed too risky as to render them unachievable. With respect to monitoring CCMP strategies, these climate vulnerability areas likely require heightened focus to ensure that changing conditions are adequately tracked.

Under the Healthy Habitats goals and strategies (strategy numbers follow each bulleted point), the following risks stood out as greatest:

- Climate stressors are likely to create a high risk to the successful implementation of best management practices for forests (H2.2).
- The task of inventorying, mapping, and enhancing habitat for fish and crabs was deemed very vulnerable as a result of climate change impacts biasing assessments, shifting species range, shifting food, and inducing earlier spawns or otherwise changing spawning habitat (H3.1).
- Increased frequency and duration of rainfall events and sea level rise were seen as threats to protecting and restoring horseshoe crab habitat, eroding it away, reducing spawning events, and impacting opportunities for volunteer activities around horseshoe crabs (H3.4).

Under the Strong Communities goals and strategies, the following were regarded as higher risk:

- Restoring working waterfronts while confronted with increased frequency and duration of rainfall events that could damage waterfronts and wetlands, diminishing fish populations and impacting local industry; as well as sea level rise that threatens to overtake waterfronts altogether (C1.1).
- Utilizing natural areas and waterfronts to connect people to the Delaware Estuary is vulnerable to sea level rise, which may lead to a loss of waterfronts and coastal areas (or access to these areas) over time.

Finally, for the Clean Waters goals and strategies, the most vulnerable were judged to be:

- Sea level rise permanently inundating contaminated waterfront sites before they have been remediated (W1.2);

- Increased frequency and duration of rainfall events disturbing installations and limiting opportunities available for installations and maintenance (W3.2); and
- Warmer water impacting monitoring on salinity impacts and flow needs for biological/ ecological endpoints by increasing the risk of algal blooms and oyster disease (W3.5).

CCMP Strategy and TREB Action Comparison Matrix

PDE worked with the STAC to compare actions and needs related to TREB indicators to the CCMP strategies to help identify common resource protection and restoration priorities. The resulting CCMP Strategy and TREB Action Comparison Matrix was created as an Excel workbook. The CCMP Strategy and TREB Action Comparison Matrix includes numerous activities and needs that directly relate to monitoring. The CCMP-TREB Needs workbook contains:

- **CCMP-TREB Nexus Matrix (Tab 1):** Pivot chart demonstrating TREB indicators that are supported by CCMP strategies. Under each supported TREB indicator, associated supporting CCMP strategies and lead organizations for both the TREB indicator (chapter author) and CCMP strategy Core Partners are listed to demonstrate lead organizations responsible for the listed activities;
- **TREB Outliers Matrix (Tab 2): TREB indicator**s that have no corresponding CCMP strategy to directly support the TREB indicator actions and needs;
- **Indicator-Measure Matrix (Tab 3)**: Matrix displaying TREB indicators with direct links to CCMP Performance Measures and Key Deliverables.

Outlining the TREB indicators supported by CCMP strategies in the CCMP-TREB Nexus Matrix provides a synopsis of how CCMP strategies and TREB indicators are working towards common goals with overlapping partners. The CCMP Strategy and TREB Action Comparison Matrix can assist with CCMP tracking and implementation by identifying TREB indicators with direct links to CCMP Performance Measures and Key Deliverables. This helps identify additional datasets that can be used to track CCMP progress that might not be captured through the current CCMP tracking reporting tool.

Reviewing gaps identified in the TREB Outliers Matrix helps identify key environmental indicators that should be considered for incorporation in future CCMP updates and revisions (Appendix E). Since the environmental indicators listed in the TREB are indicators that are robustly monitored across the Delaware River Basin, TREB indicators missing from the 2019 CCMP should be evaluated for future CCMP integration. Further, CCMP strategies not currently represented in the TREB, may be additionally important to consider for tracking through TREB or other related efforts. For instance, as TREB focuses on quantitative and scientific output, Strong Communities and other strategies pertaining to outreach or education tended to be least represented in the TREB but still represents a critical component of improved conditions in water quality across the Delaware River Estuary and Basin.

Gap Analysis Summary and Prioritization of Monitoring Needs

After reviewing the results in the CCMP Strategy and TREB Action Comparison Matrix, members of the STAC and MACC were asked to rank the level of importance of TREB and CCMP activities based on their expertise and knowledge of current and future Delaware Estuary priorities and needs. A STAC Priorities List Development workbook with a list of TREB indicators and CCMP strategies was circulated to STAC and MACC for committee members to rank their top ten priorities. STAC and MACC members were asked to prioritize 10 of the 39 total CCMP strategies and 10 of the 61 total actions listed in TREB (summary in Appendix E).

Consensus Views on Delaware Estuary Monitoring Priorities

Through a gap analysis reviewing the results of the Monitoring Assessment effort (Baseline Monitoring Inventory, monitoring workshop, and expert survey results) and CCMP-TREB comparison matrices and input priority ranking received by STAC and MACC participants, 10 priorities for monitoring activities across the watershed were identified (Table 5)(Appendix F). Priorities were assigned by averaging expert ranks of individual CCMP and TREB as they related to each monitoring activity. These priorities were also cross-walked with gaps that were identified between the TREB and CCMP (Appendix E, F). Generally, the CCMP has no explicit strategies that directly address several TREB indicators for water quality, climate change, and species- or clade-specific population dynamics (e.g., weakfish, osprey and macroinvertebrates). The TREB, on the other hand, seldom addresses CCMP strategies associated with engagement, education, or promotion of water or habitat qualities.

Delaware Estuary Monitoring Priorities

In the following pages, further detail about each monitoring priority is described. These descriptions include key driving questions for each priority, which aim to help clarify possible data metrics and deliverables for each priority. In addition, we highlight main monitoring activities found in the CCMP Tracking Database, Baseline Monitoring Inventory database, and list lead experts on the subject. Each priority also has key action(s), as well as possible mechanisms for implementing these actions, which serve as recommendations for priority implementation. It is important to note that many of the DELEP partners and other organizations implementing monitoring activities will have different timelines for projects; therefore, timeline information is not reported here. Instead, timeline updates will occur as information about general or priority monitoring is collected within other regularly scheduled communications (e.g., CCMP strategy monitoring updates). Lastly, the monitoring priorities described here are scientific and quantitative in nature, but it is important to note that a large portion of the CCMP is focused on strengthening communities, as Theme 2. Theme 2 goals and strategies may not yet have quantitative data metrics. Therefore, to help guide prioritization of engagement and outreach tasks, we list associated CCMP strategies from the "Strong Communities" theme in the priority narrative below, in addition to the strategies for "Clean Waters" and "Healthy Habitats."

Table 5. Monitoring activities with associated STAC and MACC member priority listings.

Priority monitoring activities	Weighted priority rank (average priority score)
Water chemistry (pH, salinity, contaminants) and its effects on key living resources	1 (3.67)
Nutrient pollution and its effects on dissolved oxygen concentrations and estuary-dependent living resources (e.g., fish, shellfish, submerged aquatic vegetation)	2 (4.23)
Occurrence of endangered, invasive or otherwise important species	3 (5.08)
Climate change, especially extreme events (temperature, precipitation) and its ecological effects	4 (5.30)
Sediment quantity, quality and beneficial management efforts in the tidal estuary	5 (5.35)
Sources of water quality impairment and management efforts to reduce pollutants	6 (5.65)
Distribution and abundance of non-commercial bivalve shellfish (e.g., ribbed mussels, freshwater mussels)	7 (5.75)
Tidal wetland condition, and efforts to sustainably manage and restore tidal wetlands	8 (5.76)
Critical habitat availability for fish, blue crabs, horseshoe crabs, shellfish, and SAV	9 (6.14)
Restoration progress, especially regarding natural and nature-based techniques	10 (6.38)

Water chemistry (pH, salinity, contaminants) and its effects on key living resources
W3.1, W3.2, H3.1-5
C2.1, C2.5, C2.6, C2.7

How is water chemistry (e.g., pH, salinity, contaminants) affecting the distribution of estuary-dependent plants and animals?

Example activities in Monitoring Inventory Delaware River Main Channel Deepening (VERSAR), Special Protection Waters Monitoring (DRBC), Delaware StreamWatch (Delaware Nature Society), National Coastal Condition Assessment (EPA)

Action DELEP partners will continue to support ongoing water chemistry monitoring activities throughout the region. DELEP partners will also be encouraged to incorporate water chemistry monitoring into their living resource work, and share that data to provide a more holistic picture of water chemistry throughout the estuary as well as its potential impacts. Sharing avenues include but are not limited to during the annual MACC meeting or during quarterly STAC meetings. DELEP partners will continue to monitor water quality in its projects in the Delaware Estuary where it is already implemented. In addition, where desired, DELEP partners will attempt to link potential water quality to change in living resource health whenever possible.

Mechanisms Share SOPs or BMPs with relation to water quality monitoring; peer review manuscripts or reports relating to effects of water chemistry on living resources in the estuary; share new information and/or provide updates on water chemistry at meetings with DELEP partners (MACC, STAC or other groups); provide letters of support to partners; secure funding for water chemistry research and monitoring; support state and DRBC initiatives to better capture quantitative data.

Experts DRBC, United States Geological Survey, EPA, States, NJ Audubon, PDE

Nutrient pollution and its effects on dissolved oxygen concentrations and estuary-dependent living resources (e.g., fish, shellfish, submerged aquatic vegetation)
W1.5, H3.1-5
C2.1, C2.5, C2.6, C2.7

How is nutrient pollution influencing dissolved oxygen concentrations? How are dissolved oxygen concentrations affecting the distribution of estuary-dependent plants and animals?

Example activities in Monitoring Inventory DRBC Delaware Estuary Water Quality, DRBC Biomonitoring, Temple University William Penn Upstream Suburban Philadelphia monitoring, Philadelphia Water Department Delaware and Schuylkill Boat Runs, and Academy of Natural Science of Drexel University Patrick Center Environmental Monitoring

Action DELEP partners will support organizations in the watershed who are already studying the effects of DO through participation in workgroups, and will encourage each other to

be engaged in the analysis and discussion. DELEP partners will be encouraged to continue to improve DO models, as new data is enmassed around the region. DELEP partners will be encouraged (e.g., through workgroups, like MACC and PDE STAC) to increase their understanding of the effects of DO on living resources in the region. DELEP partners will also be supportive of continued funding opportunities for studying these effects in new or continuing projects.

Mechanisms Facilitate partnering with modelers and industry, share information on reducing anthropogenic nutrient runoff; promote importance of estuary-dependent living resources on social media; provide letter(s) of support for partners; secure funding to monitor nutrient levels at field sites throughout the estuary; secure funding to provide mitigation that will positively impact dissolved oxygen levels.

Experts DRBC, USGS, States, Rutgers University Haskin Shellfish Research Laboratory, ANSDU

Occurrence of endangered, invasive or otherwise important species
W1.2, H3.5
C2.1, C2.5, C2.6, C2.7

What is the distribution or abundance of endangered, invasive, or otherwise important species? What factors contribute to these species' distribution or abundance? How do population dynamics change spatially and temporally across these distributions?

Example activities in Monitoring Inventory Academy of Natural Sciences, Stroud Water Research Center, National River and Streams Assessment (NRSA - EPA), Atlantic Sturgeon Study (Delaware State University), Songbird migration and breeding bird monitoring (Delaware State University), Bat inventory (Delaware State University)

Action DELEP partners will continue to garner external partnerships with entities that work closely with endangered or invasive species, as well as continue study of important species like freshwater mussels. DELEP partners will maintain openness to sharing information with those working with endangered or invasive species relative to its ongoing projects to potentially fill gaps or provide connections between comparative ecosystems or organisms.

Mechanisms Secure funding to facilitate research of invasive and endangered species; encourage partnerships between entities researching invasive and endangered species in the estuary; provide letter(s) of support for entities working with invasive or threatened species; share importance of endangered species conservation; inform of risks of expanded distribution of invasive species, assist in creating or sharing information to the public about threatened species in the region.

Experts USFWS, ANDSU, Delaware State University

Climate change, especially extreme events (temperature, precipitation) and its ecological effects

H3.1, H3.3, H3.4, H3.5

C2.1, C2.5, C2.6, C2.7

How is climate changing? What are the ecological consequences of a changing climate?

Example activities in Monitoring Inventory DRBC Delaware Estuary Water Quality, National River and Streams Assessment (NRSA - EPA), Wetland CO_2 and CH_4 exchange (Villanova University)

Other monitoring examples NOAA National Centers for Environmental Information (NCEI)

Action Support DELEP entities that study climate and collect relevant data following storm events. Advocate for new or continuing projects being carried out by DELEP partners, specifically any that would investigate ecological effects of climate change.

Mechanisms Secure funding for long-term climate monitoring; promote importance of climate science; share information on reducing human impacts on climate; promote importance of studying extreme storms in relation to climate.

Experts Penn State University

Sediment quantity, quality and beneficial management efforts in the tidal estuary

W2.3, W2.5, W3.5, H1.2

C2.1, C2.5, C2.6, C2.7

What is the quantity and quality of sediment in the waterways of the Delaware Estuary and Basin? How have beneficial management efforts in the tidal estuary progressed?

Example activities in Monitoring Inventory DNREC Wetland Monitoring and Assessment Program; Bureau of Ocean Energy Management offshore sand resources (DGS)

Other monitoring examples Regional Sediment Management, MACWA, NRCS Soil Surveys

Action Encourage DELEP partners to continue sediment analyses and carry on with beneficial management throughout the estuary and maintain openness to including sediment analysis in future projects as well. Continue to include sediment management in discussions at MACC and STAC meetings, and it's connection with climate change.

Mechanisms Promote the importance of sediment management in the Delaware Estuary with stakeholders and funders; help partners through letters of support when needed; share updates about sediment management at meetings and conferences; encourage conversation with partners and experts about best management practices; secure funding to continue sediment research and BMP formulation.

Experts ACoE, DRBC, USGS, NRCS

Sources of water quality impairment and management efforts to reduce pollutants
W1.1, W1.2, W1.3, W1.5, W2.2, W2.3, W2.4, W2.5, W2.6
C1.2, C1.3, C2.1, C2.2, C2.5, C2.6, C2.7

What and where are sources of water quality impairment? What management efforts have been undertaken to address these issues?

Example activities in Monitoring Inventory PWD Quarterly Dry Weather Grab Sampling, DE River Tributary Monitoring Project (The Watershed Institute)

Action DELEP partners will continue to support and promote the efforts of DRBC for monitoring water quality, and identifying sources of its impairment. DELEP partners will continue to share water quality data through already established workgroups, and will partner in ways to reduce pollutants.

Mechanisms Secure funding to identify and potentially resolve water quality impairments; help partners through letters of support; promote water quality importance on social media; share new information and/or provide updates on water chemistry when possible; develop outreach and engagement strategies to promote best practices for maintaining good water quality in the Estuary; support and participate in multi-agency workgroups, as needed, to help guide decision-making about water quality impairments in the Estuary.

Experts DRBC, States

Distribution and abundance of non-commercial bivalve shellfish (e.g., ribbed mussels, freshwater mussels)
W1.2, H3.5
C1.2, C1.3, C1.4, C2.1, C2.5, C2.6, C2.7

What is the distribution and abundance of non-commercial bivalve shellfish? What factors contribute to patterns in their distribution and abundance?

Example activities PDE's FMRP, PDE's MuCWI, State databases

Action PDE, with partners, will continue to lead freshwater mussel assessments and research in the Delaware Estuary through the FMRP and MuCWI programs. PDE will also perform assessments on the distribution and abundance of ribbed mussels in tidal wetlands when possible and feasible, as funding allows. DELEP partners, especially the states, will be engaged in sharing distribution data.

Mechanisms Secure funding for FMRP; secure funding for MuCWI; secure funding for research on non-commercial bivalve distribution and abundance; promote the importance of non-commercial bivalves to Estuary condition and health; help partners through letters of support; support and participate in multi-agency workgroups, as needed, to help decision-makers consider the role of these bivalves to the ecology of the Estuary.

Experts PDE, Rutgers University

Tidal wetland condition and efforts to sustainably manage and restore tidal wetlands

H1.1, H1.2, H1.3, H1.4, H3.1

C1.1, C1.2, C1.3, C1.4, C2.1, C2.5, C2.6, C2.7

What is the spatial distribution of tidal wetland condition? How successful are efforts to manage and restore tidal wetlands? How do tidal wetlands respond to pressures (e.g., urbanization, eutrophication, and/or climate change)?

Example activities in Monitoring Inventory DNREC Wetland Monitoring and Assessment Program, NJDEP Beneficial Use of Dredged Material to Restore Salt Marshes

Other monitoring examples PDE's MACWA, PDE's DELSI

Action PDE, with DELEP partners, will continue to lead research and assessments on tidal wetland condition in the Delaware Estuary. PDE will also continue to promote and participate in local and regional workgroups focused on the science and restoration of tidal wetlands.

Mechanisms Secure funding for MACWA; secure funding for DELSI; secure funding for research and assessments of tidal wetland condition or extent; help partners through letters of support; promote the importance of functioning wetlands for the health of the Estuary; support and participate in multi-agency workgroups to help decision-makers consider the role of tidal wetlands to the health of the Estuary.

Experts PDE, States

Critical habitat availability for fish, blue crabs, horseshoe crabs, shellfish, and SAV

H3.1, H3.3, H3.4, H3.5

C1.2, C1.3, C1.4, C2.1, C2.5, C2.6, C2.7

What is the distribution of critical habitat availability for fish, blue crabs, horseshoe crabs, shellfish, and SAV? What factors contribute to the distribution of these critical habitats? How are population and community dynamics changing with change in availability of critical habitat(s)?

Example activities in Monitoring Inventory Baseline Monitoring of Submerged Aquatic Vegetation in the Delaware Estuary (EPA R3), National River and Streams Assessment (NRSA - EPA), Academy of Natural Sciences, Stroud Water Research Center, NJ Delaware Bay Young of the Year Trawl Survey

Action DELEP partners will continue to support and promote the efforts of the various entities that are performing research and assessments of critical habitat availability for fish, blue crabs, horseshoe crabs, shellfish, and SAV.

Mechanisms Secure funding on critical habitat distribution and abundance for fish, blue crabs, horseshoe crabs, shellfish, and SAV; promote and support partners performing research on the critical habitat availability for fish, blue crabs, horseshoe crabs, shellfish, and SAV; help partners

through letters of support; promote the importance of critical habitats in the Estuary; create time in events or meetings for practitioners to share their data with managers.

Experts USFWS, States, Rutgers University, PDE, EPA

Restoration progress, especially regarding natural and nature-based techniques

H1.2, H.1.3, H.1.4, H3.1, H3.2, H3.3, H3.4

C1.1, C1.2, C1.3, C1.4, C2.1, C2.2, C2.5, C2.4, C2.6, C2.7

How have restoration efforts, particularly natural and nature-based techniques, progressed?

Example activities DNREC Wetland Monitoring and Assessment Program, MACWA, DELSI, NJDEP Beneficial Use of Dredged Material to Restore Salt Marshes

Action DELEP partners will continue to promote and participate in local and regional workgroups convening for the science and restoration of tidal wetlands, especially those with focus on natural and nature-based techniques. DELEP partners will also continue to perform research and design to increase the usability of natural and nature-based techniques as funding allows. DELEP partners will also continue to build tools and other resources for practitioners to support the feasibility of using natural and natural-based techniques in current and future projects.

Mechanisms Secure funding for the restoration, intervention, or enhancement of habitats in the Estuary using natural and nature-based techniques; secure funding for DELSI; secure funding for data-driven tool development, with a focus on ecological form and function; help partners through letters of support; promote the natural and nature-based techniques as alternatives to traditional methods; support and participate in multi-agency workgroups to help decision-makers consider the role of tidal wetlands to the health of the Estuary, and how natural and nature-based techniques are valuable options to consider.

Experts USFWS, PDE, States, Contractors

NEXT STEPS

What data are needed to address our monitoring priorities?

Defining recommended data metrics for each priority provides clear direction on the most appropriate attributes associated with goals of the CCMP. Table 6 outlines the connection of monitoring priorities described in this report to CCMP strategies and TREB chapters in accordance with their associated data metrics, partner(s), and funding sources. This table will help keep track of the monitoring priorities for CCMP strategies being implemented as part of DELEP. Ultimately, this table should be used to help guide DELEP partners prioritize activities for monitoring or other projects to help further CCMP goals and how those efforts may continue given who leads these on DELEP's behalf. Additionally, many existing monitoring activities cover multiple priorities, so support for multi-agency partnerships that result in data collection on CCMP strategies should remain a focus of DELEP partner support. For instance, DRBC leads many water quality objectives (priorities 1, 2, and 6), while some priorities have multiple entities involved (priorities 3 and 9).

What will DELEP partners do with CCMP monitoring data received?

Over the next 5 years, DELEP partners will, in an ongoing manner, synthesize monitoring efforts in the CCMP tracking database (organized by theme) to ensure that data are generated relative to CCMP needs. This process also helps DELEP partners identify gaps associated with CCMP actions and priorities in the numerous monitoring programs being carried out in the focus area. The CCMP-TREB crosswalk is another example of this gap analysis. For TREB, these gaps will be incorporated into the routine conversation about the environmental indicators reported in the TREB. TREB authors, contributors, and collaborators can develop indicators that meet priority needs. Reporting on the synthesis of monitoring activities, through the MINA report and other follow-up efforts, also ensures that DELEP partners can support efforts (e.g., through existing or new partnerships) to address monitoring gaps. Promotion and communication about the monitoring gaps associated with CCMP strategies and the priorities is also a primary charge of DELEP over the next 5 years (e.g., in PDE's Estuary News, etc). To achieve CCMP implementation, next steps will include following up with the monitoring efforts and CCMP strategies associated with the priorities listed here, encouraging connections between existing or new projects with the CCMP, and providing the needed support or guidance to keep CCMP strategies at the forefront of management efforts.

Since tracking monitoring programs helps assess CCMP implementation and supports periodic TREB indicator reporting, the three strategies outlined in the Monitoring Approach will continue in the future. These three strategies include 1) joint meeting of the Science & Technical Advisory Committee (STAC) and the Monitoring Advisory & Coordination Committee (MACC), 2) TREB reporting every 4-5 years, and 3) inventory monitoring activities and needs every 5 years. The next monitoring workshop will take place in 2023-2024 in order to reassess current long-term monitoring activities and ensure that the monitoring inventory serves as a living blueprint for guiding investment of limited resources into changing monitoring priorities.

Table 6. Monitoring priorities table, with associated CCMP actions and TREB indicators, recommended data metrics, existing or possible partnerships, and leading bodies which typically fund associated monitoring and research.

Priority level	Monitoring objective(s)	CCMP action(s) & TREB indicators	Recommended data metrics	Partnerships	Major funding bodies*
Water chemistry (pH, salinity, contaminants) and its effects on key living resources					
1	• Monitor water chemistry in the Delaware Estuary and its tributaries • Monitor habitat use and distribution of key species of fish, shellfish, and vegetation	W3.1, W3.2, H3 6.1-12, 3.1.3, 3.1.4, 3.1.5, 3.1.6, 3.1.8, 3.2.3, 3.2.4, 3.2.5, 3.2.6	• Dissolved and particulate nitrate, nitrite, total nitrogen, total phosphorus, carbon; pH, alkalinity, dissolved oxygen, specific conductance (salinity), organic/inorganic contaminants • Abundance, and movement/dispersal (if applicable) of shad, alewives, sturgeon, freshwater mussels, and submerged aquatic vegetation	DRBC, USGS, states, USFWS, universities	DRBC (through state and federal budgeting); DELEP (TREB)
Nutrient pollution and its effects on dissolved oxygen concentrations and estuary-dependent living resources (e.g., fish, shellfish, submerged aquatic vegetation)					
2	• Monitor Delaware River and Bay nutrient concentrations and DO • Monitor habitat use and distribution of key species of fish, shellfish, and submerged aquatic vegetation	W1.5, H3 6.1-6.12, 3.1.1, 3.1.2, 3.2.1, 3.2.2	• Dissolved and particulate nitrate, nitrite, total nitrogen, total phosphorus, carbon; pH, alkalinity, dissolved oxygen • Abundance, and movement/dispersal (if applicable) of shad, alewives, sturgeon, freshwater mussels, and submerged aquatic vegetation	DRBC, USGS, states, universities	DRBC (through state and federal budgeting); DELEP (TREB)
Occurrence of endangered, invasive or otherwise important species					
3	• Monitor the distribution or population size of invasive species and research their effects on natural communities • Monitor the distribution of critical habitat and population sizes of endangered, threatened, or other functionally important species	W1.2, H3.5 6.2, 6.5, 6.7, 6.9, 6.10	• Spatial and temporal distribution of invasive plants and animals • Invasive species population dynamics and distribution • Metrics to assess current or potential of invasive or non-native species to native species and communities • Population dynamics of functionally important species susceptible to pressures from invasive species • Spatial and temporal distribution of rare, threatened, or endangered species, as well as their associated critical habitat • Population dynamics of rare, threatened or endangered species	States, universities, USFWS, NOAA	Multi-state and federal coordination through DELEP (TREB)

Table 6 Continued.

Priority level	Monitoring objective(s)	CCMP action(s) & TREB indicators	Recommended data metrics	Partnerships	Major funding bodies*
Climate change, especially extreme events (temperature, precipitation) and its ecological effects					
4	• Monitor estuary-wide temperature, precipitation, and storm activity • Monitor and research the effects of climate trends, including storm frequencies and intensities, along with their effects on the function and distribution of key habitats, including, but not limited to, forests, non-tidal wetlands, tidal wetlands, and submerged aquatic vegetation	H1.1, H1.2, H1.3, H1.4, H3.1 5.1, 5.2, 5.3, 7.1, 7.2, 7.3, 7.4	• Daily verage temperature, maximum temperature, minimum temperature, cumulative precipitation, precipitation frequency and duration, precipitation-evapotranspiration (drought), storm frequency and duration, storm average wind speed and direction, streamflow/discharge, aquifer storage capacity and recharge, snowfall, ice jams, sea level rise • Leaf or flowering phenology of plants; migration phenology of animals, spatial distribution of plants and animal species (or clades), habitat transitions, habitat productivity, and/or other functional parameters	States, PDE, universities	DELEP (CRE, TREB)
Sediment quantity, quality and beneficial management efforts in the tidal estuary					
5	• Monitor sediment quantity and quality within the tidal estuary • Monitor the quantity and quality of sediment being imported into or exported from the tidal estuary • Research and implement beneficial reuse or other ecologically supportive sediment management tactics in the Delaware Estuary and its tributaries	W2.3, W2.5, W3.5, H1.2 4.1, 4.2, 4.3, 4.4, 4.5	• Distribution of soil pedons (via subaqueous soil surveys), sediment grain sizes, contaminant concentrations, organic/inorganic fractions, and overall sediment volume • Grain sizes, contaminant concentrations, organic/inorganic fractions, and overall concentration of sediments suspended in the water, as well as their spatial and temporal dynamics • Number of beneficial reuse research or implementation projects with specific ecologically supportive goals (e.g., habitat creation, water quality improvement, or ecological function enhancement)	States, USACOE, DRBC, USGS, NRCS	Multi-state and federal coordination through DELEP (TREB)

Table 6 Continued.

Priority level	Monitoring objective(s)	CCMP action(s) & TREB indicators	Recommended data metrics	Partnerships	Major funding bodies*
Sources of water quality impairment and management efforts to reduce pollutants					
6	• Inventory and monitor the sources of water quality impairment in the Delaware Estuary and its tributaries • Monitor water chemistry in the Delaware Estuary and its tributaries • Monitor activities aimed to manage and reduce the sources of water quality impairment in the Delaware Estuary and its tributaries	W1.1, W1.2, W1.3, W1.5, W2.2, W2.3, W2.4, W2.5, W2.6 3.1, 3.2	• Dissolved oxygen, pH, TSS, carbon; dissolved and particulate nitrogen, total nitrogen, total phosphorus, alkalinity, salinity, and temperature; organic and inorganic pollutants • Spatial distribution of point and non-point sources of key nutrients or pollutants • Number of management activities, regulations, and/or actions focused on the reductions of water quality impairment	States, DRBC, USGS	DRBC (through state and federal budgeting); DELEP (TREB)
Distribution and abundance of non-commercial bivalve shellfish (e.g., ribbed mussels, freshwater mussels)					
7	• Monitor and inventory the distribution and abundance of non-commercial bivalve shellfish	H3.3, H3.5 6.10	• Population dynamics of functionally important non-commercial bivalves (e.g., freshwater mussels, ribbed mussels) • Spatial and temporal distribution of native freshwater mussels and ribbed mussels, as well as their associated habitat	PDE's FMRP/ MuCWI, universities, USFWS	Multi-state and federal coordination through DELEP (TREB)
Tidal wetland condition, and efforts to sustainably manage and restore tidal wetlands					
8	• Monitor tidal wetland condition and track extent • Research and monitor restoration techniques • Create support tools and disseminate findings	H1.1, H1.2, H1.3 5.2, 8.2, 8.3, 8.4	• Tidal wetland extent over time (e.g., acres) • Tidal wetland condition across the watershed, relative to pertinent stressors (e.g., urbanization, eutrophication) • Tidal wetland responses to sea level rise and climate change • Various metrics for gauging the success of tidal wetland restoration or intervention tactics	PDE/BBP MACWA, DELSI, USWFS, states, universities	EPA WPDG, DELEP (TREB, NEPORT)

Table 6 Continued.

Priority level	Monitoring objective(s)	CCMP action(s) & TREB indicators	Recommended data metrics	Partnerships	Major funding bodies*
Critical habitat availability for fish, blue crabs, horseshoe crabs, shellfish, freshwater mussels and SAV					
9	• Monitor the extent and distribution of critical habitats for fish, blue crabs, horseshoe crabs, SAV, and shellfish	H3.1, H3.3, H3.4, H3.5 5.1, 6.2, 6.7, 6.10	• Spatial and temporal distribution of critical habitats for fish, blue crabs, horseshoe crabs, SAV, and other shellfish, such as oysters • Metrics associated with the population or community dynamics of fish, blue crabs, horseshoe crabs, and shellfish relative to their critical habitats	PDE's FMRP/ MuCWI, universities, USFWS, EPA	Multi-state and federal coordination through DELEP (TREB)
Restoration progress, especially regarding natural and nature-based techniques					
10	• Track projects across the Delaware Estuary and its tributaries that improve ecological functionality or intervene the loss of ecological conditions • Monitor and support investments in natural and nature-based techniques • Research and track measures of restoration success relative to changing ecological functioning	H1.2, H.1.3, H.1.4, H3.1, H3.2, H3.3, H3.4 5.1, 5.2, 5.3, 8.2, 8.3, 8.4,	• Number of implemented restoration or intervention projects with specific ecologically supportive goals (e.g., loss intervention, habitat creation, water quality improvement, or ecological function enhancement) • Number of research and logistical pilot projects with goals of improving restoration or intervention success or feasibility • Number of investments, funding opportunities, and total number of dollars available and/or spent on natural and nature-based restoration techniques • Various metrics for gauging the success of restoration or intervention tactics, relative to both project-specific goals, as well as Estuary-wide benefits (e.g., net ecosystem service changes)	States, USFWS, PDE	DELEP (NEPORT)

How will DELEP partners continue to make connections with the CCMP in the next 5 years?

One of the important strategies for supporting CCMP action through data collection is acknowledging and engaging partners that have principal roles in CCMP monitoring and implementation. PDE and other DELEP partners host the PDE Environmental Summit biennially. Holding CCMP-specific social gatherings and assigning time in the Summit schedule to allow participants to become familiarized with the CCMP is critical for continued success. These interactions allow time for a diverse group of individuals to consider how CCMP strategies and goals align with the various types of monitoring activities that they manage. Additionally, activities and information are highlighted in PDE's Estuary News newsletter, distributed to subscribers seasonally, that pertain to specific CCMP themes or strategies through call out boxes on specific articles. This gives readers the opportunity to draw connections between the scientific community and other efforts across the Estuary that seek to implement various monitoring activities aligned with CCMP strategies or goals. In relation, PDE also produces a State of the Estuary Report every 5 years, which is formulated from updates and findings from the same year's edition of the TREB. This provides a community-friendly approach for constituents in the Delaware River Basin to easily and clearly follow along with monitoring activity in their region and also make connections from the report to the various CCMP strategies that it aims to address.

Additionally, DELEP partners like PDE regularly acknowledge CCMP strategies in letters of support for partners petitioning for funding. As PDE staff often review the nature of grant proposals before writing letters of support, providing direct connections to CCMP strategies in these letters allows funders to see the estuary-wide importance of work being conducted by partners in support of a broader goal of improving environmental qualities across the region. Not only do these letters promote the CCMP, but they also create a record of support for achieving the various goals outlined in the CCMP at large.

As DELEP partners continue to message out the importance of connecting the CCMP goals with on-going and developing projects, organizations may face several questions about how to make CCMP connections with their own projects. Below, we answer some frequently asked questions (FAQs) to help develop guidance on making project-specific connections with CCMP strategies and priorities. These FAQs will also be maintained on the PDE website.

Where can I find CCMP strategies, monitoring needs, or current priorities?

The CCMP, and all its related products and reports, can be found at: https://delawareestuary.org/our-plan-2/

How can I find out more detail about the current monitoring activities that are relevant and applicable to CCMP strategies?

The primary way to find information about all current or past monitoring projects is through the Delaware Estuary *Baseline Monitoring Inventory Database*, housed on PDE's CCMP webpage. This spreadsheet, available as a direct Excel workbook download or a Google Sheet, provides

information regarding project leads/entities, applied methodologies, and associated CCMP strategies, among other relevant details.

Where can I find grant opportunities to support the CCMP strategies, monitoring needs, or priorities?

The following entities have supported CCMP strategies in the past and their websites can be periodically checked for new funding opportunities: William Penn Foundation, National Fish and Wildlife Foundation - Delaware River Program, National Fish and Wildlife Foundation - Delaware Watershed Conservation Fund, NOAA Office of Coastal Management, EPA - National Estuary Program, National Wildlife Federation, Restore America's Estuaries - NEP Watersheds Grant Program

What steps can I follow to make connections between my monitoring efforts and CCMP strategies?

You can follow these steps to help make connections between your work and CCMP strategies:

1) Familiarize yourself with the CCMP strategies and subscribe to PDE's *Estuary News*;

2) Submit your work to the CCMP tracking surveys;

3) Participate in workshops and meetings, such as PDE's Science and Environmental Summit;

4) Develop research questions framed around CCMP goals and strategies;

5) Synthesize your data in context of CCMP strategies and priorities into final report(s) or other products.

How will we monitor our accomplishments?

Continuing to organize and produce TREB regularly, as well as producing other routine reports on the status and trends of key metrics that pertain to CCMP strategies or priorities, is an essential part of tracking what has been accomplished and how significant progress has been. Regular meetings with the STAC and MACC to receive updates on monitoring, projects, and funding will also be part of our tracking effort. Over the next 5 years, reports and DELEP-related meeting minutes (i.e., STAC, MACC, EIC, and/or other relevant meetings) will be collected and interpreted relative to CCMP goals in order to highlight progress made in the Estuary and included in the Annual Monitoring Inventory Update. Additionally, these highlights will be shared among the DELEP partners to ensure successes are acknowledged and possible needs are addressed in regular meetings. These highlights will then be included in Estuary News, social media posts, emails sent to PDE subscribers, or through other avenues of communication. Routine reporting and review of monitoring activities in this fashion will allow the DELEP Management Conference and its partners to help sustain high priority monitoring, achieve results towards CCMP goals, and adapt to new priorities as they arise.

To further evaluate how these priorities are being tended to, PDE will conduct a brief survey

with 2-3 experts of each of these topics. Experts are identified in this document but may change given institutional adjustments; if a subject expert should become unavailable, a replacement will be identified whenever necessary and possible. Broadly, the survey will inquire about the status of the priority, the outcomes of the monitoring efforts in the past year (or since the last survey), whether there are any changes or gaps that have arisen in the past year (or since the last survey), and whether there is any assistance needed from DELEP partners. The survey will also ask respondents to briefly synthesize any progress relative to success measures listed in the CCMP (see section "How will we measure success?"). During this time, the experts will also be asked to share new reports or discoveries they have made throughout their monitoring efforts to better upkeep the inventory database. This effort will begin in late March 2022 and will be titled the Annual Monitoring Inventory Update. We anticipate voluntary participation from those invited given that their work will be promoted and information and/or data gaps will be shared.

Over the next 5 years, DELEP seeks to have this report referenced regularly in order to aid all future monitoring efforts, but specifically for the top 10 priorities described in Tables 5 and 6. After annual updates are made, these documents will be made shareable via the PDE website and with the STAC, MACC and EIC. Overall, the updates and supporting documents will show how monitoring priority efforts in the Estuary Focus area are working in direct relation to CCMP strategies. Performing brief, annual assessments such as this update survey allows the DELEP Management Conference to respond quickly to growing gaps, needs, or other concerns relative to these monitoring priorities. This can lead to faster action to obtain funding or provide support to partners working on priorities as needs arise. In 5 years, we will be able to report on whether the monitoring for each of these priorities has made significant progress, been addressed minimally, or needs more progress made in order to fulfill the requirements of the CCMP, and therefore will indicate whether the overall goals of CCMP implementation are being achieved for these priorities in particular.

How does this all fit together?

In this report, we summarized many activities performed by DELEP partners relative to CCMP monitoring. With so much interconnected information, and several databases from which to chose, CCMP monitoring may feel rather complex. Therefore, we created a diagram to help DELEP partners visualize how the products mentioned in this MINA report provide the basis to track CCMP actions, as well as improve decision-making for conservation and management of the Delaware Estuary Focus Area, by complimenting the Monitoring Approach (see Fig. 4, Table 2). Importantly, the Monitoring Priorities mentioned in this diagram are detailed within this report, on pages 24-31 and Table 6.

Conclusion

One of DELEP's main charges is to facilitate efforts and support programs that help implement the CCMP. DELEP partners will continue to form relationships to aid decision-makers by collecting data and serving as a neutral and scientifically focused program. However, the limiting factor to most monitoring program creation and sustainability is funding. Without

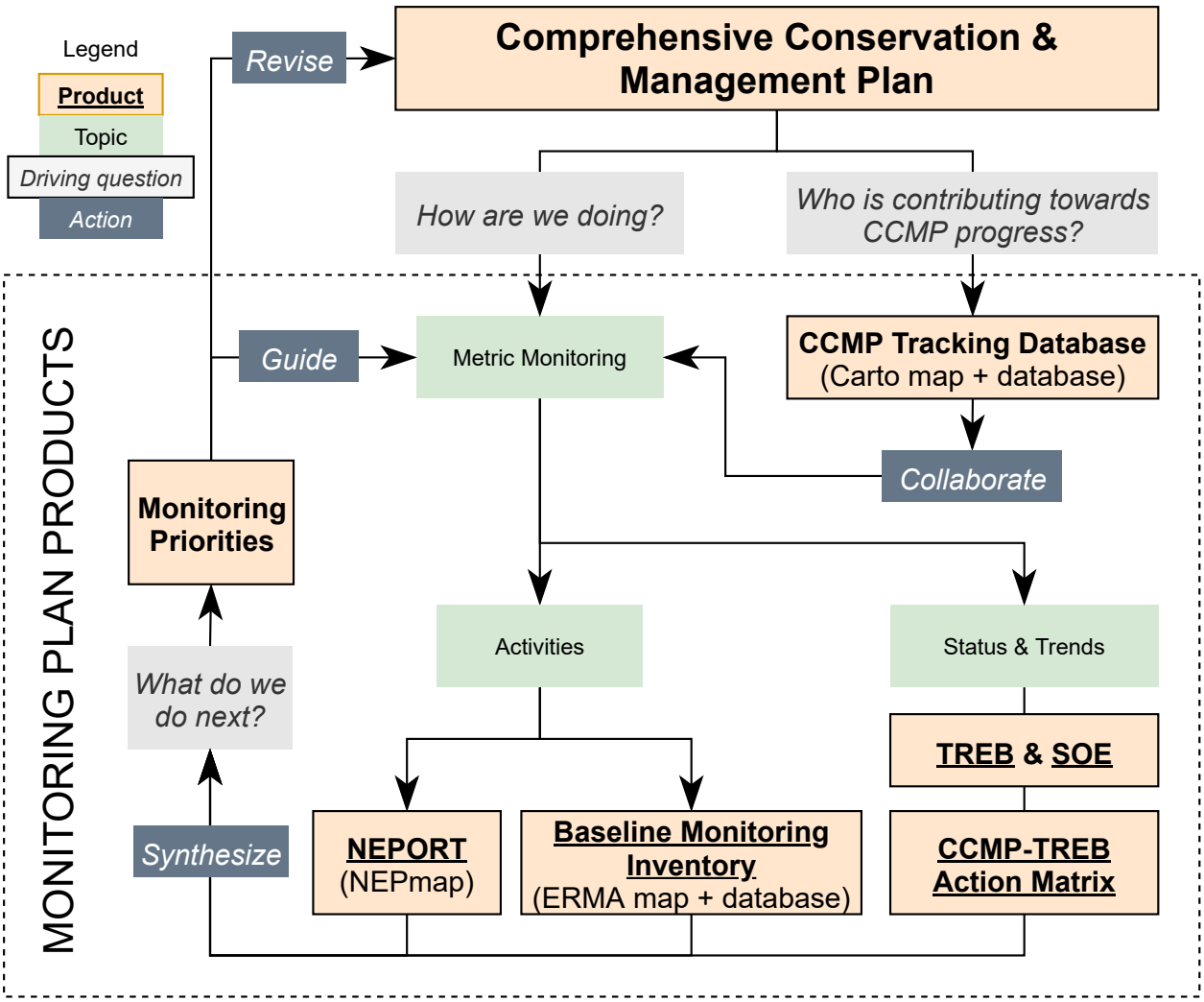

Figure 6. Simplified diagram of the products, topics, and actions that come together as the DELEP CCMP monitoring plan. Products in this diagram (orange boxes) are hyperlinked to the resource for accessibility. **Importantly, many Monitoring Priorities are specifically addressed here, in this MINA report, on pages 24-31 and Table 6.**

funding, none of the monitoring programs discussed in this report would exist and future efforts towards other CCMP strategies would not be developed. Thus, DELEP partners will continue to identify funding opportunities that would help carry out a number of CCMP strategies, as well as support the efforts of other organizations to implement CCMP strategies or goals, as needed. With the next steps outlined here, we hope that DELEP partners are able to provide the necessary engagement, communication, and support needed across the Estuary Focus Area to ensure that the community of people depending on the Delaware Estuary and Basin remain invested in the attainment of CCMP goals.

For any contributions to the monitoring inventory that become available in between reporting efforts or for questions about this report, please email **LHaaf@DelawareEstuary.org.**

REFERENCES

2019 Delaware Estuary Monitoring Inventory

- Monitoring documents referenced in this report can be found on PDE's Our Plan website https://delawareestuary.org/our-plan-2/
- Monitoring Inventory, Workshop, and Survey Results Summary Report (direct download) https://s3.amazonaws.com/delawareestuary/Final+DelEst+Monitoring+Report+03.28.19.pdf
- Delaware Estuary Monitoring Inventory Worksheet (direct download) https://delawareestuary.s3.amazonaws.com/Master-Delaware-Estuary-Monitoring-Inventory-Rev_Feb2021.xlsx
- Delaware Estuary Monitoring Inventory Google Sheet (view only) https://docs.google.com/spreadsheets/d/1QdskinqJ-xiyHiVcgImfi8pgkXxXv_9o0RhVClWR6GM/edit#gid=76032491%3Cbr%20/%3E

NOAA ERMA Delaware Estuary Monitoring Inventory Layer

- Embedded to the PDE Our Plan website https://delawareestuary.org/our-plan-2/
- NOAA ERMA website https://erma.noaa.gov/atlantic/erma.html#/layers=3+39947&x=-75.09631&y=40.61253&z=7.0&panel=layer

2019 Revised CCMP for the Delaware Estuary

- CCMP documents referenced in this report can be found on PDE's Our Plan website https://delawareestuary.org/our-plan-2/
- 2019 Revised CCMP for the Delaware Estuary (full document, direct download) https://s3.amazonaws.com/delawareestuary/2019+DelEst+Revised+CCMP.pdf
- 2019 Revised CCMP for the Delaware Estuary Brochure (direct download) https://s3.amazonaws.com/delawareestuary/CCMP+Brochure+FINAL.pdf
- 2019 – 2020 CCMP Tracking Database (direct download) https://delawareestuary.s3.amazonaws.com/EIC+Materials/MASTER_FINAL_CCMP_Projects_2019+to+2020.xlsx
- 2019 CCMP Tracking Highlights Presentation (direct download) https://delawareestuary.s3.amazonaws.com/CCMP_tracking_results_2019_PDF.pdf
- 2019 – 2020 CCMP Tracking Database (view only) https://drive.google.com/file/d/1m7dTHDd8C7MQ_ZCz0Mv3JvpKmCQO--iz/view?usp=sharing
- 2020 CCMP Tracking Highlights Presentation (direct download) https://delawareestuary.s3.amazonaws.com/CCMP_tracking_results_2020.pdf

- CCMP Strategy and Performance Measures & Key Deliverables and Summary of Corresponding Reported Activities (direct download)
  https://delawareestuary.s3.amazonaws.com/CCMP+Activities+by+Deliverables+2019+to+2020.pdf

2017 CCMP Climate Vulnerability Assessment

- 2017 CCMP Climate Vulnerability Assessment Summary Report
  https://s3.amazonaws.com/delawareestuary/PDE+CCMP+Climate+Vulnerability+Report_05.01.2017.pdf

Technical Report for the Estuary and Basin (TREB)

- 2017 Technical Report for the Delaware Estuary and Basin (website, with direct download links to the full TREB, as well as individual chapters)
  https://delawareestuary.org/data-and-reports/state-of-the-estuary-report/
- 2017 Technical Report for the Delaware Estuary and Basin (full report, direct download)
  https://s3.amazonaws.com/delawareestuary/TREB+douments/TREB_2017_new_complete.pdf
- Previous State of the Estuary reports (2002, 2008, 2012) and the 2012 TREB (website, with direct download links)
  https://delawareestuary.org/data-and-reports/state-of-the-estuary-report/

TREB-CCMP Needs

- TREB CCMP Needs workbook (direct download)
  https://delawareestuary.s3.amazonaws.com/TREB_CCMP_Needs+v4.xlsx

2013-2018 PDE Strategic Plan

- 2013-2018 PDE Strategic Plan (direct download)
  https://s3.amazonaws.com/delawareestuary/pdf/2013_strategic_plan.pdf

PDE-led Committees

- Estuary Implementation Committee meeting minutes (website with previous meeting minutes available for direct download)
  https://delawareestuary.org/committees/estuary-implementation-committee/
- Steering and Technical Advisory Committee meeting minutes (website with previous meeting minutes available for direct download)
  https://delawareestuary.org/science-and-technical-advisory-committee/
- Steering and Technical Advisory Committee Charter (direct download)
  https://delawareestuary.s3.amazonaws.com/STAC+Charter2020+Revision+Final+signatures.pdf
- 2006 White Paper on Status and Needs of Science in the Delaware Estuary (direct download)
  https://s3.amazonaws.com/delawareestuary/pdf/ScienceReportsbyPDEandDELEP/PDE-Report-06-01-ScienceWhitePaper.pdf
- Other Steering and Technical Advisory Committee Reports (website with reports available for direct download)
  https://delawareestuary.org/science-and-technical-advisory-committee/science-technical-advisory-committee-reports/

APPENDIX A - CCMP strategies

Table A1. 2019 CCMP Strategies and Goals by the Themes of Strong Communities.

THEME 2 | STRONG COMMUNITIES
GOAL 1: Increase Community Resilience And Access
• C1.1: Restore working waterfronts
• C1.2: Provide tools and technical assistance to waterfront communities & partners to improve economic and environmental resilience
• C1.3: Protect and enhance natural areas and public access
• C1.4: Connect people to natural areas and waterfronts in the Delaware Estuary
GOAL 2: Improve Public Awareness And Stakeholder Engagement
• C2.1: Through marketing and communications, build awareness and brand for the Delaware River and Bay
• C2.2: Utilize events to increase stewardship and engage new people
• C2.3: Develop and promote programs that engage teachers and schools in stewardship of the Delaware Estuary
• C2.4: Develop and promote programs with local communities and partners that foster volunteer stewardship and experiential learning
• C2.5: Publish and share outreach materials and scientific results.
• C2.6: Engage key stakeholders to coordinate science and management of the Delaware Estuary
• C2.7: Monitor, develop, and promote opportunities to assess impacts of outreach

Table A2. 2019 CCMP Strategies and Goals by the Themes of Clean Waters.

THEME 1 | CLEAN WATERS
GOAL 1: Reduce Nutrient Pollution and Its Impacts
• W1.1: Promote infrastructure-related improvements to reduce pollutants from point-sources
• W1.2: Support innovative planning and design practices to reduce nutrients from storm water and agricultural runoff through promotion, education, and implementation
• W1.3: Promote land use planning by local municipalities that prevents, reduces, and/or more efficiently manages storm water runoff to prevent pollution
• W1.4: Provide outreach and information to property owners to assist in reducing non-point sources of nutrients
• W1.5: Conduct research and monitoring on nutrient impacts in the Delaware Estuary for biological and ecological endpoints
GOAL 2: Reduce Other Pollutants and Their Impacts
• W2.1: Conduct outreach and technical assistance programs to reduce non-point sources of contaminants
• W2.2: Promote the identification, cleanup, and revitalization of contaminated sites
• W2.3: Support adaptive management and reporting of pollution reductions
• W2.4: Coordinate and promote research and monitoring efforts (chemical, physical, biological) associated with the causes of water quality impacts throughout the Delaware Estuary
• W2.5: Conduct and coordinate (where appropriate) education, research, monitoring, and communication about fish and shellfish consumption to protect human health
• W2.6: Improve, sustain, and enhance spill communication and response with Delaware Estuary partners
GOAL 3: Sustain Flow for Drinking Water and Ecosystems
• W3.1: Inform and collaborate with decision-makers and water resources managers to ensure that main-stem Delaware River flow meets the needs of the Delaware Estuary
• W3.2: Conduct research and monitoring on water quality and habitat requirements of estuary dependent species
• W3.3: Promote water conservation and water efficiency by utilities and industrial water users
• W3.4: Provide outreach and technical assistance to promote water conservation and infiltration by residential and commercial users and communities
• W3.5: Promote and assist in implementing Regional Sediment Management

Table A3. 2019 CCMP Strategies and Goals by the Themes of Healthy Habitats.

THEME 3 | HEALTHY HABITATS
GOAL 1: Prevent Wetland Loss
• H1.1: Establish clear baselines for tidal wetland conditions and track changes over time
• H1.2: Restore, enhance, and manage tidal wetlands for maximum health and resilience
• H1.3: Develop and implement natural and nature-based techniques to stabilize and restore eroding shorelines, and to build and protect wetlands, infrastructure, and other key resources
• H1.4: Protect, enhance, and improve non-tidal wetlands
GOAL 2: Stem Forest Loss
• H2.1: Inventory, map, and increase connectedness and resilience of forests for water quality
• H2.2: Promote stewardship practices by local partners for the health and sustainability of forests for water quality
• H2.3: Protect and manage high-value and threatened forests for water quality
GOAL 3: Increase And Improve Fish And Shellfish Habitat
• H3.1: Inventory, map, protect, and enhance habitat critical for fish and crabs
• H3.2: Restore oyster beds and productivity in and around the Delaware Bay
• H3.3: Inventory, restore, and manage mussel populations
• H3.4: Protect and restore horseshoe crabs and their habitat
• H3.5: Manage and improve populations of rare, endangered, or otherwise important native species in the Delaware Estuary

APPENDIX B - TREB Indicators and outcomes

Table A4. TREB chapters and associated environmental indicators. Hyperlinks to key indicator categories are provided in chapter titles.

Chapter	Indicators		
Watersheds and Landscape	• Population • Current Land Cover • Land Cover Change • Impervious Cover		• Public Open Space • Public Access Points • Natural Capital Value
Water Quantity	• Water Withdrawals: Tracking Supply and Demand • Consumptive Use • Per Capita Water Use • Groundwater Availability • Salt Front Location and Movement		
Water Quality	• Tidal	• Dissolved Oxygen Nutrients • Contaminants • Fish Contaminants • Salinity	• Emerging Contaminants • pH • Temperature • Whole Effluent Toxicity
	• Non-Tidal	• Dissolved Oxygen • Nutrients • Contaminants • Fish Contaminants	• Emerging Contaminants • pH • Temperature
Sediments	• Sediment Loading • Sediment Quantity • Sediment Organic Carbon • Sediment Grain Size • Dredging Activity		
Aquatic Habitats	• Subtidal Habitats • Intertidal Habitats • Nontidal Habitats		
Living Resources	• Atlantic Sturgeon • Blue Crab • Osprey • White Perch • Striped Bass • Weakfish		• Horseshoe Crab • American Shad • Eastern Oyster • Freshwater Mussels • American Eel • Macro-invertebrates
Climate Change	• Air Temperature • Precipitation • Extremes: Air Temperature and Precipitation • Snow Cover • Wind Speed • Streamflow • Ice Jams		
Restoration	• Acres Restored Annually • Restored Habitat Types • Restoration Needs		

Table A5. Top positive (A) and negative (B) findings from the 2017 Technical Report for the Estuary and Basin, as judged by the Science and Technical Advisory Committee and this report's authors. Impact scores are qualitative and based on 1) novelty of the finding for the 2017 reporting period, 2) relative overall impact to estuary and basin wide health, and 3) immediacy of action need. Impact scores of 1 for positives are very good, whereas a score of 6 for a negative is near detrimental. Averaging all impact scores yields a total score of 3.66, or an overall "fair" for the reporting period's estuary and basin health.

A.

Chapter	Positives		
	Indicator	Condition	Impact
Watersheds	Ecosystem Services	Worth >$12 billion annually	1
Water Quantity	Consumptive Use (Public)	Declined per capita 1990-2014	2
Water Quality	Dissolved Oxygen	Increased dramatically 1960s to present	1
Sediments	Total Organic Carbon	Decreased, suggesting lower organic pollution	2
Aquatic Habitats	Fish Passage	>160 km now accessible on the Lehigh River and Schuylkill	1
Living Resources	Striped Bass	Once nearly extirpated, the current population is a major spawning stock	1
Climate	Ice Jams	Decreased over period of record	2
Restoration	Habitat Type	Progress among types matches current priorities	3

B.

Chapter	Negatives		
	Indicator	Condition	Impact
Watersheds	Land Cover	Development continues to increase; forest acreage continues to decline	6
Water Quantity	Consumptive Use (Industrial)	Increased about 20% between 1994-2014	5
Water Quality	Nutrients	Nitrogen remains high relative to other estuaries	5
	Contaminants	Exceeds risk thresholds for consumption of many fish	5
Sediments	Sediment Budget	Sediment removal exceeds inputs, possibly impairing estuary habitats	6
Aquatic Habitats	Tidal Wetlands	Acreage decreased >1.5% 1996-2010, mainly from salt marsh loss	5
Living Resources	Atlantic Sturgeon	Despite young of year fish seen in 2009, the species is now federally endangered	6
	Freshwater Mussels	Abundance and range continues to decline	5
Climate	Precipitation	Increased, especially in the past 30 years, increased flooding	4
Restoration	Funding	Investment is very low compared to other large estuaries	6

APPENDIX C - CCMP online tracking summary

Table A6. CCMP online reporting tool information collected from partners on each CCMP activity reported.

Category	Criteria
Reference documents	• Instructions for Reporting • Map of Study Area • Link to CCMP • Project Examples
General project information	• Project Name • Associated CCMP Strategies (check boxes)
Spatial data	• Location (Lat, long/ HUC/ Waterbody name/ site name)
Project metrics	• Metric (e.g., acres, linear feet, participants)
Funding and partners	• Total Project Cost • Primary Funding Source • Lead Partner/Implementer • Other Partners
Additional information	• Project Contact Information (name, email, organization)

Table A7. Monitoring inventory criteria collected for each monitoring activity submitted.

Category	Criteria
General project information	• Characteristic Group (e.g., biological, chemical) • Parameter (e.g., relative abundance, DO) • Unit (e.g., mg/L) • Project/Contact Name and Info/Collected by
Temporal data	• Status (e.g., ongoing) • Frequency (e.g., annually, biennially) • Period (e.g., May-Sep, all year) • Start and end year
Spatial data	• State(s) (DE, PA, NJ) • HUC *(if applicable)* • Waterbody *(if applicable)* • River Mile From and To *(if applicable)*
Project and sampling notes	• Sample Matrix (e.g., water, air) • Gear/Method • Changes in sampling *(if applicable)*
Data availability and access	• Data Access (e.g., National Water Quality Data Portal) • Data Availability • Time Frame (e.g, 1991-present)
Additional information	• Project/Program objective • QAPP *(if applicable)* • Other project comments

Table A8. List of partners that directly contributed information to PDE for CCMP tracking during the 2019 – 2020 reporting years.

Organizations/departments
Association of New Jersey Environmental Commissions
Berks County Conservation District
Chester Ridley Crum Watershed Association
Delaware Department of Agriculture - Forest Service
Delaware Department of Natural Resources and Environmental Control
Delaware River Basin Commission
Delaware Valley Region Planning Commission
Tidewaters Gateway Partnership, Inc.
U.S. Environmental Protection Agency Regions II
U.S. Environmental Protection Agency Region III
National Fish and Wildlife Federation
New Jersey Department of Environmental Protection
Partnership for the Delaware Estuary
Penn State - Master Watershed Steward Program
Pennsylvania Department of Environmental Protection
Pennsylvania Environmental Council
Philadelphia Water Department
Rutgers Haskin Shellfish Research Laboratory
Schuylkill Action Network
Schuylkill Headwaters Association

Table A9. Example of associated Performance Measures & Key Deliverables for Healthy Habitats, Strategy H3.3: Inventory, restore, and manage mussel populations.

Healthy Habitats Strategy H3.3: Inventory, restore, and manage mussel populations Performance Measures & Key Deliverables:
• Increase survey coverage, both scientific and volunteer, annually to assess native freshwater mussels' status
• Conduct research and produce one report annually to demonstrate tactics to enhance freshwater and ribbed mussel populations and associated ecosystem services
• Increase populations of native freshwater mussels annually by enhancing their habitat and expanding propagation and reseeding programs
• Perform at least one project annually to sustain or enhance ribbed mussel populations, such as via hatchery propagation or use in living shorelines
• Track the number and results of surveys, research, and restoration projects related to both freshwater and saltwater mussels

APPENDIX D - Workshop and survey results

Monitoring Workshop Summary

The list of topics discussed during this workshop:

Important resources and/or parameters to monitor over the next 10 years

- Potentially missing programs/parameters from the draft Baseline and Monitoring Inventory
- Geographic data gaps
- New programs and efforts to be prioritized for the future
- Monitoring Workshop Results and Recommendations

According to workshop participants, the following resources should be monitored over the next 10 years:

- Water quality (e.g., DO, PCBs)
- Habitat (e.g., land use, land cover change)
- Species (e.g., richness, populations)
- Human-related parameters (e.g., behavioral change)

Parameters highlighted by workshop participants as potentially missing from this inventory included:

- Plants and Habitat Monitoring Activities
- Sediment stratification
- Transition zone data
- Submerged habitat data
- Forest data
- Non-Plant Living Resources Monitoring Activities
- Freshwater bivalves
- Invasive species
- Marine mammals/sea turtles
- Population-level analysis
- Delaware River and Bay Monitoring Activities
- Pharmaceuticals
- Microplastics
- Endocrine disruptors/EDCs
- Harmful Algal Blooms
- Fish tissue analysis for bioaccumulating compounds
- Tributary Monitoring Activities
- Wet weather sampling for bacteria
- Gage flow measurements (in addition to USGS data)
- Pharmaceuticals
- Fish tissue
- Cyanotoxins
- Temperatures at shorter intervals
- PCBs
- Groundwater monitoring

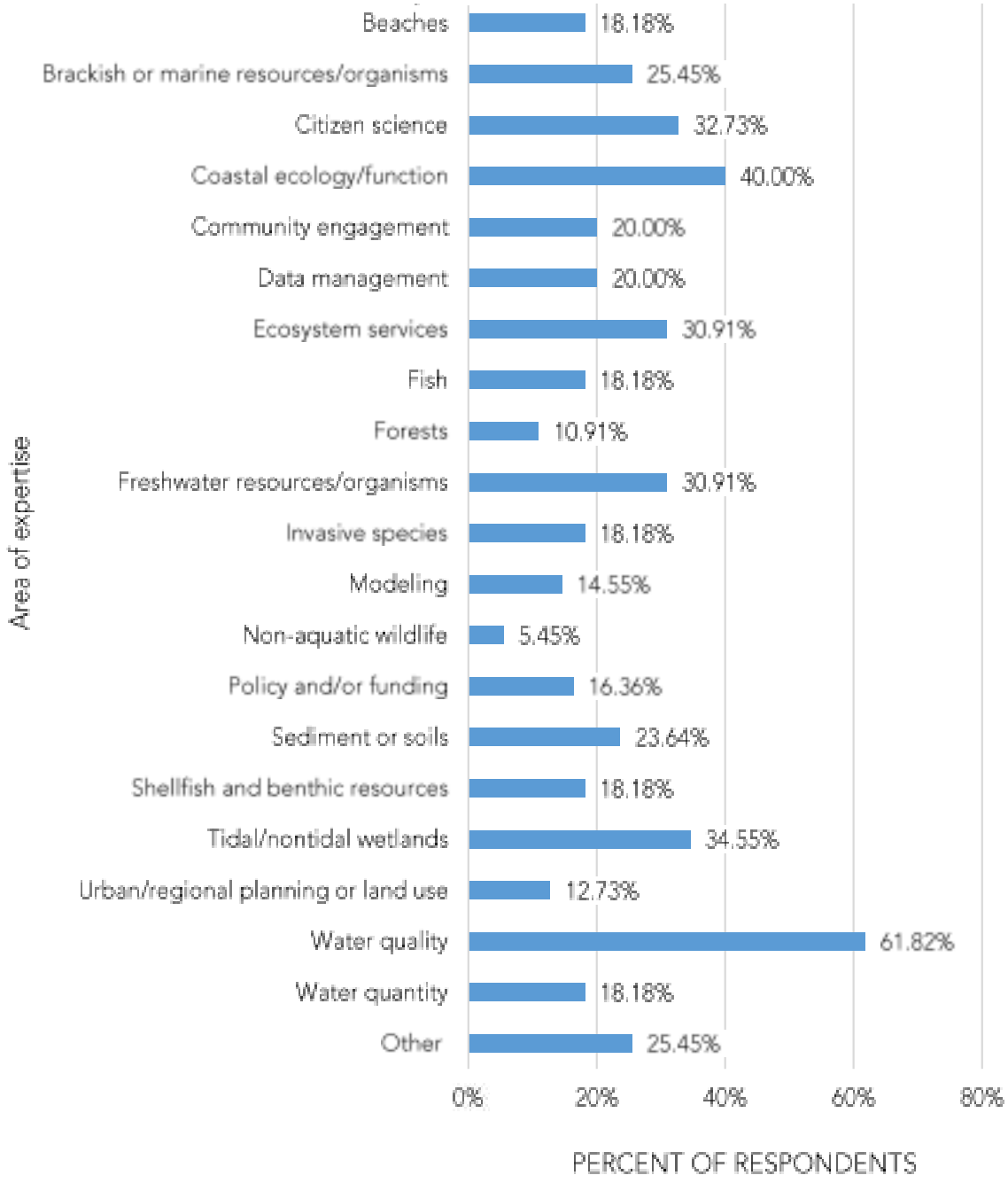

Figure A1. Area(s) of expertise for Delaware Estuary Monitoring Inventory survey respondents by response percentage

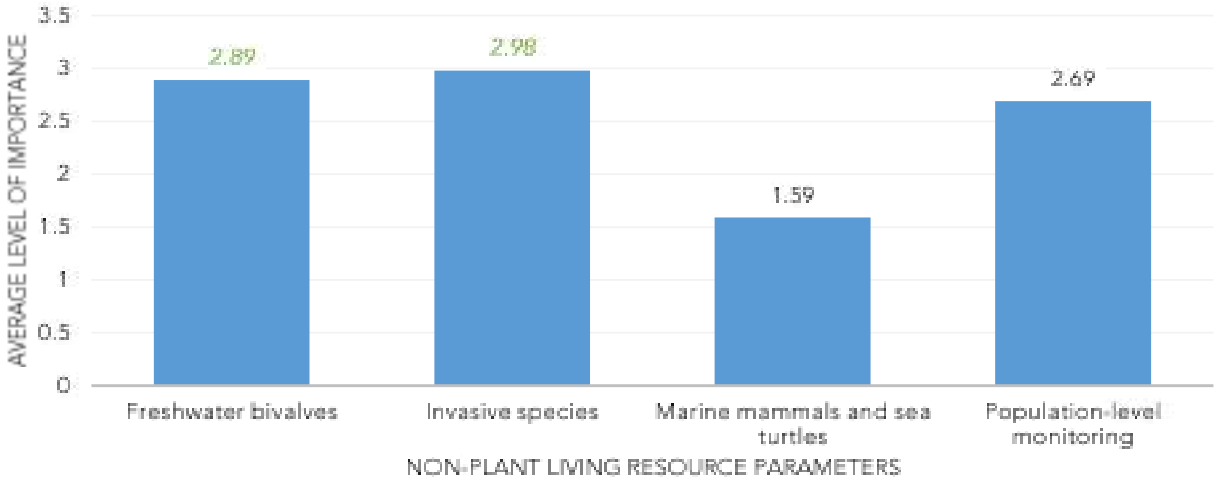

Figure A2. Ranking of non-plant living resource parameters identified as not yet being robustly monitored (where 1 is low priority and 3 is high priority). The top two parameters are highlighted with orange, bold, italicized levels of importance.

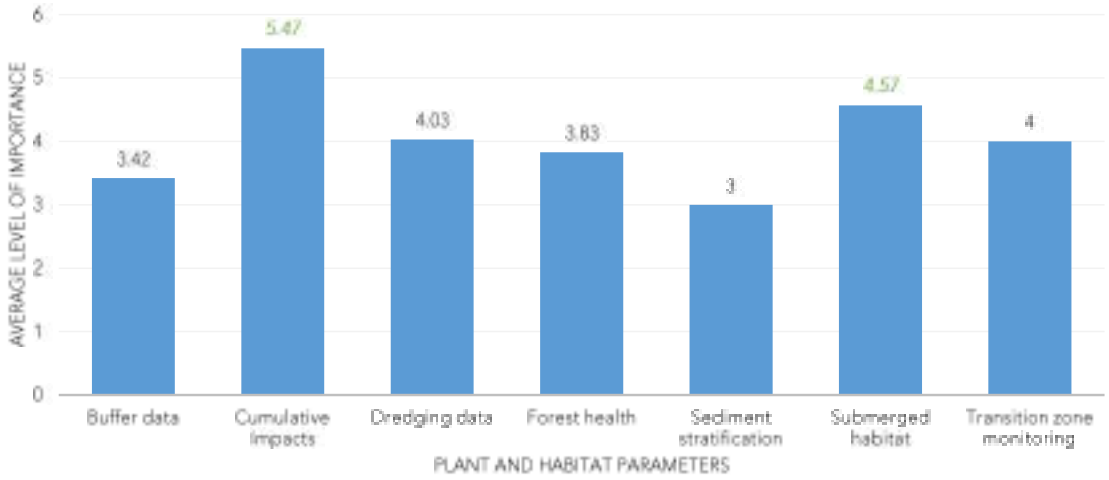

Figure A3. Ranking of plant and habitat parameters identified as not yet being robustly monitored (where 1 is low priority and 6 is high priority). The top two parameters are highlighted with orange, bold, italicized levels of importance.

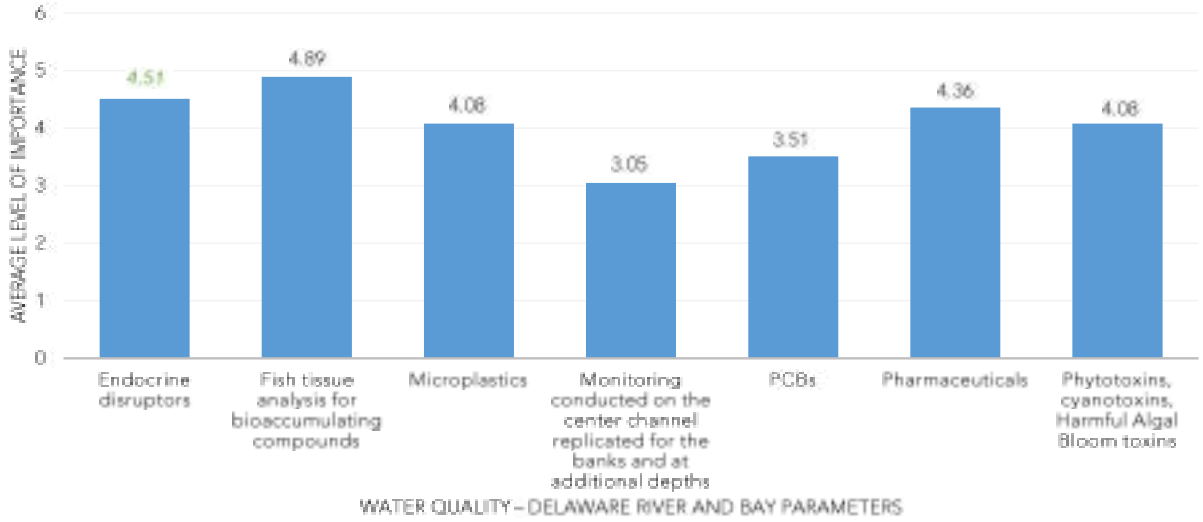

Figure A4. Ranking of water quality (Delaware River and Bay) parameters identified as not yet being robustly monitored (where 1 is low priority and 5 is high priority). The top two parameters are highlighted with orange, bold, italicized levels of importance.

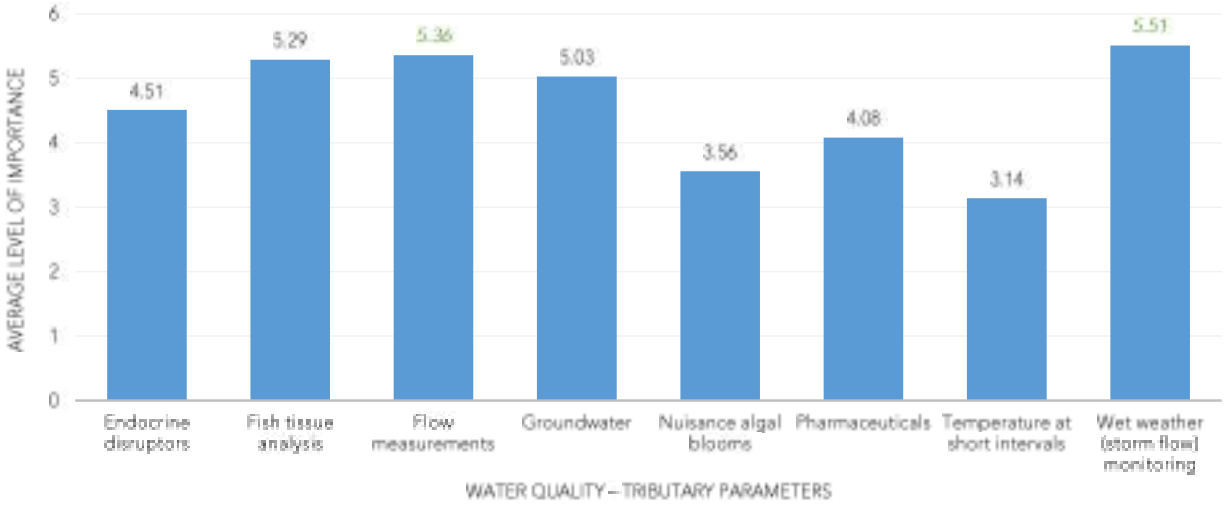

Figure A5. Ranking of water quality (tributary) parameters identified as not yet being robustly monitored (where 1 is low priority and 6 is high priority). The top two parameters are highlighted with orange, bold, italicized levels of importance.

APPENDIX E - CCMP-TREB matrix summaries

Table A10. TREB outliers matrix demonstrating TREB indicators that are not directly supported by strategies outlined in the 2019 CCMP.

TREB Chapter	TREB Indicator
WATER QUANTITY	Per Capita Water Use
	Salt Front Locations and Movement
WATER QUALITY	Tidal: pH
	Tidal: Temperature
	Tidal: Emerging Contaminants
	Non-Tidal: Nutrients
	Non-Tidal: pH
	Non-Tidal: Temperature
SEDIMENTS	Sediment Loading
	Sediment Organic Carbon
	Sediment Grain Size
LIVING RESOURCES	Macro-invertebrates
	Osprey
	White Perch
	Striped Bass
	Weakfish
CLIMATE CHANGE	Air Temperature
	Precipitation
	Extremes: Air Temperature/Precipitation
	Snow Cover
	Wind Speed
	Ice jams

Table A11. CCMP-TREB nexus matrix reflecting the CCMP strategy that aligns with each TREB section and its associated chapter.

TREB Chapter		TREB Indicator	CCMP Strategy
Watersheds & Landscapes		Population	W1.3
		Current Land Cover	W2.5, W1.5, W2.4, W3.2
		Land Cover Change	H1.1, H2.1, H2.3
		Impervious Cover	W1.3, H2.1
		Public Open Space	W1.2, H2.2
		Public Access Points	C1.3, C1.1, C1.2
		Natural Capital Value	C1.1, C1.2, H1.4
Water Quantity		Water Withdrawals	W3.2
		Consumptive Use	W3.3
		Groundwater Availability	H2.2, W3.3, W3.4
Water Quality - Tidal		Dissolved Oxygen	W1.1, W1.5, W1.2
		Nutrients	W1.5
		Contaminants	W2.2, W2.4, W2.5
		Fish Contaminant Levels	H3.1, W2.4, W2.3
		Salinity	W3.2
		Whole Effluent Toxicity	W1.1, W1.5, W2.3, W2.4
Water Quality - Non-Tidal		Dissolved Oxygen	W1.1, W1.2, W1.5
		Contaminants	W2.2
		Fish Contaminants	W2.3, W2.4
		Emerging Contaminants	W2.4
Sediments		Sediment Quantity	W3.5
		Dredging Activity	W3.5
Aquatic Habitats	Non-tidal	Subtidal Habitats	H3.1
		Intertidal Habitats	H1.1, H1.2, H1.3, H3.2
		Fish Passage	H3.1
		Freshwater Wetland Acreage	H1.4
		Hydrological Impairment	W3.1
		Riparian Corridor Condition	W1.2
Living Resources		Atlantic Sturgeon	H3.1
		Freshwater Mussels	H3.3, W1.1, C2.4, W3.2, H1.3, C1.4
		American Eel	H3.1
		Blue Crab	H3.1
		Horseshoe Crab	H3.4
		American Shad	H3.1
		Eastern Oyster	H3.1, H3.2, W2.5, H3.1, W3.2
Climate change		Streamflow	W3.1
Restoration		Acres Restored Annually	H1.2, H1.4, C1.4, H2.2
		Restored Habitat Types	C1.3, C1.1
		Restoration Need	C1.4, C1.1

Table A12. TREB indicator matrix reflecting direct links from TREB indicators to CCMP performance measures and deliverables for each strategy.

THEME 1 | Clean Waters		THEME 2 | Strong Communities		THEME 3 | Healthy Habitats	
CCMP Strategy	# TREB indicators	CCMP Strategy	# TREB indicators	CCMP Strategy	# TREB indicators
W1.1	6	C1.1	6	H1.1	6
W1.2	4	C1.2	5	H1.2	6
W1.3	4	C1.3	5	H1.3	4
W1.4	0	C1.4	3	H1.4	6
W1.5	3	C2.1	0	H2.1	8
W2.1	0	C2.2	0	H2.2	8
W2.2	0	C2.3	0	H2.3	5
W2.3	10	C2.4	1	H3.1	4
W2.4	10	C2.5	0	H3.2	3
W2.5	2	C2.6	1	H3.3	3
W2.6	0	C2.7	0	H3.4	1
W3.1	8			H3.5	1
W3.2	6				
W3.3	5				
W3.4	5				
W3.5	1				

APPENDIX F - Expert prioritization summary

Experts were asked to rank monitoring priority CCMP strategies and TREB indicators (1-10, with 1 being the highest priority). Each strategy (CCMP) or indicator (TREB) was also given a "Yes" or "No" depending on whether the respondent thought it was of high priority. This is represented as consensus of priority, where the number of "Yes" responses were divided by the total number of respondents.

Table A13. List of the CCMP strategies that were included in the top 10 future priorities STAC and MACC respondents by average priority ranking. Note that although respondents were asked to rank 10 priorities, 28 strategies are listed in this table due to tied rankings. Priority ranks are given as the average rank among respondents (±standard deviation; where no standard deviation is provided, only one respondent gave a rank for that strategy).

Priority rank average (±std)	CCMP Strategy #	CCMP Strategy Goal	Respondent consensus of priority (%)
2	C2.4	Awareness & Engagement	17%
2	H3.2	Fish/Shellfish	50%
2.5 ± 2	C2.5	Awareness & Engagement	33%
3.3 ± 2	W1.5	Nutrient Pollution	67%
3.3 ± 2	W3.2	Flow	83%
3.5 ± 4	W2.4	Other Pollutants	67%
4	W3.5	Flow	33%
4	C2.2	Awareness & Engagement	33%
4.3 ± 2	H1.1	Wetlands	50%
5	C1.3	Resilience & Access	17%
5	C1.1	Resilience & Access	33%
5 ± 2	H3.3	Fish/Shellfish	67%
5.5 ± 2	C2.6	Awareness & Engagement	33%
5.7 ± 3	H3.1	Fish/Shellfish	50%
6	W2.2	Other Pollutants	33%
6.3 ± 2	H3.5	Fish/Shellfish	83%
6.5 ± 5	W2.6	Other Pollutants	33%
6.5 ± 1	C1.4	Resilience & Access	33%
6.7 ± 2	H1.2	Wetlands	50%
6.7 ± 2	H1.3	Wetlands	67%
6.7 ± 5	H3.4	Fish/Shellfish	67%
7 ± 4	W2.3	Other Pollutants	33%
7	H2.3	Forests	33%
8	C2.7	Awareness & Engagement	17%
9	H1.4	Wetlands	17%
9	W3.4	Flow	33%
9	H2.1	Forests	33%
10	C2.3	Awareness & Engagement	33%

Table A14. List of TREB indicators that were included in the top 10 future priorities STAC and MACC respondents by average priority ranking. Note that although respondents were asked to rank 10 priorities, 34 strategies are listed in this table due to tied rankings. Priority ranks are given as the average rank among respondents (±standard deviation, where no standard deviation is provided, only one respondent gave a numeric rank for that strategy).

Priority rank average (±std)	TREB indicator	TREB Chapter	Respondent consensus of priority (%)
1.7 ± 1	Dissolved Oxygen	Water Quality - Tidal	43%
2	Nutrients	Water Quality - Tidal	29%
2.3 ± 2	pH	Water Quality - Tidal	57%
3	Sediment Organic Carbon	Sediments	43%
3	Atlantic Sturgeon	Living Resources	43%
3 ± 3	Precipitation	Climate Change	29%
3	Ice Jams	Climate Change	29%
4 ± 4	Current Land Cover	Watershed & Landscapes	43%
4 ± 3	Temperature	Water Quality - Tidal	43%
4 ± 1	Intertidal Habitats	Aquatic Habitats	29%
4	Subtidal Habitats	Aquatic Habitats	14%
4.5 ± 1	Fish Contaminants	Water Quality - Tidal	43%
4.7 ± 5	Contaminants	Water Quality - Tidal	43%
4.8 ± 3	Salinity	Water Quality - Tidal	71%
5 ± 4	Extremes: Air Temperature/Precipitation	Climate Change	57%
5 ± 4	Impervious Cover	Watershed & Landscapes	29%
5	Non Tidal - Freshwater Wetland Acreage	Aquatic Habitats	29%
5.5 ± 2	Emerging Contaminants	Water Quality - Tidal	43%
5.5 ± 1	Air Temperature	Climate Change	43%
5.5 ± 6	Non tidal - Hydrological Impairment	Aquatic Habitats	29%
5.5 ± 2	Acres Restored Annually	Restoration	29%
6	Horseshoe Crab	Living Resources	29%
6 ± 1	Restoration Need	Restoration	29%
6.5 ± 1	Freshwater Mussels	Living Resources	57%
7	Dredging Activity	Sediments	43%
7.4 ± 3	Sediment Quantity	Sediments	71%
8	Eastern Oyster	Living Resources	29%
8	Consumptive Use	Water Quantity	14%
9	Blue Crab	Living Resources	43%
9 ± 1	Restored Habitat Types	Restoration	43%
9	Macroinvertebrates	Living Resources	29%
9	Whole Estuary Effluent Toxicity	Water Quality - Tidal	14%
10	Nutrients	Water Quality - Non-Tidal	29%
10	Wind Speed	Climate Change	14%

APPENDIX G - Acronym List

Table A15. List of all acronyms referenced throughout this document referring to entities, committes, agencies, etc., involved in monitoring throughout the Delaware Estuary focus area.

Acronym	Definition
BBP	Barnegat Bay Partnership
CCMP	Comprehensive Conservation Management Plan
CRE	Climate Ready Estuaries
CVA	Climate Vulnerability Assessment
DELEP	Delaware Estuary Program
DELSI	Delaware Living Shoreline Initiative
DNREC	Department of Natural Resources and Environmental Control
DO	Dissolved Oxygen
DRBC	Delaware River Basin Commission
EIC	Estuary Implementation Committee
EPA	Environmental Protection Agency
ERMA	Environmental Response Management Application
FMRP	Freshwater Mussel Recovery Program
GIS	Geographic Information Systems
GPRA	Governmental Performance and Results Act
HUC	Hydrologic Unit Code
MACC	Monitoring Advisory and Coordination Committee
MINA	Monitoring Inventory and Needs Assessment
MuCWI	Mussels for Clean Water Initiative
NEPORT	National Estuary Program Online Reporting Tool
NJDEP	New Jersey Department of Environmental Protection
NOAA	National Oceanic and Atmospheric Administration
NRCS	National Resources Conservation Service
PADEP	Pennsylvania Department of Environmental Protection
PDE	Partnership for the Delaware Estuary
PWD	Philadelphia Water Department
QAPP	Quality Assurance Project Programs
SC	Steering Committee
SOE	State of the Estuary
STAC	Science and Technical Advisory Committee
TAC	Toxics Advisory Committee
TREB	Technical Report for the Estuary and Basin
USACOE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WPDG	Wetland Program Development Grants