  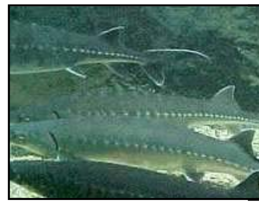 

White Paper on the Status and Needs of Science in the Delaware Estuary

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White Paper on the Status and Needs of Science in the Delaware Estuary

1. Executive Summary

In early 2005, the Partnership for the Delaware Estuary (PDE) convened a two-part science and management conference to bring researchers, resource managers and other interested parties together to summarize the current state of science and identify and prioritize science and management needs for the Estuary. The Delaware Estuary Science Conference was the first meeting of its kind in more than 10 years and attracted an unprecedented number of attendees from government agencies, academia, industry and non-governmental organizations. More than 250 scientists, managers and science-interested people met to deliver more than 130 presentations. These presentations provided a long overdue update on science activities in the Estuary and also identified critical knowledge gaps in our understanding of the estuarine environment, defined as including both tidal and non-tidal portions of the watershed. In addition, particular attention was devoted by the participants to data gaps that hamper sustainable management of natural resources. The program, abstracts and list of attendees are available in a proceedings document available at the PDE website (www.DelawareEstuary.org).

*The **aim of this white paper** is to translate the key points and science needs articulated at the conference into a consensus summary of the state of our scientific knowledge and to provide guidance for channeling future efforts toward the most pressing science and management needs.*

Specifically, the objectives of this white paper are to:
- summarize key points and science needs that were reported at the science conference and subsequent related meetings,
- synthesize key points and science needs into a consensus list of needs that is prioritized, and
- provide a "blueprint" for addressing these needs by the science and management community in the Delaware Estuary.

Section 1 of this paper consists of this executive summary. **Section 2** provides background information on the context for the science conference and subsequent activities. **Section 3** begins with a description of the conference format and a statistical characterization of the participants. Most of this section consists of detailed summaries of the 11 technical sessions: hydrodynamics and water relations; biogeochemistry and water quality; benthic communities; pelagic communities; edges and watershed linkages; data gaps, management and interpretation; the *Athos* I oil spill; water resources; living resources; edges and watershed linkages; and management needs, data coordination and advocacy.

Section 4 provides a comprehensive synthesis of principal science and management needs that contrasts and merges key points from the various session summaries in **Section 3**. This two-tiered approach of summarizing sessions and then synthesizing the summaries provides considerable detail regarding the sources of key points. It also ensures that information presented in different sessions was treated equitably. Of the 28 science and management needs expressed in the different sessions, 16 were the subject of lengthy discussions in multiple sessions. This short list of 16 needs was then divided into 10 technical and 6 operational needs. Technical needs are defined as relating to actual scientific information that is needed to better understand and manage natural resources. Operational needs are considered to be organizational actions and programs by the scientific and management community that facilitate improved environmental management. Lists of technical and operational needs were then prioritized by assigning highest rank to topics that were discussed most broadly among different sessions.

The **top ten technical needs** that were identified for advancing science and management of the Delaware Estuary ecosystem are, with top priority listed first: 1) contaminants (e.g., forms, sources, fates & effects of different classes); 2) tidal wetlands (e.g., status and trends of different types); 3) ecologically significant species and critical habitats (e.g., benthos, reefs, horseshoe crabs); 4) ecological flows (e.g., effects of freshwater inflow on salt balance and biota); 5) physical-chemical-biological linkages (e.g., effects of sediment budget on toxics and biota); 6) food web dynamics (e.g. identification and quantification of dominant trophic interactions); 7) nutrients (e.g., forms, concentrations and relative balance); 8) ecosystem functions (e.g. economic valuation of ecosystem services); 9) habitat restoration and enhancement; and 10) invasive species (e.g., monitoring and control).

The **top six operational needs** are : 1) better linkages between science and management; 2) a comprehensive conceptual framework describing key elements of the estuary ecosystem; 3) implementation of ecosystem management approaches; 4) expansion of the monitoring infrastructure with links to indicators and goals; 5) better data coordination, compatibility, quality, sharing, access and archiving; and 6) stronger public education programs that broaden understanding of the defining traits and issues in the Delaware Estuary.

Section 5 includes a description of current plans for strengthening science and addressing science needs in the Delaware Estuary. As administrator of the Delaware Estuary Program, PDE has been charged with taking a leadership role in working to bridge the various science and management communities and strengthen science coordination. For example, plans are underway to form a new Science and Technical Advisory Committee (STAC) that will provide guidance and peer review for addressing the needs identified through the conference. The STAC is expected to work with existing technical committees and to form new workgroups that will in turn be challenged with drafting specific recommendations to address particular needs. The STAC will also assist PDE and partners in determining how to best address these needs as part of the overall implementation of the Comprehensive Conservation and Management Plan and to help advance a broader science and technical agenda within the strategic planning process that is underway for PDE.

The “blueprint” in **Section 5** also outlines an iterative process for refreshing the science needs assessment by periodically reconvening the Delaware Estuary Science Conference. While the first science conference was very successful, we acknowledge that not all of the estuarine science community was able to participate. We are hopeful that there will be broader involvement in the future by holding the conference on a predictable basis.

The Delaware Estuary is one of the largest estuaries in the country and is governed by multiple states and different federal sub-regions. Its academic and resource management sectors have often been disassociated. For more than 400 years, the Estuary has supported one of the greatest population centers in the United States and it remains home to one of the largest industrial complexes in the country; however, few commercial interests are engaged in the scientific and technical community. Compared to other large estuaries, resources allocated for science and management in the Delaware Estuary are substandard. Considering these factors above with the complex natural landscape and ecology and the array of environmental issues in the Estuary, addressing the science and management needs listed above will be a challenging endeavor but worthwhile.

With these things in mind, the Partnership is committed to continuing its efforts to expand scientific participation and our knowledge of this important and complex eco-system. Future development activities will help identify additional resources to advance the science directions and needs outlined here. We will also increasingly work together with a diverse mix of academic, agency, non-profit, and commercial entities to share knowledge and data and to improve communication networks. Improved science coordination, as promoted by these actions, will directly address many of the operational needs identified above. By also working together to conceptualize and build awareness for the defining strengths, issues and science needs that distinguish the Delaware Estuary from other major estuaries in the nation, we will generate greater enthusiasm that should attract new resources to the region. This is important because accomplishing our goals will partly depend on new and sustainable funding mechanisms. New resources and improved science coordination will strengthen our capability to respond to contemporary issues such as oil spills and emerging issues such as sea level rise.

2. Background

As a National Estuary Program, the Partnership for the Delaware Estuary (PDE) is charged with implementing the goals of the 1996 Comprehensive Conservation and Management Plan (CCMP), which includes science, management and policy. Until 2004, PDE operated as a nonprofit alongside the Delaware Estuary Program (DELEP), a separate entity. The Partnership focused its attention on educating the public about the Estuary and building stewardship for this important natural resource. DELEP worked to facilitate interstate coordination and enhance overall resource management capacity. In 2004, DELEP and PDE merged to form a single organization - the Partnership for the Delaware Estuary, a National Estuary Program.

The reorganized Partnership is now charged with addressing the full complement of actions called for in the CCMP, including science and technical investigations. Of paramount initial importance was the need to assess the state of science in the ecosystem, and to build consensus in defining and prioritizing future science and restoration activities for the Delaware Estuary. It had been ten years since a science-themed meeting was convened. Recognizing this void, in early 2005 PDE convened a science conference to bring scientists, policy-makers, resource managers and other science-interested parties together to discuss the state of the field and to build consensus regarding future science needs.

This White Paper on the Status and Needs of Science in the Delaware Estuary concludes this process by summarizing common ground on future science directions from the 2005 Delaware Estuary Science Conference (Sections 3.1 to 3.7). The conference was highly successful in bringing scientists and managers together as a community and stimulating group discussion about science needs. The intention is to reform a Scientific and Technical Committee for the Estuary Program, which will work to find ways to address these needs and provide peer review.

In the interim between the conference and the writing of this White Paper, the momentum of the conference has continued and further discussion has occurred. For example, in September 2005 a workshop was held to discuss monitoring needs for the Delaware Estuary and to design a framework for implementing a NOAA Integrated Ocean Observing System (IOOS) program in our system. Since many of the needs expressed at the IOOS workshop added to those expressed at the Science Conference, the proceedings from that workshop were also used for the development of this White Paper (Section 3.8). The reader is directed to the following two documents for much of the source material used to prepare this White Paper:

> "Proceedings of the First Delaware Estuary Science Conference" (PDF file):
> http://www.delawareestuary.org/scienceandresearch/datasetsandreports/index.asp
> The IOOS Workshop Proceedings are expected to be made available at:
> http://www.njmsc.org/

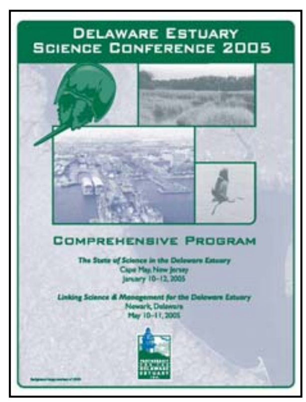
Additional source material consisted of notes contributed by some session moderators, and these individuals are acknowledged as the authors of this document.

3. The 2005 Delaware Estuary Science Conference

3.1 Context

As one of its first actions as the home of the National Estuary Program, the Partnership convened the two-part Delaware Estuary Science Conference in January and May, 2005. The meeting was attended by more than 250 of the region's top science and policy representatives. PDE was assisted by more than a dozen partnering agencies and groups.

3.2 Objectives



The goals of the conference were to bring together researchers, resource managers and other interested parties who have a vested interest in the science of the Delaware Estuary, and to assess the current state of knowledge about the system. Attendees were well represented from both sides of the bay, the lower bay, upper freshwater tidal reaches, and the non-tidal watershed. Besides sharing their knowledge, participants discussed present activities and pledged to integrate and coordinate efforts in the future. In accordance with the purpose of the conference, all speakers and attendees were pressed to help chart future science needs for the Delaware Estuary.

3.3 Format

The conference consisted of eleven sessions and more than 100 presentations. The January meeting included Sessions 1-7 and was oriented toward research scientists who are most interested in how the system works and who are actively engaged in collecting or interpreting scientific information. Session 7 was included in the January program to address the *Athos* I oil spill that occurred in November 2004.

The May portion of the conference was designed to be more issue-oriented and of special interest to those who rely on scientific information. In both events, all presenters, moderators and attendees were asked to assess the current state of science in the Estuary and to help prioritize science needs for guiding future science in the Estuary. The themes of the two meetings were:

"The State of Science in the Delaware Estuary," Sessions 1-7
January 10-12, 2005, Cape May, NJ

"Linking Science and Management for the Delaware Estuary," Sessions 8-11
May 10-11, 2005, Newark, DE

The interval between the two events was used to compile interim summaries on the current state of our knowledge from the research scientists' perspective. These summaries were prepared by moderators from January for delivery as short recap talks to launch each of the sessions in May. Whereas most of the oral presentations given in January were contributed, the presenters at the May meeting were selected to ensure that science needs would be addressed from the perspective of resource managers and other stakeholders. The number of oral presentations for the May meeting was capped to limit the duration of the meeting and to minimize overlap of topic coverage. Contributed poster presentations represented an important component of both the January and May meetings.

Participants included scientists, resource managers, agency personnel, industry representatives, conservation groups, and the public. All presenters and attendees were asked to provide input on the most pressing scientific issues, data gaps, and recommendations for guiding future science funding within the system. This input was collected in presentations, workshops, question and answer sessions, and via written answers on the questionnaires in program packets. Following the conference, several of the conference moderators and steering group members continued to work with the Partnership to synthesize the messages and priorities in presentations and other input.

3.4 <u>Program</u>

The first portion of the Science Conference, "The State of Science in the Delaware Estuary" (January 10-12, 2005; Cape May, NJ) consisted of seven sessions. These were:1) Hydrodynamics & Water Relations, 2) Biogeochemistry & Water Quality, 3) Benthic Communities, 4) Pelagic Communities, 5) Edges & Watershed Linkages, 6) Data Gaps, Management & Interpretation, and a late addition 7) The *Athos* I Estuary Oil Spill.

The second portion of the conference, "Linking Science and Management for the Delaware Estuary" (May 10-11, 2005; Newark, DE) consisted of four sessions. These were: 8) Water Resources, 9) Living Resources, 10) Edges & Watershed Linkages, and 11) Management Needs, Data Coordination and Advocacy.

In addition to these eleven regular sessions, the program of both meetings contained a variety of invited plenary presentations, invited keynote presentations, special roundtable workshops, and a special invited panel discussion by regional environmental leaders.

Although not directly connected to the Delaware Estuary Science Conference, the NOAA sponsored Integrated Ocean Observing System workshop in September 2005 picked up on many of the same messages at the conference. The workshop's focus was on ways to address needs related to our technological and information management infrastructure. Because this workshop advanced the discussion from the conference, the key points and ideas expressed at the workshop are included in this paper (Section 3.8).

The full conference program with abstracts and presenter details is provided in the PDF document titled the *Proceedings of the First Delaware Estuary Science Conference* (see above).

3.5 Statistics and Participation

Attendance totaled 260 individuals for the January and May meetings. To be comprehensive and inclusive, one of the principal goals of the conference was to attract scientists and science-interested individuals from a wide geographic and institutional range. Table 3.1 summarizes the geographical range represented by the participants of each meeting, and those who attended both events. Attendees came from ten different states, with greatest representation by those from Delaware, New Jersey and Pennsylvania. Representation was quite balanced between Delaware and New Jersey, and more than half of those from these two states who attended in January also returned in May.

Table 1. Registered attendance at the 2005 Delaware Estuary Science Conference as quantified by state.

Representation by State	January	May	Both
Delaware	53	65	34
Maryland	14	13	9
Massachusetts	2	2	1
New Jersey	57	56	33
New York	3	6	1
Pennsylvania	42	31	17
Rhode Island	1	0	0
Virginia	0	1	0
West Virginia	3	0	0
Washington, D.C.	1	4	1
Total Attendees	**176**	**178**	**96**

Balanced representation was also apparent with regards to the type of institutional affiliation of attendees (Table 2). Scientists, resource managers and other officials representing governmental organizations were most numerous, followed by scientists and educators from academia. In addition, industry, non-profit and other non-governmental organizations were well represented.

Table 2. Registered attendance at the 2005 Delaware Estuary Science Conference as quantified by type of institutional affiliation.

Representation by Affiliation	January	May	Both
Academia	51	37	24
State and Regional Agency	38	42	23
Federal Agency	49	46	22
Industry	19	25	11
Non-profits, NGO's and others	29	28	16
Total Attendees	**176**	**178**	**96**

As described above, a diverse program format was offered. If special panel speakers and introductory speakers are considered along with formal scientific presentations, a total of 133 presentations were given (Table 3). The January meeting contained slightly fewer presentations but lasted longer (2 ½ days) than the May meeting (2 days) because presentations were longer on average and a half day was devoted to workshop roundtable discussions.

Table 3. Numbers of different types of presentations at the 2005 Delaware Estuary Science Conference.

	January	**May**	**Total**
Lead-off Speaker	3	8	11
Keynote/Plenary Speaker	2	5	7
Invited Oral Presentation	8	25	27
Contributed Oral Presentation	30	0	36
Contributed Poster Presentation	12	17	29
Moderator Summary Presentation	1	6	7
Panel Speaker	6	10	16
Total Presentations	**62**	**71**	**133**

3.6 Session Reports (with workshop notes)

A summary of each session is provided below. For each session, the titles, authors and principal points of oral and poster presentations are tabulated. Key observations, questions and science needs that were articulated across each session were then synthesized by comparing the contents of all presentations, dialogue during question and answer forums, notes from workshops (January), and written feedback on questionnaires completed by conference attendees. These key points from individual sessions are listed topically, followed by a list of any topics that were missing from the session. Major points and science needs that cross-cut many of the sessions, roundtable discussions, and question and answer sessions are summarized in Section 4.

3.6.1 *Session 1: Hydrodynamics & Water Relations*

The focus of this session was on the overall water budget and physical processes of the Delaware Estuary. Topics included water quantity and flow from the basin, water withdrawals, water discharges, salt balance, sea level rise, hydrodynamics, and mixing. Session 1 was the smallest session with four presentations (Table 4.) Session 1 topics were further discussed, from the perspective of applied science and resource management, in Session 8 (Section 3.6.8.)

Collectively, these talks and discussions indicate that the Delaware Estuary has undergone tremendous physical changes over the past 3,000 years due to natural processes. For example, 3,000 years ago the bay portion was about 60% of the present area, and fringing marshes were more extensive. Sea levels rose approximately 400 feet as the continental ice sheets melted about 12,000 years ago, drowning the ancestral Delaware River valley. Shorelines stabilized in their present locations around 4,000 years ago, and since then the Estuary has continued to widen and shoal.

In addition to natural processes, more recently human-induced changes have also altered the physical character of the Estuary. In particular, deepening of the ship channel and shoreline development have both contributed to a decrease in river width in the upper Estuary, but the width and volume of the bay portion appears to have increased. As a result, salt water moves farther up the Estuary and more sediment is deposited on shoals.

Table 4. Titles, authors and key points of presentations delivered in Session 1, "Hydrodynamics & Water Relations," which was moderated by Jeff Fischer, Pierre LaCombe and Ralph Spagnolo on January 10, 2005 in Cape May, NJ.

Title	Authors	Key Point
The present state of knowledge of the tidal and residual circulation in the Delaware Estuary and adjacent continental shelf	R. Garvine	The current field in Delaware Estuary is split into tidal and residual components, and we are getting better at forecasting circulation patterns.
Historical changes in the morphology of the subtidal Delaware Estuary	C. Sommerfield and D. Walsh	Dredging and other engineering works have substantially altered the cross-sectional morphology, volume and sediment budget of the estuary.
On the current variability in the upper Delaware Estuary	K. Wong	Tidal variability in upper Delaware Bay results mainly from lunar effects, with amplitude decreasing with depth.
Saltwater intrusion into Cape May County aquifers from Delaware Bay	P. Lacombe	Intrusion of saltwater is forcing well closures, increasing yearly, and mainly results from groundwater withdrawals.

Key points, observations, questions and science needs of Session 1 are summarized topically below.

3.6.1.1. Tidal Currents

Modeling of tidal currents is important for shipping and also to understand water mixing. Presently, tidal currents appear to be well modeled, but some aspects of residual currents (e.g., buoyancy-driven and wind-driven factors) are not well modeled. A more complete understanding of these components of currents is needed for modeling material transport.

3.6.1.2. Salt Balance

The Delaware Estuary is unique among large American estuaries in having a substantial freshwater tidal region, considered one of the largest of its kind in the world. The main mixing zone between seawater and freshwater occurs in the middle of the Estuary. As discussed more fully in other sessions (e.g., Session 8), rising sea level, changes to freshwater inflows, and other factors might be leading to movement of the salinity gradient towards the upper Estuary. This in turn could be having ecological effects, and more study will be needed to deduce such impacts.

In addition to its ecological effects within the tidal Estuary, changes in the balance between saltwater and freshwater are already impacting human activities in southern New Jersey. For example, in Cape May County saltwater from Delaware Bay is infiltrating the groundwater leading to salt contamination of wells for drinking water. While it appears that most of these changes in the salt balance of groundwater are being driven by groundwater withdrawals, rising sea level is expected to contribute to this problem in the future.

3.6.1.3. Monitoring

Long-term monitoring of physical processes (e.g., tidal currents, sediment deposition) is lacking in the Delaware Estuary. Improvement in our monitoring capabilities is a fundamental need.

3.6.1.4. Data Issues – Coordination and Consistency

Lack of data consistency and access were identified as significant impediments to gaining a more integrated understanding of the hydrodynamics and physical processes of the Delaware Estuary. The Estuary is home to numerous agencies with different jurisdictions. The difficulty in obtaining consistent data for resource evaluations presents a major management challenge. Improved sharing of information was considered a critical scientific need by participants of this session.

3.6.1.5. Conceptual Framework

Currently, there is no consistent, comprehensive framework for interpreting scientific results (e.g. sediment budget and water balance). The science and management community would benefit by having a conceptual framework that organizes and summarizes key physical processes.

3.6.1.6. Management of Water Balance and Use

Water relationships in the Delaware Estuary are governed in large part by the many human modifications to the hydrodynamics of the system. The many competing needs for water quantity, both in the watershed and the coastal plain, presents a daunting challenge for environmental management.

3.6.1.7. Linking Science and Management

It is currently difficult to find, interpret, and use scientific information for management decisions. There is a need for agencies and academic institutions to work more closely together (e.g., bathymetric surveys, models).

3.6.2 *Session 2: Biogeochemistry & Water Quality*

The intended focus of this session was on water quality and biogeochemical cycling in the Delaware Estuary. All ten presentations focused on some aspect of either water or sediment quality (e.g., nutrients, contaminants), and little was said regarding the biogeochemical balance of the system (Table 5. Session 2 topics were further discussed, from the perspective of applied science and resource management, in Session 8 (Section 3.6.8).

Collectively, the presentations and discussions in Session 2 indicate that the Delaware Estuary has undergone substantial improvement over the past 30-50 years in many key water quality metrics. Considerable problems remain with regard to legacy pollutants such as PCB’s, other chlorinated hydrocarbons, and selected metals. In addition, evidence was presented suggesting that some classes of pollutants such as

Table 5. Titles, authors and key points of presentations delivered in Session 2, "Biogeochemistry & Water Quality," which was moderated by Jonathan Sharp and Ed Santoro on January 10, 2005 in Cape May, NJ.

Title	Authors	Key Point
Organochlorine compounds and trace elements in fish tissue and streambed sediment in the Delaware River Basin, NJ, PA and NY, 1998-2000.	J. Fischer, K. Romanok, R. Brightbill, K. Riva-Murray, and M. Bilger	DDT, PCB's and mercury remain significant contaminants in fish tissue, and fish-eating frequently exceeds guidelines.
Pesticide compounds in streamwater of the Delaware River Basin, PA, NJ, NY, and DE, Dec. 1998 – Aug. 2001.	R.E. Hickman	Drinking water standards for key pesticides such as atrazine were exceeded at 5 sites and wildlife guidelines were exceeded at 11 sites
Marsh sediments as records of eutrophication and metal pollution in the urban Delaware Estuary.	T. Church, C. Sommerfield, D. Velinsky, D. Point, C.Benoit, D. Amouroux, D. Plaa and O. Donard.	Two cores from fringing marshes near Philadelphia indicate that the large P increases after 1950 have recently declined, large N increases continue, and many industrial metals show 2-4 fold+ increases since 1950.
Patterns of sport-fish consumption at six Pennsylvania sites along the tidal portion of the Delaware River with special emphasis on shore anglers	A. Faulds, N. Connelly, B. Knuth, J. Benowitz, J. Matassino, and K. Norton	Surveys of more than 1000 anglers on the Delaware River near Philadelphia indicate low awareness regarding fish consumption advisories, possibly due to language barriers with ethnic groups.
Water Quality in the Delaware Estuary.	E. Santoro	DO and bacteria conditions continue to improve in the main channel and high nutrients do not appear to be causing eutrophication. Shorelines and tributaries differ from the main channel.
Preliminary analysis of total nitrogen and total phosphorus loads and factors affecting nutrient distribution within the Delaware River Basin	M. Chepiga, S. Colarullo and J. Fischer	The main point sources for total N and P in the fluvial system appear to be from municipal and industrial activities, animal waste, fertilizers, and atmospheric dep.
Quantitative modeling of nitrogen loading to Delaware Bay: sources, fluxes and management options.	D. Whitall	Human wastes contribute substantially to N loadings to DE Bay, and more wastewater treatment would produce further reduction in N.
Polychlorinated biphenyl accumulation in Delaware River Estuary food webs	J. Ashley, D. Velinsky, M. Wilhelm, J. Baker and M. Toaspern	PCB concentrations in biota reflected those in sediments, which were highest adjacent to urban and industrialized regions.
Attenuation of nitrogen fluxes during groundwater seepage across a beachface at Cape Henlopen, DE.	R. Hays and W. Ullman	Groundwater inputs to the estuarine system are variable and poorly measured, but they could be important sources of N and organic contaminants.
Water and sediment quality of the tidal freshwater Schuylkill River, PA: understanding sources and fate of nutrients and chemical contaminants.	D. Velinsky and J. Ashley	The tidal freshwater Schuylkill River has some of the highest PAHs in the mid-Atlantic region as well as relatively high sediment trace metals and PCBs.

hydrocarbons (e.g. PAH's) could be more problematic than expected. Discussions also pointed out that we need to learn more about the existence and effects of substances of emerging concern such as pharmaceuticals and personal care products (PPCP's).

Key points, observations, questions and science needs are summarized topically below.

3.6.2.1. Monitoring

A diverse array of programs currently exist to monitor water quality in the Delaware Estuary and its watersheds, particularly with regard to specific areas or classes of compounds. The "Estuary Boat Run" operated by the Delaware River Basin Commission (DRBC) was discussed as an example of a successful long-term monitoring program that provides critical year-to-year information on measures such as dissolved oxygen and nutrient concentrations in the main channel. Another important program is the EPA National Coastal Assessment (NCA), which enables direct comparison of monitoring among different estuaries and coastal communities. Classes of contaminants such as PCB's are also targeted for study and monitoring by different regional and state agencies, since it is well established that they remain as significant problems in our system and are the subject of TMDL actions.

Despite this seeming wealth of monitoring activities, there is much to be done to strengthen the temporal and spatial robustness of our water quality monitoring (see below), to address understudied and emerging pollutants (Section 3.6.2.2), and to better link existing efforts (Section 3.6.2.3). Current monitoring efforts and needs will be reviewed in further detail in Section 4.

The Boat Run led by DRBC is regarded as the best continuous, long-term water quality monitoring program in the Estuary. No other monitoring program samples a general, representative suite of water quality metrics as often or in as many locations across political and agency boundaries as this program. The NCA program is important for its comparability to other systems, but its temporal resolution is limited to annual surveys. The Boat Run is also limited because it is not continuous throughout the year because of hazards associated with winter sampling. Conference participants recommended that winter sampling options be reconsidered as new automated technologies are developed. Another way to strengthen the Boat Run may be to expand spatial sampling along the margins of the Estuary because Boat Run results (and other studies) have shown that water quality can differ markedly between the main channel and peripheral areas such as shorelines and tidal tributaries. In particular, nutrients and pathogens may be higher along edge habitats.

3.6.2.2. Contaminants

Data from the Boat Run and other programs have clearly documented that water quality has improved considerably with regard to the biological oxygen demand associated with upgrades in wastewater treatment over the past 50 years. More recently, improved conditions have also been reported for certain contaminants such as phosphorus and lead.

Nevertheless, many challenges remain. Legacy pollutants such as dioxin, PCB's, and mercury persist in our watershed, and existing monitoring programs may not be adequate enough to meet management and policy needs. Concentrations of these compounds in water and sediments often exceed standards for wildlife and human drinking water. Moreover, although concentrations in fish tissue also exceed guidelines for human consumption, many people continue to consume fish taken from contaminated areas.

Evidence was also presented showing examples of high concentrations of some pesticides and hydrocarbons (e.g., PAH's), suggesting that the prevalence, fate and effects of these compounds may be understudied in our system and therefore should be examined more closely. Emerging pollutants such as pharmaceuticals and personal care products (PPCP's) merit greater attention by both researchers and managers. Toxic chemicals associated with flame retardants, stain repellants, paper coatings, and industrial surfactants and lubricants are also of growing interest. For many contaminants, we can look back and learn more about past conditions using new approaches such as marsh cores.

3.6.2.3. Data Issues - Coordination

Thanks to the collaborative efforts of regional groups such as the Toxics Advisory Committee (TAC) of DRBC and the Delaware Estuary Program, water quality research, assessment and monitoring appears to be more coordinated than other areas of environmental science and resource management. Nevertheless, many conference participants suggested that different monitoring and assessment efforts should be better linked into a more comprehensive framework that relates to food web dynamics (Section 3.6.2.4) and considers the full range of contaminants (Section 3.6.2.2).

3.6.2.4. Physical-Chemical-Biological Linkages

An interesting feature of the Delaware Estuary is that eutrophication problems appear rare in relation to other large American estuaries that have similar high nutrient inputs. It appears that one important reason for this is high turbidity that may inhibit blooms of phytoplankton in the water column of the upper and middle Estuary. In other estuaries high turbidity is believed to be symptomatic of problems, such as high stormwater runoff and erosion in the watershed. However in the Delaware Estuary, this high turbidity is thought to be a natural feature, partly because the Estuary is very well mixed and hydrodynamically active. This paradoxical phenomenon is an example of the importance of understanding how the physical, chemical, and biological features of the Estuary relate, and how they sometimes contribute to unexpected biological outcomes.

Although many chemical and physical properties of water quality are being monitored in the Delaware Estuary, there is relatively little study and assessment of coincident biological interrelationships. As examples, we need to know more about the biological fates and effects of contaminants in the food chain. We also wish to learn whether persistent contaminants may be inhibiting biological activity. The interrelationships between the effects of toxics and eutrophication, and between water quality and trophic transfer efficiencies, need to be better studied. Finally, we would like to know whether high turbidity and contaminant concentration might be affecting microheterotrophic production.

3.6.2.5. Tidal Wetlands and Riparian Buffers

Both water quality and biogeochemical cycling in the waters of the tidal Estuary are certain to be significantly affected by interactions with edge habitats, such as the tidal wetlands that fringe much of the Estuary and riparian buffers lining the non-tidal tributaries. A growing body of scientific research indicates that wetlands and riparian corridors provide important ecosystem services by removing or detoxifying many classes of contaminants. For example, wetlands were listed as a sink for N and so they can reduce N loadings in the Estuary. We have yet to incorporate the roles of these habitats in nutrient and contaminant budgets because of the complexity of modeling linkages among habitats. We need to develop an understanding of the effect of riparian and wetland habitats on various aspects of water quality in the Estuary.

3.6.2.6. What was missing from Session 2?

- Endocrine disruptors and emerging contaminants such as pharmaceuticals and hormone products were not covered, except in side discussions.
- Tributyltin (TBT), perfluorooctanoic acid (PFOA), and ammonium perfluorooctanoate (APFO; a.ka. C-8) were not well covered, but could be significant contaminants in the Delaware Estuary.
- Biogeochemical cycles were not discussed per se, even though concern exists regarding the status and effects of nutrient ratios (e.g., N:P) and the balance of other minerals (e.g., silica).

3.6.3 *Session 3: Benthic Communities*

Session 3 focused on the structure and function of the benthic portion of the Estuary. Topics mainly consisted of physical (sediments, mudflats, reefs) and biological (oysters, mussels, horseshoe crabs, blue crabs, SAV and benthic algae) characteristics (Table 6.) The living resources covered in Session 3 were further discussed in Session 9 (Section 3.6.9) from the perspective of applied science and resource management.

Collectively, the talks and discussions of Session 3 indicate our overall state of knowledge of the benthos is fair to poor in the Delaware Estuary. Useful long-term data exist for the status and trends for selected important species, such as blue crabs (*Callinectes sapidus*), American oysters (*Crassostrea virginica*), and horseshoe crabs (*Limulus polyphemus*). These data exist mainly in the form of commercial exploitation statistics, and so their relevance to the status and trends of natural populations must be interpreted carefully. Comparing these three ecologically significant species, time-series "catch data" for oysters are excellent, for blue crabs fair to good, and for horseshoe crabs poor to fair.

Beyond these three significant benthic resources, we have a poor understanding of the benthic community. A comprehensive survey of soft bottom benthos was last undertaken in the 1970's, although there appears to have been some smaller benthos studies in the 1990's. Functional aspects of the benthos and pelagic-benthic coupling processes are not well studied in the Delaware Estuary. There are remarkably few data on tidal freshwater benthos.

Key points, observations, questions and science needs of Session 3 are summarized topically below.

3.6.3.1. Data Sets and Monitoring

Long-term datasets are increasingly valued for their utility in detecting trends in environmental conditions, such as salinity regimes. We have very little time-series data for benthic inventories in the Estuary. The strongest long-term data are for oysters, with limited time-series information for blue crabs and horseshoe crabs. The last survey of benthic organisms was completed in the 1970s, and so we are long overdue for a comprehensive benthic assessment. Monitoring programs could be strengthened by incorporating more benthic community metrics; however, more cost-effective methods for benthic sampling and sample processing are also needed so that data needs can be met despite weak science funding.

Table 6. Titles, authors and key points of presentations delivered in Session 3, "Benthic Communities," which was moderated by John Kraeuter on January 11, 2005 in Cape May, NJ.

Title	Authors	Key Point
Supply of blue crab postlarvae to juvenile habitat in Delaware Bay: a classic case of biophysical coupling.	C. Epifanio	Recruitment of blue crabs may be a function of megalopal supply to juvenile habitat, which can be modeled each year.
Blue crab population dynamics in DE Bay: density dependent juvenile mortality and the relationship between spawning stock and recruitment.	D. Kahn	Blue crab stocks appear healthy and stable at present, and current harvest rates appear sustainable. Cold winters significantly affect blue crab stocks.
Perspectives on the status of horseshoe crab research in Delaware Bay.	M. Botton and R. Loveland	Horseshoe crabs appear to be in decline, but it is unclear if this is part of a natural cycle or a result from habitat impairment. Little is known about their ecology.
Oysters and oystering in Delaware Bay.	S. Ford and D. Bushek	Oyster stocks are at an all time low due to many factors such as disease, and more recently, poor recruitment.
The status and future of benthic macrofauna science in the Delaware Estuary.	F. Steimle	With few exceptions, benthic communities and benthic-pelagic coupling processes remain very poorly studied and monitored.
Discerning impacts of sediment contamination on benthic communities in Delaware Bay.	I. Hartwell, L. Claflin and J. Hameedi	A sediment quality assessment was made for Delaware Bay based on the sediment quality triad and use of a stratified-random sampling design.
3-D Thermal mapping shows that intertidal groundwater seeps can help to structure sandflat biodiversity.	R. Dale and D. Miller	Groundwater seeps were studied in relation to benthic fauna by mapping temperatures over small spatial scales.
Use of surf clam shell to enhance oyster seed bed production in Delaware Bay	R. Babb, J. Hearon and D. Bushek	Use of surf clam shells promotes oyster seedbed production, thereby helping restore the fishery and ecological function.
Potential impact of the non-native marine isopod *Synidotea laevidorsalis* (Miers 1881) in the Delaware Bay.	S. Boyd and D. Bushek	Since first being discovered in DE Bay in 1999, non-native isopods appear to have become widespread with unknown effects.
Restoration of the Cape May Salt Oyster.	S. Tweed and J. Tweed	New aquaculture methods were developed to help restore "Cape May Salt" oysters.
Utilizing native oyster seed to enhance oyster populations and aquaculture: the New Jersey experience.	S. Tweed	Spat collectors were used to enhance oyster recruitment for aquaculture operations.

3.6.3.2. Data Gaps – The Benthos

We know very little about the bottom of the Delaware Estuary, including physical and biological traits. The last comprehensive survey of benthic fauna was completed in the 1970s. A geographical assessment of the distribution and diversity of benthic macroinvertebrates has been completed by NOAA as part of a sediment quality assessment. However, with the exception of the 1970's survey, the few studies that have been undertaken have focused primarily on the middle and lower Estuary, and very little is known about the benthic community in the freshwater tidal zone. We also know little about the reef worm communities of the deeper areas of Delaware Bay. Are there "ecologically significant" species or assemblages/communities that we currently know little about? Are there any biological "hot spots" in the benthos?

3.6.3.3. Data Issues - Coordination

Scientific and technical data collection for the benthic community is mainly associated with short-term studies that are patchy within the system, leading to virtually no communication among different research and management groups. For example, an observation was made that there appears to be 3 or 4 trawl surveys in progress, but with no apparent overall plan to coordinate data interpretation. Useful benthic data appears to be collected by different state agencies and industry (e.g., PSEG data on marsh benthos), but at present this information is not being effectively shared and used.

3.6.3.4. Contaminants

High concentrations of many toxic compounds are known to exist in sediments of the Estuary. Little information is available on the effects of these toxics on benthic communities, either directly or in relation to sediment type. Uptake of specific contaminants in tissues of benthic organisms is being examined in a variety of state and federal programs. Furthermore, current biomonitoring and bioassay efforts use a variety of indicator taxa (zooplankton, amphipods, mysids, worms), and the NOAA IBI-Benthos program is an example of efforts directly assess the ecological conditions of the bottom habitat. More can be done, however. Despite worldwide acceptance that benthic organisms represent some of the best bioindicators, the National Status and Trends Mussel Watch (tissue uptake of contaminants) has not yet been fully extended to the upper estuary. Although numerous studies are examining the extent of contaminants ion the tissues of bottom organisms, there remains a need to better understand the ecological consequences because of the potential for bioaccumulation, bioconcentration, and biomagnification of contaminants in the benthic food web

3.6.3.5. Life History Data

Many presenters discussed the need for better life history information to strengthen our understanding and predictive capability regarding the population dynamics of ecologically significant species. For example, horseshoe crab stocks appear to be declining, but the reasons for this are unclear. To what degree is the decline associated with beach erosion from sea level rise, fishery pressure, and inter-annual variation in recruitment? What natural and human factors affect recruitment, and how does variability in recruitment translate into variability in the strength of a particular year class? The point was made that we know very little about the critical habitat needs, diet, and mortality of juvenile horseshoe crabs in particular.

Blue crabs and oysters, although better studied than horseshoe crabs, also have key life history traits that are poorly understood, complicating our ability to manage these fisheries and restore populations when they become depleted. For both species, debate continues regarding the linkages between recruitment dynamics and stock maintenance. What exactly is the overfishing threshold for blue crabs in Delaware Estuary? In addition to planting more shell for settlement, how can we enhance natural sets of oysters?

3.6.3.6. Food Web Dynamics

Due to high turbidity, greater average depths, and other factors, there appears to be lower primary production (e.g., submerged aquatic vegetation, seagrass, macroalgae) in benthic communities of the Delaware Estuary, compared to other large mid-Atlantic estuaries. This remains to be thoroughly investigated. Much of the Estuary is also known to support low primary production by phytoplankton in the water column. Yet, secondary production in the benthos still appears high, overall. Further insights are needed to determine if other organic matter sources support the bulk of secondary production in the benthos, such as allochthonous (i.e., detrital) inputs from wetlands and uplands. There is also a need to quantify the significance of bacteria and microheterotrophs in benthic food webs. Lastly, future studies of food web dynamics in the Estuary must be sure to consider the likelihood of high geographical and seasonal variability.

3.6.3.7. Ecosystem Function and Benthic-Pelagic Coupling

We need to know more about how water quality may be affected by benthic organisms, such as oyster reefs and mussel beds. There is also little known about the ecological significance of mysids and swarming amphipods that live as epifauna or near the bottom. Biological processes at the sediment-water interface are likely to be important for carbon balance, biogeochemical cycling, and the fate and effects of contaminants. What are the main nutrient cycling dynamics through benthic communities? What ecosystem functional services are rendered by healthy benthic communities, and are these functions impaired anywhere in the Estuary?

3.6.3.8. Linkages to Other Basins

Linkages between riverine, estuarine, coastal and marine habitats are mainly studied in relation to water quality and pelagic living resources. We would like to know more about how the benthic community may be coupled among these systems. Are there any critical links?

3.6.3.9. What was missing from Session 3?

- Bottom-associated finfish such as sturgeon were not discussed.
- The prevalence and importance of benthic producers such as submerged aquatic vegetation (SAV) and microphytobenthos was not examined by any presenter.
- Physical processes and bottom-mapping were not covered, although they were discussed to a degree in other sessions.
- Artificial reefs and shellfish reefs are known to enrich biodiversity and productivity and provide essential fish habitat, but these topics were not covered per se in the conference.
- Microbial ecology is a large component of benthic community dynamics, but was not covered in depth.

3.6.4 *Session 4: Pelagic Communities*

Pelagic communities consist of physical, chemical and biological interrelationships in the water column, including microorganisms, phytoplankton, zooplankton and fish. Some living resources covered in Session 4 were further discussed in Session 9 (Section 3.6.9) from the perspective of applied science and resource management.

Presentations and discussions in Session 4 indicated that we have a moderately good understanding of the physical and chemical environment of the pelagic system, and we also know something about our top consumers thanks to stock assessments for finfish. We have a patchy understanding of physical-chemical-biological linkages, base-of-food-web dynamics that sustain pelagic fisheries, the fate and effects of toxic compounds in pelagic food webs, and spatial variation of all of these topics across the Estuary. As an example, we know virtually nothing about zooplankton dynamics in Delaware Estuary, despite the clear trophic importance of these animals in the pelagic food chain. Our weak understanding and interest in pelagic community ecology may be one reason why only five presentations were contributed to this session (Table 7).

Table 7. Titles, authors and key points of presentations delivered in Session 4, “Pelagic Communities,” which was moderated by Susan Kilham on January 11, 2005 in Cape May, NJ.

Title	Authors	Key Point
Dynamics of photoheterotrophic bacteria in the Delaware Estuary.	L. Waidner, M.Cottrell and D. Kirchman	Photoheterotrophic bacteria were highest in the turbidity maximum where they may play a large role in DOM degradation.
Bacterial production and respiration in the Delaware Estuary.	D. Kirchman	(canceled, from abstract) Microbial respiration plays a large role in the overall budgets of O_2, C, and N.
High nutrient and low growth in the Delaware Estuary: evaluation of primary production using a long-term database.	K. Yoshiyama	Phytoplankton productivity does not often relate to nutrient concentrations, being suppressed by light limitation, suboptimal nutrient ratios and probably contaminants.
Mycobacterial infections in striped bass (*Morone saxatilis*) from Delaware Bay.	C. Ottinger and J. Brown	Mycobacterial infections in striped bass cause lesions, emaciation and economic impacts
Aquatic resources of the Delaware Estuary.	E. Santoro	Some living resources appear to be declining, others are doing well, and PCB’s remain problematic in fish tissue.

Key points, observations, questions and science needs of Session 4 are summarized topically below.

3.6.4.1. Food Web Dynamics and Microbial Ecology

Within the open water areas of the Estuary there appears to be generally low primary production, including both benthic communities (e.g. submerged aquatic vegetation, microphytobenthos) and pelagic communities (phytoplankton), although exceptions may occur in some areas. As noted above (Section 3.6.3.5), this low primary productivity appears to result primarily from natural factors (e.g., high turbidity, depth). Hence, food web dynamics might be governed primarily by allochthonous inputs of detrital matter and the conversion of detrital matter by microheterotrophs. Microbial activity is also responsible for the conversion of dissolved organic matter and remineralization of wastes.

What are the ecosystem roles and effects of different types of microorganisms in different areas of the Estuary; e.g., why are nitrifiers active in urban areas and is this significant for nutrient models? Can we make better use of emerging technologies (e.g., microarrays, flow cytometry) to identify the prevalence and activity of different microbes.

How does the relative balance of autotrophic and heterotrophic activity vary seasonally and spatially within the Estuary? What are the relative contributions of the different types of autotrophs and microheterotrophs to secondary production by finfish and shellfish?

3.6.4.2. Linkages to Tidal Wetlands and Watersheds

Allochthonous inputs of organic matter to the Estuary can originate from streams and rivers in the watershed as well as from the outwelling of plant matter from tidal wetlands. What proportion of fixed carbon in the open estuary is derived from the *in situ* production of phytoplankton and benthic producers, versus organic matter inputs from the watershed or tidal marshes? What is the significance of bacteria and microheterotrophs in the pelagic food web and for pelagic-benthic coupling processes? How does the microbial community and base-of-food-chain character vary spatially and seasonally within the Estuary? i.e., what is the importance of tidal marsh production as a food source that ultimately supports finfish production in the open Bay? What is the role of fringe marshes as nursery areas? How are pelagic communities in the tidal estuary affected by flow management in the watershed?

3.6.4.3. Contaminants

What is the fate and effects of toxics in pelagic food webs? What are the relative effects of contaminants that are not routinely monitored, such as chlorination, antibiotics, and pharmaceuticals? Does toxic inhibition of primary production occur, and if so, how significant is this throughout the Estuary? What are the implications to human health of contaminants in pelagic communities?

3.6.4.4. Diseases

How widespread are diseases in pelagic species such as finfish, and are diseases significant enough to affect harvests? Are viruses a problem? What are the potential and actual effects of multiple stressors; e.g., are disease effects exacerbated by other stressors?

3.6.4.5. Habitat Restoration and Enhancement

Restoration of pelagic fish stocks, such as sturgeon, shad and river herring, will be substantially improved by the continued enhancement and restoration of the habitats on which they depend. Dam removal, maintenance of fish passages, improvements to spawning substrates and refugia, are all known to provide tangible benefits to pelagic fish stocks in the Estuary.

In addition, continued remediation of essential fish habitat such as oyster reefs will provide similar benefits. Artificial reef construction may provide additional opportunities to enhance pelagic communities.

3.6.4.6. Data Gaps and Monitoring

As noted above, to better model the pelagic community and understand trophic transfers, we must fill key data gaps related to critical food web components such as zooplankton. What is the nature and significance of competitive interaction between ctenophores and larval and juvenile fish? Monitoring programs should be broad-based, capturing functionally dominant components of the physical, chemical and biological ecosystem.

Inter-annual variation in pelagic community dynamics may occur in response to shifts in prevailing environmental conditions, such as due to climate variability. Studies to monitor shifts in pelagic conditions following major flow perturbations would be worthwhile.

On a separate note, invasive species such as flathead catfish, snakeheads, and western mosquito fish may threaten to imbalance to our pelagic communities, and monitoring programs for non-native and invasive species should be implemented or strengthened.

3.6.4.7. Management

Ecosystem-based management may provide for an improved understanding and assessment of pelagic communities.

3.6.4.8 Identity and Education

Why is the Delaware Estuary so important? What are the signature traits that distinguish it from other seemingly similar systems? What are the ecosystem services and economic outputs that the Estuary provides for us? Educational programs that lead to an improved understanding of these values of the Estuary were identified as a critical need in the Session 4 workshop discussion. Until a large cross-section of the populace, including elected officials, understands the answer to these questions, we will have difficulty in managing the resources and gaining support for scientific programs.

3.6.4.9. What was missing from the Session 4?

- Food web models and stable isotope studies
- Toxics in the pelagic food web (e.g., biomagnification, tracers of urban effects)
- Pelagic-benthic linkages (especially in lower estuary)
- Climate effects (e.g., inter-annual variation, large rain events, hurricanes)
- Physical-biological linkages (e.g., connection to flow models)
- Upstream-downstream linkages
- Uniqueness of Delaware Estuary

3.6.5 *Session 5: Edge Communities and Watershed Linkages*

Science and management of the Delaware Estuary is not restricted to the tidal system nor the primary shoreline of the open waters of the main channel and bay. In addressing the many linkages among the open tidal estuary, the fringing tidal wetlands, and non-tidal portion of the watershed, Session 5 was the largest of the eleven conference sessions with twelve presentations (Table 8). Session 5 topics were further discussed, from the perspective of applied science and resource management, in Session 10 (Section 3.6.10). Linkages between tidal and non-tidal portions of the Basin are of fundamental importance, much the same as linkages among physical, chemical and biological components of the ecosystem.

One example of the need for understanding such linkages that was articulated at the conference was the possible connection between freshwater flow in the Delaware River (non-tidal, physical) and the health of living resources in the Estuary (tidal, biological). This topic is discussed more fully below in Section 3.6.8 (Session 8). Another “linkage” message was that the nearly contiguous band of tidal marshes in the middle and lower estuary are a signature trait with a largely unstudied and untold functional importance. It is believed that these extensive wetlands function as “kidneys” or “lungs” that help to sustain water quality, abate floods, and provide critical habitat and nursery areas for fish and wildlife.

Table 8. Titles, authors and key points of presentations delivered in Session 5, "Edge Communities and Watershed Linkages," which was moderated by Daniel Soeder and Danielle Kreeger on January 11, 2005 in Cape May, NJ.

Title	Authors	Key Point
Mitigating problems in the Delaware Estuary: selecting plants to hone the functions of the edges.	D. Seliskar, J. Gallagher, J. Wang and M. League	Understanding and exploiting the genetic diversity of native marsh plants at the estuary's edge can help mitigate many challenging coastal problems.
Species interactions along edge communities of Delaware Bay: using a baywide telemetry array to track horseshoe crabs and migrant shorebirds.	D. Smith, L. Brousseau, K. Kalasz, K. Bennett and M. Millard	Tracking of horseshoe crabs, red knots and ruddy turnstones suggested that beaches selected by shorebirds for feeding on horseshoe crab eggs were not related to beach use by the crabs.
Beach dynamics, shore protection and habitat restoration for horseshoe crabs in Delaware Bay.	N. Jackson, D. Smith and K.Nordstrom	Beach nourishment provides an opportunity for restoring horseshoe crab habitat on eroding or armored shorelines, but the type of fill sediment and other technical aspects are critical to success.
Meta-analysis of horseshoe crab and shorebird research on the Delaware Bay – are there enough horseshoe crab eggs to sustain spring shorebird migration?	E. Stiles and D. Mizrahi	A management plan adopted in 1998 to limit horseshoe crab harvests has not reversed their decline in Delaware Bay, and more drastic measures may be needed to restore crabs and shorebirds.
Ospreys of Delaware River and Bay: contaminant exposure, reproduction and habitat suitability.	B. Rattner, P. Toschik and P. McGowan	Ospreys are a top piscivorous predator and good indicator of aquatic ecosystem health, but contaminants continue to stress ospreys in the northern part of the Delaware Estuary
Ecology and population structure of a model community of vertebrates in wetlands in the Delaware Estuary: effects of habitat changes on turtles.	H. Avery, K. Klein, J. Spotila and W. Bien	The effects of wetland fragmentation and isolation on turtle populations near Philadelphia Airport were significant but appeared to vary among turtle species.
High incidence of deformity in aquatic turtles in the John Heinz National Wildlife Refuge.	B. Bell	Embryonic deformity rates in turtles were associated with contaminants in an urban wetland, suggesting they may serve as good indicator for environmental pollution.
Use of Alaska Steeppass fishways to promote herring passage at low-head dams on Delaware Estuary tributaries.	K. Strait	Fish ladders constructed on 4 dams in NJ and 8 dams in DE successfully passed adult fish within one year and showed increasing trends in passage each year.
Conservation and propagation of freshwater, brackish & estuarine bivalves for ecosystem services.	D. Kreeger	Robust populations of bivalves historically existed throughout the watershed and their restoration can benefit water quality and provide critical ecosystem services.
Dr. Jekyll and Mr. Hyde: comparing rhizome growth of native and non-native populations of *Phragmites australis.*	M. League, D. Seliskar and J. Gallagher	A non-native haplotype of *Phragmites australis* with robust rhizome and shoot growth may be responsible for its invasiveness in Mid-Atlantic marshes.
Deterioration of a mid-Atlantic coastal marsh.	D. Soeder and D. Birch	Hydrologic processes in marshes must be better understood to address the impacts of land use changes, sea level rise and other factors on marsh loss.
Tissue culture generated native marsh plants: alternative plants for wetland creation & restoration.	J. Wang, D. Seliskar and J. Gallagher	Tissue culture techniques could be used to develop plants with traits needed for wetland preservation and restoration.

Key points, observations, questions and science needs are summarized topically below. Not all of these directly related to the session theme, but they were included if they appeared to have broader significance.

3.6.5.1. Ecological Flows

Freshwater flows in the non-tidal portions of the watershed are known to affect living resources in the streams and rivers themselves, but questions were raised regarding the possible added effects on living resources in the tidal estuary. Reduced flows to the estuary could affect key habitats and biota in the tidal regions, particularly if the prevailing salt line advances up the Estuary. One widely-discussed case study was the possible impact of reduced flow on oysters (*Crassostrea virginica*), which are impaired by saltier waters because of increased prevalence of disease agents. Native plants living in freshwater tidal marshes (e.g., wild rice, *Zizania aquatica*) were also identified as at risk if prevailing salinity rises above zero.

Oyster reefs and freshwater tidal marshes are regarded as signature habitat types of the Delaware Estuary, and both are considered here for different reasons. Oyster populations are currently under pressure from disease impacts and a recent decline in recruitment. Freshwater tidal marshes are situated in the urban corridor of the estuary where they are impacted by development pressure and pollution. We need to develop a better understanding of how the magnitude and seasonal timing of freshwater flow affects the salinity of the Estuary and the proximity of the salt line to sensitive biota such as oysters and habitats such as freshwater tidal marshes. Is flow management and alteration consequential enough to affect biota and key ecological processes in the tidal estuary? How significant are ecological flow effects compared to other impacts (e.g. sea level rise)?

3.6.5.2. Tidal Wetlands

The Delaware Estuary is unique among large east coast estuaries in having fringe tidal marsh around nearly the entire perimeter, ranging from the mouth of Delaware Bay up to near Wilmington, DE. Historically, this contiguous fringe of tidal marsh extended farther up through the freshwater tidal system as well. This band of wetlands around the margin helps to remove suspended particulate matter and nutrients, for example. What is the current status and trends for the principal types of tidal wetlands in the Estuary? What are the rates of marsh habitat loss/degradation, and what is the relative impact of recent efforts to restore marshes? What is the economic value of a healthy fringe marsh to the Estuary, and does the value differ among marsh types, dominant vegetation types, and/or geographical regions?

With rising sea level and other factors, erosion of wetlands along the seaward margins are likely to continue. Hence, even without further direct conversion or impairment by humans, net losses of wetland acreage are expected to mount. What challenges and opportunities exist to consider projected sea level rise in land use planning? One area of promise is to look landward and identify areas that tidal wetlands may be permitted to reclaim. As sea level has risen in the past, tidal marshes have undergone a landward retreat, but existing developments and other impediments will restrict this natural progression. Can we incorporate upland “buffers” into our plans whereby we identify and set aside adjacent uplands to permit conversion to tidal marshes?

Global warming and associated climate change is predicted to raise water temperatures and possibly alter gas exchange processes, and these effects could become more pronounced in exposed marshes and intertidal mud flats. How will these changes affect ecological structure and function?

3.6.5.3. Contaminants

Some members of the public are ignoring fish consumption advisories, and there is continuing interest in learning why this is and developing solutions.

Some classes of contaminants appear to be moving through the food web and concentrating in top predators (osprey). Despite decreasing use and prevalence, why are downward trends still not discernable for some organic compounds and trace elements? What are the contaminant reservoirs and release mechanisms?

3.6.5.4 Linkages to Other Basins

Migratory birds, finfish, blue crabs and horseshoe crabs are examples of biota that move among coastal and estuarine habitats. How are these biota affected by differences in water-quality among basins, major tributaries, tidal estuaries and the coastal ocean (e.g. Pew Oceans Commission 2003; U.S. Commission on Ocean Policy, 2004; see also IOOS Workshop, Section 3.8.)

3.6.5.5 Conceptual Framework

The Delaware Estuary is markedly different from other large American estuaries in terms of its physical, chemical and biological character. The principal science and management challenges here are not necessarily the same as in other mid-Atlantic systems such as Chesapeake Bay. As yet, we have not formulated a distinct, comprehensive, conceptual framework that describes the overall structure, function and management challenges for our estuary.

Can we follow actions in the CCMP and use information presented at this conference to prepare a conceptual framework that captures the essence and functionally dominant traits of the Delaware Estuary and which has wide-ranging utility for scientists and managers? Can existing monitoring efforts be integrated into this conceptual framework? Can future monitoring efforts, and environmental indicators and goals, be linked to the core ecological components and signature characteristics in this model?

A comprehensive, integrated and ecologically-based monitoring framework that is attuned to the unique aspects and challenges of our system would be a tremendous asset for establishing policy and guiding management decisions. In addition, if the unique essence and workings of the Delaware Estuary can be defined in a simple conceptual model understandable by the public, this should generate greater enthusiasm and support for our environmental programs and ultimately help raise national awareness and increased resources with which to study and manage the Estuary.

3.6.5.6. Data Issues – Coordination

No dedicated, centralized database exists that maintains a broad cross-section of environmental science and technical information for the Delaware Estuary. Existing databases are either not comprehensive, not fully accessible, or are rarely updated. The Partnership for the Delaware Estuary and Delaware River Basin Commission are examples of groups that would be appropriate hosts for such an information node. A “data clearinghouse” would include web-accessible datasets and reports related to all natural resources throughout the Estuary. All information would be organized in a straightforward and comprehensive conceptual model (see above).

3.6.5.7. Science, Policy and Management Linkages

Best practices for environmental resource management are increasingly recognized as following natural watershed boundaries. We are still encumbered by "vertical" institutional and bureaucratic structures that are not amenable to "horizontal" approaches that cut across groups. This is particularly true in the Delaware Estuary, which is managed by a diverse array of federal, regional and state agencies that have jurisdictional boundaries and widely differing areas of interest and expertise. How can we better integrate these efforts and make the most efficient use of limited resources?

3.6.5.8. Economic Valuation of Ecosystem Services

Ecological resources abound within the Delaware Estuary, but very little effort has been devoted to assigning economic value to the goods and services rendered by our estuarine environment. What is a healthy Delaware Estuary worth in terms of dollars and cents? How can we make a better case to the public about why the Delaware Estuary is important to them?

3.6.5.9. What was missing from Session 5?

- Considerable attention was given to some groups of living resources, but others were absent from the program. For example, edge habitats of the Delaware Estuary are home to many types of mammals, amphibians and waterfowl.
- The microbial ecology of fringing marshlands was not covered, but is thought to be play an important role in energy and biogeochemical cycling in the system.
- Exotic/invasive species problems were only briefly discussed, although they are known to be critically important in governing the structure and function of tidal wetlands (e.g., *Phragmites*).
- Climate change and sea level rise were discussed peripherally in relation to tidal wetlands, but a fuller treatment could have been given. Mechanisms and processes of wetland loss in the Delaware Estuary are poorly-understood, but are probably more complex than just sea level rise.

3.6.6 *Session 6: Data Gaps, Management and Interpretation*

Each of Sessions 1-5 identified data-related problems as being fundamental limitations on our science and technical understanding and ability to manage resources in the Delaware Estuary. The objective of Session 6 was focused on addressing these data-related problems, which include both shortfalls in data completeness and challenges with data management. Problems with data completeness include data gaps, lack of long-term datasets, and incomplete or inconsistent monitoring activities. Problems with data management include access issues, lack of coordination and integrative models, and lack of a central clearinghouse for science and technical information. Technical challenges and opportunities were also discussed, such as use of GIS and continuous data recorders for long-term monitoring and assessment.

Topics covered in Session 6 (Table 9) were further discussed in Session 11 (Section 3.6.11) from the perspective of applied science and resource management. In addition, monitoring challenges and opportunities were further discussed at the IOOS/NWQMN Workshop in September 2005 (Section 3.8).

Table 9. Titles, authors and key points of presentations delivered in Session 6, "Data Gaps, Management & Interpretation," which was moderated by Jawed Hameedi and Ed Santoro on January 11, 2005 in Cape May, NJ.

Title	Authors	Key Point
Delaware Bay Observing System (DBOS).	M. Badiey and K. Wong	A sensor-based long-term monitoring network has potential for long-term monitoring of physical and non-physical parameters in Delaware Bay.
Using fish tumor surveys to evaluate habitat quality in the Delaware Estuary watershed.	A. Pinkney and J. Harshbarger	Fish tumor surveys and biomarkers can serve as monitoring tools for identifying contaminant problems, such as PAH's.
Visualizing fisheries data: the temporal integration of a comprehensive, multi-gear dataset in the Delaware Estuary.	S. Shotzberger	Visualization approaches for presenting fish survey data are more intuitive and can highlight temporal and spatial patterns.
Status and temporal trends of toxic contaminants in Delaware Bay: evidence from bivalve tissues.	G. Lauenstein and J. Hameedi.	Downward trends exist for tissue concentrations of most toxic chemicals, except for PAHs and some trace metals.
Long-term data sets on the biology and ecology of the American oyster, *Crassostrea virginica*, in DE Bay.	J. Kraeuter, S. Fegley and E. Powell	Datasets spanning 50+ years exist for many oyster metrics, and long-term data and continuous monitoring are critically important for science and management.
Spatial and temporal distribution of horseshoe crab (*Limulus polyphemus*) spawning in DE Bay: insights from six years of standardized monitoring.	D. Smith, B. Swan, B. Hall, S. Michels, S. Bennett and K. O'Connell	Horseshoe crab populations appear to be stable or slightly declining, and surveys must consider the timing of spawning and other life history traits.
Use of LIDAR remote sensing to characterize beach morphology for a study of horseshoe crab habitat selection in the Delaware Bay.	J. Young, A. Rafter, D. Smith and W. Wright	LIDAR data allowed for measurement of beach morphology over fine spatial scales, which is important information for habitat models for horseshoe crabs.
Developing a GIS database for the Delaware River.	C. Bartlett, R. Stahl and C. Wallace	A GIS-based database of chemical, physical and biological information is being developed for DE Bay.

Key points, observations, questions and science needs of Session 6 are summarized topically below.

3.6.6.1. Conceptual Framework

A broad-based conceptual model is needed to capture the essence of the major physical, chemical, and biological components and linkages in the estuary, including interactions with the watershed and coastal systems. An ecologically-based conceptual model for the Delaware Estuary would provide a powerful tool to identify data gaps, guide scientific research and monitoring efforts, foster consistency and sharing of datasets, and promote the distinguishing characteristics of the system to the public. Participants in the roundtable workshop for Session 6 suggested that this new conceptual framework be used to organize an updated version of the report titled "The Scientific Characterization of the Delaware Estuary" (DELEP 1996).

3.6.6.2. Monitoring Needs

For some aspects of water quality and living resources, we are fortunate in having long-term datasets for the Delaware Estuary; e.g., DRBC "Boat Run" and Rutgers oyster surveys, respectively. It is imperative that these programs be continued to maintain the integrity of long-term monitoring data, which is critical for assessing status and trends. The comprehensiveness of existing monitoring efforts can be strengthened by adding metrics that address underrepresented elements that may be functionally important. Some examples of metrics that could be included are listed below (Sections 3.6.6.6 to 3.6.6.8), and others are discussed in other session summaries.

With continued funding constraints, the design of future monitoring programs must carefully balance competing needs. On one hand, a key point from Session 6 is that there is a need to increase the comprehensiveness of existing monitoring activities to capture all of the functionally dominant physical, chemical and biological processes and components, as articulated in an integrated conceptual framework (Section 3.6.6.1). On the other hand, participants in Session 6 acknowledged the critical importance of maintaining existing long-term monitoring efforts. Any increase in resources for monitoring should be carefully allocated towards those significant, underrepresented ecosystem components that are identified by the conceptual framework. Furthermore, we must make the most of new technologies that offer promise for cost-effective monitoring such as remote sensing and sensor arrays, while recognizing that these technologies must always be calibrated with ground-truthing.

<u>3.6.6.3. Indicators, Goals and Forecasting</u>

Efforts to develop environmental indicators and measurable goals for the Delaware Estuary have met with mixed success and technical criticism. Part of the reason has been: the lack of a comprehensive, ecologically-based conceptual framework, a lack of coordination, the lack of involvement by technically proficient scientists and data problems, such as data gaps, lack of access, and inconsistency of assessment methods

Development of indicators and goals that capture the important elements of a commonly accepted conceptual framework and link to monitoring activities would have enormous value for environmental managers and education and outreach activities. By emphasizing desired future conditions, this would strengthen efforts to improve forecasting capabilities and link science to policy outcomes.

<u>3.6.6.4. Data Issues - Coordination</u>

No single entity is currently charged with compiling science and technical data into a central repository. Development of a scientific information clearinghouse of raw data, analyzed data, and technical reports would provide an important service to the scientific community in the Delaware Estuary.

<u>3.6.6.5. Data Archiving</u>

Loss of data is internationally regarded as an emerging danger with the digitalization of science and management. Traditional archiving methods such as written logs and hardcopies should not be abandoned.

3.6.6.6. Contaminants

There is a fundamental need for a better understanding of how contaminants interact together and with physical and biological elements of the ecosystem. Specific examples include more focused studies on how sediment toxicity affects the food web, interactions between contaminants and nutrient cycling, and attention to contaminants of emerging concern (e.g., flame retardants [PBDE], perfluorooctanoic acid [PFOA], pharmaceuticals). How do contaminant body burdens in fish relate to the pathology of fish diseases? Are estrogenic substances a problem in fish, as increasingly seen elsewhere? There is also a need for a contaminated sediment management strategy.

3.6.6.7. Habitat Information

In addition to needing more information on the status, trends and importance of edge habitats such as fringing wetlands (Session 5), discussions in Session 6 also pointed out the need for better mapping of other critical habitats. For example, benthic maps of the bottom structure are needed to understand essential fish habitat.

3.6.6.8. Invasive Species

No integrated strategy exists to guide science, management and policy actions regarding invasive non-indigenous species. For example, despite common knowledge that exotic species introductions often occur as a result of transportation and shipping commerce, no strategy has been developed and implemented to manage ballast water and cope with introductions of non-native species.

3.6.7 *Session 7: The Athos I Oil Spill and Its Impact on the Delaware Estuary*

The Delaware Estuary Science Conference occurred soon after the oil spill from the *Athos* I tanker, which occurred on November 27, 2004. To provide an opportunity to learn about the status of the event and discuss future implications for science and management of the Estuary, a special session was added to the program in both the January and May meetings (collectively referred to as Session 7, Table 10). Since the purpose of this White Paper is to summarize the main conference messages and assess future science needs, this summary of Session 7 focuses on the broader issues related to the spill, such as the need for better monitoring of the fate and effects of contaminants associated with hydrocarbons.

For more information on the nature of these presentations, the reader should consult the conference proceedings. Key points that relate to future science needs and environmental spill response are summarized below.

3.6.7.1. Emergency Management

The structure and function of the Delaware Estuary ecosystem differs in many important respects from other large American estuaries, and it also contains distinct biological resources (e.g. horseshoe crabs, sturgeon) and habitats (e.g., freshwater tidal marshes) of special interest. Concern was expressed at the conference by a wide cross-section of the scientific community that local and regional expertise was not consulted or involved in the initial spill response.

Table 10. Titles, authors and key points of presentations delivered in Session 7, "The *Athos* I Oil Spill and Its Impact on the Delaware Estuary," which was moderated by Tom Fikslin on both January 12, 2005 in Cape May, NJ, and again on May 12, 2005 in Newark, DE.

Title	Authors	Key Point
(January) Summary of the event.	L. Trumball	The timeline and spill response of the *Athos* I oil spill was presented.
(January) Summary of immediate impacts and plans to assess long-term impacts.	S. Krest	The Natural Resources Damage Assessment (NRDA) process was explained as it related to the *Athos* I spill.
(January) Recommendations for assessing long-term impacts and for response to future spills.	T. Fikslin	The long-term impacts of the *Athos* I spill are uncertain, and local expertise can be called on to help with this and future spills.
(May) Update on the response to the *Athos* I spill.	J. Conrad	The timeline, response and oil recovery efforts for the *Athos* I spill were reviewed.
(May) Update on the Natural Resource Damage Assessments.	J. Hoff	The current status and future plans for the NRDA process were explained.
(May) Coordination for future spill events in the Delaware Estuary.	T. Fikslin	An opportunity may exist to strengthen our ability to respond to future spills, and local and regional coordination can help.

It should be stressed that there was broad support and understanding that the initial emergency response for events such as oil spills must continue to be managed by those entities responsible for implementing the Area Contingency Plan. Formalized mechanisms need to be put into place that would identify and include available expertise during the emergency management process. Local and regional scientific and technical experts could greatly aide in the Command Center decision making process by providing strategic input. This would allow for a more efficient and effective prioritization and protection of critically sensitive habitats and resources, and ensure that sample collection for damage assessment considers the complex physical, chemical and biological nuances of the Delaware Estuary.

In addition to the contribution that local and regional experts can provide from a scientific standpoint, conference attendees also suggested that local resource management and scientific leaders must be better informed during initial communications to ensure protection of human health. For example, during the first few days following the *Athos* I spill, senior representatives from the Delaware River Basin Commission, Partnership for the Delaware Estuary, and Philadelphia Water Department obtained information from the news media despite the proximity of the spill to population centers and water intake structures on the Delaware River. Improved communication and coordination of information would strengthen our ability to not only manage and protect natural resources but also help to safeguard human health.

3.6.7.2. Contaminants

Many attendees at the Science Conference pointed out that oil spills of various magnitudes occur every year. Numerous presentations and discussions also indicated that contaminants associated with hydrocarbon use and shipping (e.g. PAH's) are prevalent in the system, understudied, and likely to be of significant environmental concern. The cumulative effects of spill after spill, combined with hydrocarbon pollution from the watershed, are unknown. The *Athos* I spill highlighted the importance of strengthening our assessment of the fate and effects of classes of contaminants such as hydrocarbon breakdown products that may not be monitored as well as other types of contaminants that are the focus of current regulations and actions.

3.6.7.3. Policy Considerations

The Delaware Estuary is home to one of the largest freshwater ports in the world and represents the second largest petrochemical port in the United States. Despite this and the emerging concerns about the fate and effects of hydrocarbon contaminants in the estuarine food chain, the oil industry does not contribute any resources to monitoring or other estuarine science programs. Furthermore, oil imports by single-hulled tankers, which are more prone to spills, continue despite decades of efforts to mandate a switchover to double-hulled tankers. Management and policy efforts must continue to look for opportunities to prevent future spills by promoting safer oil shipping, build support for improve environmental monitoring of hydrocarbon contaminants, and to ensure that suitable restitution and restoration is accomplished when spills occur.

Although these points and needs are framed in the discussion that centered on the *Athos I* spill and oil shipping in general, it is important to recognize that these same messages apply to other industries as well. The Philadelphia metropolitan region boasts one of the world's greatest concentrations of heavy industry. Development of an Early Warning System is needed. And as yet, there is no current industry support for broad-based environmental monitoring in the Estuary.

3.6.8 *Session 8: Water Resources*

The focus of Session 8 was on science and management linkages that relate to water resources, which was a broad theme that included such topics as water quantity, freshwater inflow, water and salt balance, dams, erosion, sea level rise; water quality, stormwater, and contaminants. Preliminary presentations and discussions relating to water resources and associated issues were covered in Sessions 1 (Section 3.6.1) and 2 (Section 3.6.2) as well. Session 8 presentations are summarized in Table 11. Key points, observations, questions and management needs of Session 8 are summarized topically below.

3.6.8.1. Ecological Flows

Salinity in the Estuary is sensitive to a variety of natural hydrodynamic and climatic factors, including variation in freshwater inflow and tidal currents associated with year-to-year changes in climate (temperature, rainfall, snow melt). In addition, discharges of freshwater to the estuary have been altered and largely dampened by regulation of the Delaware River about Trenton since the 1970's. Unidirectional shifts in the balance between salt and fresh water are also likely because of sea level rise.

Increasing salinity in the middle and upper estuary is likely to have a variety of direct and indirect effects on the ecology of those areas, particularly for biota that are insensitive to saltwater. For example, documented losses of freshwater tidal marshes and the upstream migration of brackish marsh communities demonstrate the potential impacts of flow regulation that need further investigation. As noted in Section 3.6.5, freshwater tidal wetlands are a signature trait of the Delaware Estuary having high primary productivity, biodiversity and functionality. The acreage of these marshes may be less than 5% of historic levels, and what remains appears to be critically imperiled by the direct effects of land development, degradation and perhaps intrusion of brackish water.

Table 11. Titles, authors and key points of presentations delivered in Session 8, "Water Resources," which was moderated by Bob Tudor, Jeff Fischer and Jonathan Sharp on May 10, 2005 in Newark, DE.

Title	Authors	Key Point
Technical support needs for estuary inflow policy decision making.	R. Fromuth and H. Quinodoz	The relationship of riverine inflow to oyster habitat and freshwater marshes would be better defined with updated flow/salinity models incorporating sea level rise.
Freshwater inflow management and the Delaware Estuary: assessing ecological consequences and future approaches.	C. Apse, J. Hoffman and S. Ford	OASIS is an important tool for the non-tidal river and more work is needed to assess relationships between freshwater Inflow, estuary salinity and oyster spat survival.
Scientific issues in developing TMDLs: PCBs in the Delaware Estuary.	T. Fikslin	Significant loadings of PCBs originate from nonpoint source runoff, point sources, the two largest tributaries and contaminated sites.
Endocrine disruptors, bacteria source tracking, BMP monitoring: managing emerging issues in Delaware Estuary tributaries.	C. Crockett	Better regulatory and scientific approaches are needed to minimize risk of bacteria and emerging pollutants on recreation and drinking water supplies.
Developing nutrient criteria for estuaries: an update on Delaware Estuary and USEPA's perspectives.	I. Davis	Nutrients are a common problem nationally, and EPA water quality criteria developed for freshwater ecoregions are now being developed for estuaries.
… And the good news is that the Delaware Estuary is less vulnerable to rising sea level than Chesapeake Bay.	J. Titus	A higher tidal range and extensive tidal wetlands along Delaware Bay will help protect adjacent uplands more than in other systems such as Chesapeake Bay.
The Corps' role in the Delaware River.	R. Ruch	The Estuary's most pressing needs will be best met by increased information-sharing and partnerships that help leverage funds.
Biological indicators of water quality.	R. MacGillivray and T. Fikslin	A set of biological parameters should be added to existing chemical metrics to strengthen the comprehensiveness of monitoring in the Delaware Estuary.
Relations of water quality to land use in drainage basins of four tributaries to the Toms River, Ocean County, NJ.	R. Baker and K. Hunchak-Kariouk	Land development in the basin was found to be an important predictor of nutrient loads and other contaminants in streams and ultimately Barnegat Bay.
Water withdrawals and transfers in the Delaware River Basin in New Jersey.	J. Hoffman and S. Domber	Defining all components of the water budget (anthropogenic as well as meteorologic) is a critical step in managing water resources.

Indirect effects of increasing salinity are best exemplified by the potential increase in the virulence and prevalence of disease agents that impact oysters in Delaware Bay. As discussed in Session 3 and here, the pathogens Dermo and MSX are sensitive to low salinity and are most damaging to oyster populations in dry years when freshwater flows are relatively low.

Both the average annual flows and the variability in flow throughout the year are important ecologically. This is because natural variability in key physical components might be an important force in structuring biodiversity and "re-setting" processes in the Estuary. Management of both base flow and flow variation is usually most difficult in dry years. The science of estuary inflow management is still evolving and since freshwater inflows vary significantly among years because of natural climate variability, adaptive management is critical. Allocation of sufficient freshwater inflow for the Estuary is as much a political as a biological process, as seen in examples across the world.

Specific discussion highlighted the need for an updated hydrodynamic model for the entire Estuary, including the lower zones, and requiring additional salinity, temperature and flow data. An upgrade of the salinity-flow relationship in the DRBC OASIS model might allow for more informed management decisions to best benefit of Estuary resources (e.g., oysters, freshwater tidal marsh).

3.6.8.2. Contaminants

A variety of scientific studies and monitoring activities have provided valuable information regarding the fate and transport of some classes of contaminants, the nature of their sources, and within classes such as PCB's their biological effects. There remains much to be learned about the sources, fates and effects of other classes of contaminants. These include compounds of emerging concern, such as endocrine disruptors (EDC's) and pharmaceuticals and personal care products (PPCP's). Other classes of compounds that have been around for some time but haven't been carefully examined or monitored include hydrocarbons (PAH's).

In addition to strengthening the comprehensiveness of contaminant studies, monitoring, and where appropriate regulation, another pressing need is to develop a better understanding of the biological effects of contaminants in natural settings where organisms may be stressed by a multitude of density-dependent factors and mixtures of contaminants. Currently, biological assessments in Delaware Estuary are confined to a relatively limited array of biodiversity surveys, bioassay tests and tissue burden analyses. How are contaminants taken up into the benthic and pelagic food webs? What are multiple stressor impacts, and can chronic toxicity under ambient conditions contribute to disease pathology?

3.6.8.3. Pathogens

Pathogens that affect both wildlife and human health remain a serious risk in the Delaware Estuary, despite improvements in wastewater treatment and reduction in fecal coliforms over the past 40 years. Pathogens include a diverse array of bacteria, viruses, protists and parasites. Sources of bacterial contamination are well established in the Estuary. A need exists to recommend appropriate management and policy actions to eliminate those sources. Furthermore, the buildup of antimicrobial resistance in human pathogens represents an emerging problem for environmental management because some of these drug-resistant organisms survive in natural aquatic systems. Homeland Security concerns should be prominent considerations because of the high international traffic in and out of our ports, and their proximity to drinking water intakes.

3.6.8.4. Nutrients

Eutrophication does not appear to be a common or widespread problem in the Delaware Estuary, unlike many other large American estuaries (see also Section 3.6.2). This does not necessarily indicate that high nutrient concentrations are not a problem. Over the past 50 years, concentrations of nitrogen and phosphorus have risen dramatically. Phosphorus has been reduced more recently because of the ban on use of phosphorus detergents, but nitrogen inputs continue to rise. As a consequence, the stoichiometric balance of C, N and P appears to have undergone substantial system-wide shifts over time and may be tilting toward a high N:P ratio.

Long-term shifts in nutrient balance could be having substantial effects on food web dynamics, biogeochemical cycles, and living resources. In other systems where nutrient ratios have been more closely considered, departures from normal Redfield ratios (e.g., 106:16:1 for C:N:P) can contribute to harmful algal blooms and impairment or alteration of marsh biodiversity and function. Future monitoring for nutrients should consider not only the form (dissolved versus particulate, organic versus inorganic) but the relative ratios for different macronutrients, as well as for other elements known to limit or govern production (e.g., silica, iron).

3.6.8.5. Monitoring

Taken together, Sections 3.6.8.1 to 3.6.8.4 highlight the need for continued monitoring of key hydrodynamic and water quality conditions, and they also suggest that existing efforts could be further strengthened by a more broad-based monitoring network.

3.6.8.6. Physical-Chemical-Biological Linkages

Taken together, Sections 3.6.8.1 to 3.6.8.4 demonstrate how key biological outcomes such as the health of living resources are affected by interactions with physical and chemical processes such as flow, salinity and water quality. In keeping with the worldwide trend toward greater sophistication of environmental science, we must follow suit by forming multi-disciplinary teams of specialists that can work together to build understanding of complex ecological relationships. The need for greater study of physical, chemical and biological linkages was a recurring theme in Session 8 and throughout the Science Conference.

3.6.8.7. Indicators and Goals

To justify implementation of new policies and regulatory actions for contaminants, it is important to demonstrate the effectiveness of source reduction strategies. For example, decade-scale correlations are well-documented for the improvement of oxygen conditions in the upper estuary as a result of wastewater treatment, and for the reduction in phosphorus loadings to the Estuary as a result of the ban on phosphorus detergents. Development of indicators and measurable goals related to water quality and contaminants is imperative. We must work now to identify and develop indicators that can be prepared from existing information, but we must also marshal resources to develop new indicators in the future that are cost-effective and that can strengthen the comprehensiveness of current assessments by filling crucial data gaps.

3.6.8.8. Identity and Education

Ecotourism & recreation presents many opportunities for increasing the public's understanding and appreciation for the natural resources of the Delaware Estuary also presents challenges because contaminants and pathogens can affect human health. As we work to increase public access and use of the region's water resources, it will be increasingly important for us to provide timely and meaningful information on water quality, which can be used to guide daily decisions by the public (use decisions).

3.6.9 *Session 9: Living Resources*

Living resources were discussed from the perspective of resource management in Session 9, building on scientific perspectives from Sessions 3 (Benthic Communities, Section 3.6.3) and 4 (Pelagic Communities, Section 3.6.4.) Topics included biological resources that have commercial value (finfish, oysters, blue crabs, horseshoe crabs) as well as those that do not (shorebirds, raptors, turtles, other invertebrates, invasive species) (Table 12).

Table 12. Titles, authors and key points of presentations delivered in Session 9, "Living Resources," which was moderated by Dorina Frizzera, John Kraeuter and Susan Kilham on May 10, 2005 in Newark, DE.

Title	Authors	Key Point
Fisheries management issues in Delaware Estuary.	R. Allen	Fisheries management would benefit from better coordination and methods standardization among multiple agencies.
Catfish, snakehead and mosquitofish in the watershed of the DE Estuary.	R. Horwitz, P. Overbeck and A. Faulds	Three introduced fish species might have important ecological effects, are capable of rapid spread, and will be difficult to control.
Efforts to enhance oyster resources in Delaware Bay.	R. Babb and D. Bushek	Low recruitment cannot sustain the oyster fishery and efforts are underway to revitalize oyster stocks by planting shell.
The decline of the Delaware shorebird stopover and new opportunities for recovery.	L. Niles, A. Dey and K. Clark	Recovery of shorebirds such as red knots must include a flyway-wide protection system modeled from waterfowl programs.
Salt marsh trophic pyramids: being a monograph on marsh meals of monumental meaning.	M. Matsil	Some ecosystem components are functional dominants and restoration should target their functionality.
American shad restoration in the Delaware River Basin.	J. Brown	Current shad restoration efforts are focusing on building fish passage facilities on the Schuylkill and Lehigh Rivers.
Freshwater turtle communities as indicators of anthropogenic perturbation and habitat fragmentation in the DE Estuary ecosystem.	K. Klein, H. Avery, J. Spotila and W. Bien	Habitat fragmentation impairs wildlife in freshwater tidal wetlands of Delaware Estuary.
The Delaware Bay Oil Spill 2004: utilizing the Migratory Bird Treaty Act and the North American Wetland Conservation Act to help make birds and their habitats whole.	A. Manus and A. Milliken	Existing laws provide useful mechanisms to marshal resources for enhancement and restoration of natural resources in estuaries.

Key points, observations, questions and management needs of Session 9 are summarized topically below.

3.6.9.1. Monitoring

The maintenance of long-term data sets through continued monitoring was considered paramount for management of living resources, tracking trends, and guiding restoration activities.

3.6.9.2. Data Issues – Coordination

Fisheries management would benefit considerably by a closer examination of long-term data series for all species. Sharing of information, collaboration among studies, and better consistency of survey methods would also strengthen management of living resources throughout the Estuary.

3.6.9.3. Physical-Biological Linkages

The effects of climate variation on fisheries production was cited as another example of the need for a better understanding of key physical-biological linkages that are important for resource management. In addition to inter-annual shifts in prevailing climatic conditions, the effects of severe weather events on finfish population dynamics were also discussed as being poorly understood.

3.6.9.4. Food Web Dynamics

Understanding both the seen and unseen linkages between species can yield important information for resource management. For example, management of living resources such as shorebirds may be enhanced by understanding the population dynamics of horseshoe crabs, which produce energy-rich eggs that appear important for migratory shorebirds. This interspecific interaction between birds and crabs represents a case study for the importance of understanding food web dynamics to better inform management decisions and set environmental policy. Food web dynamics are also known to govern production of many species of finfish.

3.6.9.5. Tidal Wetlands

Most of the commercially important living resources of the Delaware Estuary depend on tidal marshes for either food, spawning and nursery areas, or for refugia from predation. This includes most finfish and blue crabs. Considerable effort has been spent to understand and quantify the significant role that these fringing marshes play in the life history and production dynamics of fish. Considering the extent of marshes in the Estuary, they may play a significant indirect role in supporting secondary production by microheterotrophs and invertebrates in the open waters of the Estuary. What is the net exchange of dissolved organic matter and detrital matters between tidal marshes and open waters? What proportion of the diet of benthic invertebrates (e.g., infaunal worms, oysters) is supported by marsh-derived production? A better understanding of trophic connections between marshes and open waters would strengthen food web models for the Estuary.

3.6.9.6. Invasive Species

Evidence was presented that the introduction of invasive species can occur through the seafood industry and aquarium trade, as well as via shipping related biological contamination such as in ballast water. Some of the fish species recently introduced into the Delaware Estuary are regarded as voracious predators that can reproduce quickly, representing a substantial threat to the balance of native food webs.
To assist in managing these invasive species, there is an urgent need for greater monitoring. There is also a need for more scientific study of the impacts of invasive species on the distribution and population dynamics of native species that may be affected.

3.6.9.7. Ecosystem Management

Now more than ever the political entities with jurisdiction over the Delaware Estuary need to develop the methodology to manage the Estuary as a whole, instead of on an individual species or a per state basis.

3.6.9.8. Conceptual Framework

Ecosystem management must be rooted in a comprehensive, ecologically-based conceptual framework that captures the structural and functional essence of the Delaware Estuary. As yet, a conceptual framework such as this has not been developed.

3.6.9.9. Modeling

Ecosystem modeling is increasingly being adopted as a fundamental need and natural extension of fishery stock management (see also Section 3.6.11). Ecosystem models should be based on a comprehensive conceptual framework, which still needs to be developed.

3.6.9.10. Indicators and Goals

Management of living resources may benefit by adopting a short list of high priority indicator species that are specific for the Delaware Estuary, easy to set goals for, and which relate to other key system components identified in the conceptual framework.

3.6.9.11. Habitat Restoration and Enhancement

Questions were raised about the effectiveness of efforts to assign value to living resources as part of Natural Resource Damage Assessments and to the long-term effectiveness of resulting restoration work that is usually undertaken. Typically, values are only assigned to those living resources that are visible, readily enumerated, and which engender public attention (e.g., eagles, herons). Injury to the hidden community of functional dominants such as benthic invertebrates, microfauna, and the microphytobenthos are not gauged, despite their life-support roles for species that are evaluated. Loss of habitat functionality and impairment of ecosystem functions are not negotiated, despite research that shows long-lasting damage to functionality in most cases where the NRDA process is invoked.

Considering that the NRDA valuation process is unlikely to be comprehensive, it is critically important that restoration and enhancement actions be effective when undertaken as mitigation to repair any damages. Long-term monitoring and maintenance is required to ensure that both the structure and function are restored in habitats that are impacted.

3.6.9.12. What was missing from Session 9?

- Information about the status of dominant autotrophs such as submerged aquatic vegetation (SAV) was largely absent from Session 9 and the Science Conference as a whole. With the exception of marsh vegetation (e.g., Sessions 5 and 10), there was remarkably little attention devoted to the base of the food chain, including both key primary producers and microheterotrophs. Most scientists believe that SAV are not a prominent feature in the Delaware Estuary in the same way that they are in Chesapeake Bay and many other estuaries. Some question whether SAV might be seasonally abundant and ecologically significant in the tidal freshwater estuary. Perhaps much more importantly, the role of the "secret garden" of benthic algae that live on intertidal and shallow subtidal surfaces is understudied and poorly recognized. There is mounting evidence that benthic algae can be very productive compared with other autotrophs and are more nutritious for the consumer food web than phytoplankton or detritus from vascular plants.

- Essential fish habitat was not discussed. Oyster reefs, artificial reefs, and other habitat features are increasingly seen as biological hot spots. Living resources might be enhanced by improving our understanding of the role that such habitats play in the Delaware Estuary, and working to safeguard and augment such habitats.

3.6.10 *Session 10: Edges and Watershed Linkages*

Session 10 built on the science and technical presentations in Session 5, by focusing on management concerns related to edge habitats and watershed linkages. Since Session 5 (Section 3.6.5) was the largest session and included a program addressing more basic scientific concepts and needs. To avoid redundancy Session 10 was designed to address more applied issues related to land use planning, habitat fragmentation, wetland assessment, upland and riparian buffers, invasive species, and issues associated with conservation, restoration, mitigation and enhancement (Table 13).

Key points, observations, questions and management needs from Session 10 are summarized topically below.

3.6.10.1. Linking Science and Management

Most presentations and discussions in this session emphasized the need for improving links between science and management. For example, land use planners and local and regional governance would benefit from having an improved translation of scientific concepts and information. Specifically, more useful tools and metrics for assessing and forecasting conditions need to be developed to enable prediction of environmental outcomes expected to result from different policies and decisions. To facilitate information exchange, technology transfer and coordination between scientific and management sectors, strong support was voiced for continuing to hold regional conferences such as the Delaware Estuary Science Conference on a regular basis.

3.6.10.2. Identity and Education: (Re-)Connecting People to the Resource

Over the past 50-100 years, the identity of the people in the Delaware Estuary and River Basin is believed to have become increasingly disconnected from their natural landscape. Reconnecting people to the water through increased education and recreation is seen as one mechanism for improving support and awareness for environmental resource management in the Estuary.

An obvious need is to increase recreational opportunities along the riverbanks and shores of the Estuary. This is particularly true in the upper area of the tidal Estuary where most of the population lives and where riverfronts and shorelines are least accessible due to industrial use and other development. Another paradoxical challenge exists because tidal wetlands, which are one our greatest environmental assets, are also viewed as barriers that prevent many recreational uses. Reconnecting people to the water will therefore require creative solutions that make the most of opportunities and resources. For example, restoration, enhancement and mitigation actions could target former industrial lands along the shoreline for conversion to wetlands and natural shorelines having boardwalks and piers that provide access for recreational fishing, birding and other activities.

Table 13. Titles, authors and key points of presentations delivered in Session 10, "Edges and Watershed Linkages, which was moderated by Carol Collier, Danielle Kreeger, Dan Soeder and John Balletto on May 11, 2005 in Newark, DE.

Title	Authors	Key Point
The A...B...CZM's of coastal management programs coincident with the Delaware Estuary!	D. Frizzera	The DE Estuary includes coastal zones in 3 states (NJ, PA, DE), each with an active Coastal Zone Management Program.
Linking land & water resources: lost in translation?	J. Rittler Sanchez	Injecting scientific understanding into local and regional planning provides the best foundation for improved decision-making.
The relevance of the National Vegetation Classification System to restoration practice.	K. Westervelt	The NVCS provides a useful tool to describe vegetation communities for identifying and standardizing reference sites and ranking conservation status.
Wetland conservation and restoration along Delaware Bay: the edge effect.	K. Strait and J. Balletto	Wetland restoration projects can demonstrate best success if core restoration principles are followed.
Connecting the people and places of the Delaware.	J. DiBello	Parks, greenways, trails, waterfront projects, and historic preservation projects in communities improve quality of life and help reconnect people to the land.
Upper Delaware Estuary (urban corridor) regional clean-up and restoration planning initiative.	S. Hahn, D. Wehner, J. Steinbacher and L. Klein	Data from a variety of sources will be integrated to identify contaminant gradients and restoration opportunities.
Imperviousness: a performance measure of a Delaware Water Resource Protection Area Ordinance.	G. Kauffman, M. Corrozi and K. Vonck	Impervious cover is a scientifically sound management tool for use by local governments to protect and enhance water resources in the DE River Basin.
Linking estuaries science and management using comparative risk assessment and decision analysis.	I. Linkov, G. Kiker and T. Bridges	Addressing environmental threats and mitigation actions requires careful risk analysis and decision-making, modified by local considerations and user conflicts.

3.6.10.3. Tidal Wetlands

As noted in many sessions, our extensive tidal wetlands represent one of the signature elements that distinguish the Delaware Estuary from other large American estuaries. One of the presenters reminded the audience that tidal wetlands were also identified as one of the core concerns of the Comprehensive Conservation Management Plan (CCMP) for the Delaware Estuary. Specifically, under the section titled "Habitat and Living Resources Action Items," the following were included; reduce the cumulative losses of wetlands (Action H4.4), develop strategy to encourage landowners to create, protect, and restore upland buffer zones adjacent to tidal & non-tidal wetlands (Action H4.5), develop or support non-regulatory wetlands restoration programs to increase wetland acreage in Estuary (Action H4.7), reduce *Phragmites* cover in tidal wetlands (Action H5.1), encourage environmentally compatible methods for salt marsh mosquito control (Action H5.2), and restore & enhance poorly functioning tidal wetland impoundments

(Action H5.3). Continued effort is needed in support of all of these action items, particularly in consideration of the mounting threat of sea level rise. Furthermore, consideration should be given to the diversity of wetland types in the system. For example, are freshwater tidal, brackish, and salt marshes equally imperiled?

3.6.10.4. Indicators and Goals

New indicators are needed that can be used to gauge the status and trends of key "life-support" habitats in the Delaware Estuary and watershed, such as riparian corridors, wetlands and reefs. To date, attempts to develop indicators and goals to assess environmental health have focused largely on matters related to water quality and living resources, because these are areas where longer-term data exist to identify trends. Similar, long-term habitat data need to be collected to allow for the establishment of meaningful goals (e.g., wetland acreage targets) for key life-support habitats.

3.6.10.5. Ecological Flows

Linkages between the Estuary and the watershed were discussed in the context of the physical-biological case study related to the possible effects of altered or reduced freshwater inflow on living resources in the Estuary (see Section 3.6.5.2). Regulation of water balance in the Basin remains a top challenge for environmental management due to the complex array of environmental factors and user needs to be considered.

3.6.10.6 Conceptual Framework

Resource management would benefit considerably from development of an integrated conceptual framework that summarizes the key structural and functional components of the Estuary, including linkages between tidal and non-tidal components and linkages between open waters and edge communities. Having a readily understandable conceptual framework that is comprehensive and based on the best science would provide a powerful tool to prioritize management and education strategies, such as through monitoring and outreach programs. This would provide guidance for developing quantitative, numerical models, which in turn could be used to update and strengthen the scientific basis of the conceptual framework. Indicators and goals, and public programs, should be developed that represent the signature elements of the framework.

3.6.10.7. What was missing from Session 10?

- The emphasis was deliberately focused on habitat and management issues that were not well represented in Session 5. By design, Session 10 therefore did not consider the many management concerns and needs associated with living resources that depend on edge habitats, or that migrate between tidal and non-tidal habitats. Similarly, water quality (e.g. nutrients) and hydrodynamic (e.g., sediment budgets) linkages between tidal waters, edge habitats and watersheds could have been discussed more thoroughly in Session 10, but were addressed in other Sessions.
- Exotic/invasive species problems were only briefly discussed, although they are known to be critically important in governing the structure and function of tidal wetlands (e.g., *Phragmites*).
- Management concerns related to edge habitats other than tidal wetlands, such as intertidal mud flats and sandy beaches, were not well represented in Session 10, although several presentations in Session 5 indicated that proper beach management is a critical factor for providing horseshoe crab nesting sites, an important resource in the estuary.

3.6.11 *Session 11: Management Goals & Needs, Data Coordination & Advocacy*

Operational issues that confront environmental managers, such as relating to data coordination, were the focus of Session 11. Many of the same points were voiced here as in Session 6 (Section 3.6.6), and to avoid redundancy this summary of Session 11 primarily focuses on new concepts and needs that had not been previously discussed. Of particular focus was the need to build more dialogue and linkages between the community of scientists (academic, agency and industry) and the community of resource managers and policy-makers. Regional communication and public outreach also figured prominently in the presentations and discussions of Session 11 (Table 14). Key points, observations, questions and management needs from Session 11 are summarized topically below.

3.6.11.1. Conceptual Framework

An improved, integrated framework for scientific information is needed to better assess and forecast how the Delaware Estuary, watershed and coastal waters would respond to environmental stressors. A comprehensive conceptual framework would also help to identify key data gaps.

The nature of the conceptual framework discussed in Session 11 differed somewhat from that discussed earlier. References in earlier sessions regarding the need for a conceptual framework were concerned primarily with a descriptive ecosystem characterization that would summarize the principal structural and functional components. In Session 11, a conceptual framework was considered that would also incorporate socioeconomic considerations, such as port facilities and operations, fish and shellfish production, and air and water quality.

Once again, it was pointed out that any ecosystem characterization must include a delineation of habitats, because of their ecosystem services and the need to better link scientific research and management with actual land-use practices.

3.6.11.2. Indicators and Goals

As stated many times in the conference, new efforts to develop indicators and goals should be linked to the conceptual framework (Section 3.6.11.1). Important traits to consider include whether prospective indicators are specific (with a clearly stated objective), measurable (both in time and quantity), achievable (within available resources and intellectual capital), relevant (for the conceptual framework or issue being addressed). Goals must be trackable; i.e., able to be evaluated according to defined success criteria.

3.6.11.3. Monitoring

Continued water quality-related monitoring, assessment and modeling is needed to evaluate the sources and environmental factors that control high nutrient concentrations, nutrient imbalances, low dissolved oxygen levels, and importantly, concentrations of toxic chemicals in both the main stem and tributaries of the Estuary.

New technologies should be incorporated where cost-effective to promote more continuous, real-time observations for assessing event-based impacts and long-term trends in coastal environmental parameters that affect water quality and renewable resources.

Table 14. Titles, authors and key points of presentations delivered in Session 11, "Management Goals and Needs, Data Coordination & Advocacy," which was moderated by Jawed Hameedi and Ed Santoro on May 11, 2005 in Newark, DE.

Title	Authors	Key Point
Environmental indicators as performance measures in coastal resource use management.	J. Hameedi	Coastal indicators should consider both air and water quality, and habitat and living resources; and be specific, measurable, achievable, relevant and trackable.
Coastal Ocean Observing for the Delaware Estuary.	D. Chapman	The structure and goals of the Mid-Atlantic Coastal Ocean Observing Regional Association (MACOORA) are designed to provide many services to society.
Restoration banking: a conceptual framework for increasing restoration nationally.	R. Stahl	Restoration banking is conceived as a way to promote increased environmental conservation and restoration for the public while giving businesses new options.
Linking changes in valued ecosystem components to human use of coastal resources: an example from the St. Jones River Watershed, DE.	M. Reiter and G. Parsons	A modeling framework is described for linking ecosystem drivers and stressors to social and economic values.
Building an ecosystem model of the Delaware Estuary: background, goals and project status.	M. Frisk, T. Miller, S. Martell and R. Latour	A quantitative, trophic model is being developed to predict fisheries production based on key ecosystem metrics, including habitat variables.
Lost in translation or how to bridge the gap between science and advocacy.	E. Stiles and D. Mizrahi	Communication between scientists, managers and policy-makers could be strengthened by more joint, common-ground partnerships and complementary cross-references to the public and officials.
On-line access and analysis of data from NOAA's National Status and Trends Program.	E. Johnson and J. Hameedi	The NS&T Data Portal is an on-going effort to build a system to manage and disseminate data through automated analysis and visualization tools.
An information system for the Delaware River Basin.	C. Campbell	An interactive, web-based information clearinghouse is being designed for datasets and information to support management and conservation activities.
Enhancing coastal public access within the Delaware Estuary.	R. Freudenberg	A variety of actions can provide greater access to the shores of the DE Estuary, thereby promoting a greater appreciation for the Estuary by the public.
State of the Basin Report Card for the Delaware River.	G. Kauffman, M. Corrozi and K. Vonck	A DE River Basin Report card with color graphics, maps, and figures is being developed for use by the regional public, elected officials, and stakeholders.

3.6.11.4. Data Issues

Numerous presentations and discussions centered on the need to identify and link data sources, implement procedures to assure data quality and integrity, and establish mechanisms for broader dissemination and products development via the internet. Several initiatives are currently underway to build data-housing capabilities.

3.6.11.5. Links Between Science, Management and Policy-makers

Communication between scientists, managers and policy-makers could be strengthened by more joint, common-ground partnerships and complementary cross-references to the public and officials. Increasingly, our scientific understanding and proficiency is becoming more multi-disciplinary and complex, as are the issues confronting resource management. To move forward efficiently and effectively, better communication and collaboration is needed.

3.6.11.6. Identity and Education

Improved educational and outreach programs are need to increase public understanding of environmental issues, including the complexity that underlies many resource use conflicts and the challenge and need for sustainability of renewable resources and coastal amenities. The scientific and management community can foster greater public understanding by developing and promoting indicators and goals that better connect with public perceptions of the environment. We may also consider placing higher priority on restoration and enhancement activities that provide greater public access leading to educational programs and/or recreational outlets.

3.7 Invited Speakers and Special Panels

Numerous special presentations and panels were held at the Science Conference, as summarized in Table 15. Invited speakers presented a variety of points to the audience, and these stimulated considerable discussion in between sessions and during ad hoc panels in the evenings. Few specifics were recorded; however nearly all presenters called for greater linkages between scientists and managers.

It was also pointed out that we already have an existing monitoring structure that is reasonably well integrated across the watershed and which contains some long-term datasets. If added resources can be identified, existing monitoring programs can be strengthened significantly however by incorporating more broad-based metrics for living resources and habitat, by broadening the classes of contaminants monitored, and by increasing spatial and temporal resolution through a mix of added sampling and new technologies for continuous data recording.

Much of the focus during the conference was on contemporary issues that confront environmental management. Some of the plenary speakers pointed out that we still lack fundamental understanding of how some key components of the system work. There remains a need to address some significant gaps in basic information, which would require research.

Table 15. Titles, authors and key points of plenary, keynote and panel presentations delivered at the Delaware Estuary Science Conference in January and May, 2005.

Title	Authors	Key Point
(January & May) The DE Estuary: 400 years of hostile occupation and the future of science-based management.	Jonathan Sharp	The ingredients exist to develop a more science-based management approach for the DE Estuary, which would meet many needs.
(January) The state of science in the Delaware Estuary.	John Teal	The DE Estuary is different from estuaries north and south of it by having less phytoplankton and SAV and more marsh.
(May) Welcome comments by Congressman Mike Castle	Mike Castle	The natural resources of the Delaware Estuary are valuable to the public and they must be managed carefully.
(May) Introductory remarks by Linda Fischer.	Linda Fischer	Corporate stewardship can play an important role in helping to manage environmental resources sustainably.
(May) Lessons from the Chesapeake Bay Program experience.	Rebecca Hanmer	DE Estuary scientists and managers could marshal more support for environmental programs by promoting greater awareness for core issues.
(May) Challenges for the successful management of the DE Bay oyster beds of NJ: is stock sustainability reachable?	Eric Powell	Management of the oyster fishery must ensure that the abundance does not drop below a point-of-no-return level.
(May Panel Presentations) Next steps: what is needed for a sustainable commitment to improve the health of the Delaware Estuary?”	Mike McCabe, Kathleen Callahan, Bradley Campbell, John Hughes, Cathy Curran Myers, Merdith W.B. Temple, and Donald Welsh	Realistic and meaningful indicators and goals are needed to assess ecosystem health, and a variety of new initiatives are being conceived or developed to improve conditions and strengthen environmental management in the Delaware Estuary. An understanding of the interconnected structure of our environment is necessary for a sustainable commitment to the Estuary.

3.8 IOOS/NWQMN Workshop

The U.S. Ocean Action Plan has identified a need for an expanded, well-coordinated system for monitoring coastal areas and the upland regions that affect them. This national monitoring network is expected to be closely linked with the Integrated Ocean Observing System and, ultimately be incorporated into a broad Earth observing system. A workshop to discuss and design an integrated monitoring program for the Delaware Estuary was held on September 19-21, 2005, at the Cook College Campus of Rutgers University. This workshop was titled “Linking Elements of the Integrated Ocean Observing System (IOOS) with the Planned National Water Quality Monitoring Network.” Participants at this workshop came from universities (Monmouth University

Montclair State University, Oregon Health and Science University, Rutgers University, Stevens Institute of Technology, University of Delaware), state and regional agencies (Delaware River Basin Commission, New Jersey Department of Environmental Protection, New Jersey Marine Sciences Consortium), federal agencies (EPA, NOAA, USGS), and non-profits (Partnership for the Delaware Estuary), among others. Many of the 47 attendees had also attended the Delaware Estuary Science Conference, and discussions during the workshop picked up on many of the same messages and needs articulated at the conference.

One of the principal outcomes from the workshop was an expressed need to develop a pilot IOOS for the Delaware Estuary and its watershed, since named the Delaware Estuary Watershed to Ocean Observing System (DEWOOS). One principal benefit of an IOOS system would be the coordinating functions, which would provide a framework for identifying monitoring needs and opportunities to improve efficiency and comparability of existing programs. The following summarizes some of the more specific science needs that were articulated by a consensus of attendees at the IOOS/NWQMN Workshop and which could possibly be addressed by an IOOS program.

Science needs expressed at the IOOS Workshop are grouped here as being either technical or operational in nature. Technical issues are further classified as relating to either environmental quality (i.e., physical and chemical forcing functions) or ecosystem health (i.e., biological endpoints).

3.8.1 *Technical Issues*

3.8.1.1. Environmental Quality

3.8.1.1.1. Physical-Chemical-Biological Linkages - Sediments. Much remains to be learned about the sediment budget for the Delaware Estuary and Basin, with important implications for managing stormwater runoff, maritime exchange, deep-water dredging, and ensuring sufficient sediment to sustain tidal marsh accretion. This in turn is important for contaminant transport and fate, and for biological and habitat traits. The development of a regional sediment management plan is needed, which was identified as a priority of the Ocean Commission Report (Chapter 12).

3.8.1.1.2. Freshwater Inflow. Reduction or alteration of freshwater inflow, considered in combination with rising sea level, is likely to shift the salinity gradient towards the upper estuary. This could have important ecological consequences for biological resources such as freshwater tidal vegetation and oysters, and more study and monitoring is needed to deduce such impacts and trends.

3.8.1.1.3. Contaminants. Toxic compounds remain one of the most important concerns for environmental management in the Delaware Estuary and Basin. Despite reductions and increased regulatory actions, many classes of contaminants persist and continue to threaten wildlife and human health problems. New classes of emerging pollutants and Homeland Security issues add to these existing concerns.

3.8.1.1.4. Nutrients and Biogeochemical Processes. The concentrations, forms and relative ratios of various macronutrients (N, P) and micronutrients and minerals (Si, Fe) are critically important for governing the structure and function of biological processes. Although eutrophication is not a widespread problem in the Delaware Estuary, the biological balance of the system remains at risk due to nutrient shifts.

3.8.1.2. Ecosystem Health

3.8.1.2.1. Indicators and Goals - Ecologically Significant Species. For general purposes, species of animals and plants can be considered ecologically significant species if they are recognized and appreciated as being signature traits of the system and if they are ecologically significant as functional dominants. Horseshoe crabs, oysters and American shad are examples of ecologically significant species that should be monitored as key indicators of living resources.

3.8.1.2.2. Tidal Wetlands. The Delaware Estuary is unique among large east coast estuaries in having fringe tidal marsh around nearly the entire perimeter. These marshes play important roles in the life history of estuarine fauna and flora as well as protecting against floods and helping to regulate water quality, hydrology, and sediment budgets. The functions and status of tidal wetlands represents an important habitat component that should be included in a comprehensive, estuary-wide monitoring program.

3.8.1.2.3. Food Web Dynamics. The health of aquatic communities can be assessed in large part by characterizing, understanding and monitoring primary production, heterotrophic production, and trophic transfers and food web links that sustain fish and shellfish production. At present, we have a patchy understanding of food web dynamics in the Delaware Estuary, and new technologies offer opportunities to monitor these elements.

3.8.2. *Operational Issues*

3.8.2.1. Data Issues. A variety of data-related problems currently challenge scientists and managers. These include a lack of data coordination, integration, and comparability, and a variety of schemes for quality assurance, archiving, and access. Data gaps are also widespread, particularly with regard to spatial coverage and long-term record-keeping. Better data coordination, through an IOOS-based network and other means, is becoming increasingly important as digital technologies and data management schemes become more diverse and central to managers.

3.8.2.2. Linking Science and Management. Greater coordination of monitoring efforts among the many local, regional and federal agencies would improve linkages between science and management activities.

4 Science and Management Needs

Current top science and management needs for the Delaware Estuary are presented in this section. These were compiled through careful analysis and compilation of more than 150 presentations and related discussions at the 2005 Delaware Estuary Science Conference (January and May, 2005; 250 attendees; Sections 3.1 to 3.8) and the IOOS/NWQMN Workshop (September 2005; 47 attendees; Section 3.9). The needs assessment was performed with a two-tiered approach designed to ensure objectivity and fairness among sessions and meetings that had different foci.

First, the principal points and needs expressed in each session were summarized (Section 3.) Second, science and management needs expressed in the different meetings were distilled into a one list by cross-comparison (this Section). An attempt was made to filter out redundancy between the January and May meetings, and so this comparison is tempered by the knowledge that the final list of top points in Sessions 8-11 may have been slightly repetitious of Sessions 1-6 but may have omitted some messages that recurred from Sessions 1-6. This list was also tempered by comments recorded in question and answer sessions, formal and ad hoc panel discussions, and on “needs assessment” questionnaires completed by attendees.

Clearly, most of the key points and needs identified in this White Paper are based on discussions and proceedings by those who attended the Science Conference and subsequent meetings. Despite best attempts to involve the broadest cross-section of the science and management community, there were some topics and areas of expertise that were underrepresented at these meetings. Examples can be found in the sections titled “What was missing?” This needs assessment is expected to be refreshed periodically, providing future opportunities for addressing any underrepresented or emerging issues and needs.

Twenty-eight different key points and science and management needs were expressed in the different forums, as analyzed in Section 3 and summarized in Table 16. Note that many of these topics are interrelated, some even representing sub-topics of others. This list of 28 science and management needs was next grouped into two categories, technical and operational. Technical needs consist of the actual quality and quality of scientific information needed to understand and manage the natural resources in the Delaware Estuary. Operational needs are considered to be actions related to the organizational interrelations, programmatic agendas and operational processes that define how the scientific and management community works together and promotes its messages to policy-makers and the public.

The top ten technical needs and top six operational needs required to advance the scientific understanding and management capabilities of the Delaware Estuary are summarized in Sections 4.1 and 4.2, respectively. Topics were retained on this list if broad support and attention was devoted to them.

Table 16. Key points and science and management needs expressed in the eleven sessions at the Delaware Estuary Science Conference (January and May, 2005) and the IOOS/NWQMN Workshop (September 2005), organized by topic area.

Topic	**Forum**											
	Science Conference Session											**IOOS Workshop**
	1	2	3	4	5	6	7	8	9	10	11	
Conceptual Framework & Modeling	X				X	X			X	X	X	
Identity & Education				X				X		X	X	
Monitoring	X	X		X		X	X	X	X		X	X
Indicators and Goals						X		X	X	X	X	X
Data Issues, Archiving & Coordination	X	X	X		X	X			X		X	X
Data Gaps			X	X								
Physical-Chemical-Biological Linkages		X						X	X			X
Tidal Currents	X											
Ecological Flows & Salt Balance	X				X			X		X		X
Water Use Competition	X											
Contaminants & Emerging Substances		X	X	X	X	X	X	X				X
Nutrients & Nutrient Ratios								X				X
Diseases in Wildlife				X				X				
Pathogens for Humans								X				
Life History Data			X									
Invasive Species						X			X			
Food Web Dynamics			X	X					X			X
Microbial Ecology				X								
Benthic Ecology			X									
Benthic-Pelagic Coupling			X									
Tidal Wetlands & Sea Level Rise		X		X	X				X	X		X
Ecologically Significant Species and Habitats		X		X		X			X			X
Habitat Restoration & Enhancement				X					X			
Ecosystem Function & Economic Valuation			X		X							
Linkages to Other Systems			X		X							
Link Science & Management	X				X					X	X	X
Emergency Management							X					
Ecosystem Management & Other Policy Considerations				X	X		X		X			

4.1 Technical Needs

The top 10 technical needs required to advance the scientific understanding and management capabilities of the Delaware Estuary are listed in Table 17 and described more fully below.

Table 17. Top ten technical needs for advancing science and management of the Delaware Estuary.

Top Ten Technical Needs
1. **Contaminants** (forms, sources, fates & effects for different classes)
2. **Tidal Wetlands** (status, trends and relative importance of different types)
3. **Ecologically Significant Species & Critical Habitats** (benthos, reefs, horseshoe crabs)
4. **Ecological Flows** (effects of base and episodic flows on salt balance & biota)
5. **Physical-Chemical-Biological Linkages** (e.g., sediment budget effects on toxics & biota)
6. **Food Web Dynamics** (key trophic connections among functional dominant biota)
7. **Nutrients** (forms, concentrations and relative balance of macro- and micronutrients)
8. **Ecosystem Functions** (assessment and economic valuation of ecosystem services)
9. **Habitat Restoration and Enhancement** (science & policy)
10. **Invasive Species** (monitoring, management & control)

A description of each of these ten science needs listed in Table 17 follows below. It is important to note that additional technical needs were expressed at the Science Conference, and other data gaps were articulated that are not listed specifically here; e.g., airshed linkages and climate effects. Future iterations of the Science Conference and White Paper are planned, which will allow additional science needs to be addressed along with any new issues that emerge in the interim.

4.1.1. *Contaminants*

As a former center for the Industrial Revolution in the New World and continuing as one of the top industrial regions in the United States, the greater Philadelphia region contains a pollutant legacy lasting more than 300 years. A TMDL (total maximum daily load) process is underway in the tidal river and estuary to address the legacy of polychlorinated biphenyls (PCBs), and mercury levels in fish tissue. These necessitate consumption advisories for many edible estuarine and freshwater fish species. Although much of the present pollutant runoff can be attributed to past industry, the byproducts of numerous human activities continue to be problematic and new classes of pollutants are being recognized.

Data from the DRBC Boat Run and other programs have documented that water quality has improved considerably over the past 50 years, such as with regard to the increase in oxygen concentration in association with upgrades in wastewater treatment over the past 30 years. More recently, improved conditions have also been reported for certain contaminants such as phosphorus and lead.

Many challenges remain. Existing monitoring programs may not be adequate to meet management and policy needs related to legacy pollutants such as dioxin, PCB's, and mercury that persist in our watershed. Concentrations of these compounds in water and sediments often exceed standards for wildlife and human drinking water. Some classes of contaminants are still moving through the food web and concentrating in top predators, and concentrations in fish tissue frequently exceed guidelines for human consumption. Despite warnings, many people continue to consume fish taken from contaminated areas.

Evidence was also presented showing high concentrations of some pesticides and hydrocarbons (e.g., PAH's), suggesting that the prevalence, fate and effects of these compounds may be understudied in our system. Emerging pollutants such as endocrine disruptors (EDC's) and pharmaceutical and personal care products (PPCP's) merit greater attention by both researchers and managers.

Very little information exists regarding the biological effects of many of these toxics on the natural assemblages of organisms that live in the Estuary. Resources are so limited that current bioassays consist of only a few standard protocols for pelagic zooplankton. Benthic toxicity assessments by NOAA (and EPA and State of New Jersey) have been completed on amphipods, mysids, worms, and bivalves s part of IBI-Benthos surveys. Programs such as the National Status and Trends Mussel Watch could be extended farther up into the freshwater portion of the estuary. There is much to be learned about the routes by which contaminants enter the system (e.g. can they travel via groundwater seeps?), the reservoirs for contaminants, the release mechanisms, and the implications for wildlife and human health. For these reasons, contaminant-related issues remain one of the top environmental priorities for resource management in the Delaware Estuary and Basin.

4.1.2. *Tidal Wetlands*

Tidal wetlands represent one of the defining characteristics of the Delaware Estuary ecosystem. The natural landscape is dominated by a nearly contiguous band of these marshes around a large portion of the system below Wilmington. No other large American estuary contains such an extensive network of tidal marshes. As Dr. John Teal remarked at the Science Conference:

> *"Delaware Bay is different from estuaries north and south of it - different in sediment loading and in the type of edge. In Delaware Bay, the silts and fines are abundant, resulting in less phytoplankton and little SAV compared to other estuaries, but there is more marsh and therefore more nursery habitat for commercial and recreational fishes."*

These wetlands are crucial ecotones between upland and aquatic areas that help to maintain water quality, and intercept and filter runoff and water flushing to and from the Bay. They also serve as critical feeding and nursery areas for many prominent fish and shellfish, provide habitat for birds, and they provide a "first line of defense" buffer against floods. The diversity of marsh types in the Estuary is also high, with salt marshes of the lower Estuary grading to brackish and freshwater tidal wetlands in the upper Estuary. Due to land conversion and degradation, perhaps less than 5% of the pre-settlement acreage of freshwater tidal marshes remains. Therefore, some marsh types are more imperiled than others. We need to know the status and trends for the principal types of tidal wetlands, rates of marsh habitat loss/degradation/rehabilitation, the economic value of a fringe marsh, and whether the values differ among marsh types, dominant vegetation types, and/or geographical regions.

Although wetlands are conspicuous, diverse and have high functionality in the Delaware Estuary, no one agency or organization is currently charged with monitoring the status and trends of these critical habitats. Even in areas that are not facing development pressure, tidal wetlands are expected to be increasingly imperiled due to sea level rise, land subsidence, sediment starvation, invasive species and other factors. Global warming and associated climate change is also predicted to raise water temperatures and possibly alter gas exchange processes, and these effects could become more pronounced in exposed marshes and intertidal mud. We need to know how these changes will affect the ecological structure and function of our tidal wetlands, and consequently, the Estuary as a whole.

With rising sea level, tidal marshes are expected to undergo a landward retreat. But existing developments and other impediments will restrict this natural progression, likely leading to continued wetland losses if no measures are taken to permit landward retreat. Even without further direct conversion or impairment by humans, net losses of wetland acreage are expected to continue. We need to identify both challenges and opportunities that exist to consider projected sea level rise in land use planning? Land use planning for wetland protection, conservation and restoration should include policies and management for upland buffers adjacent to wetlands. This will allow for landward retreat and conversion to tidal marshes.

Thus, while there are many important natural habitats and natural communities in the Estuary that merit a coordinated regional focus (see Section 4.1.3), tidal wetlands are assigned special status in this White Paper due to their functional significance in the Delaware Estuary Ecosystem.

4.1.3. *Ecologically Significant Species & Critical Habitats*

More than 200 migrant and resident finfish species use the Delaware Estuary for feeding, spawning, or nursery grounds, including sharks, skates, striped bass, shad, sturgeon, American eel, blueback herring, Atlantic menhaden, alewife, bluefish, weakfish, and flounder (Dove and Nyman 1995). Oysters and blue crabs represent important shellfish resources in this system. The Estuary is home to the largest population of horseshoe crabs in the world, and is an important link in the migratory path of a wide variety of shorebirds and waterfowl(Dove and Nyman 1995). Important natural habitats in the Estuary are tidal marshes intertidal mudflats, oyster reefs, sandy beaches, inland wetlands, riparian corridors, and upland meadows and forests.

For the purposes of this White Paper, species of animals and plants are termed “ecologically significant species” if they are either recognized and appreciated as being functional dominants in the ecology of the system or are widely recognized as being signature traits that characterize the unique identity of the system. Another common usage term that has been used to describe these biota is “keystone species;” however, the scientific meaning of this term is assigned very specific attributes in the field of community ecology and so we will avoid using it here to avoid confusion. “Critical habitats” represent prominent habitat types that are either important centers of ecosystem function, biological hot spots containing high biodiversity, or essential habitat for species of special concern.

Benthic hot-spot communities are offered as an example of an ecologically significant biological resource that merits further attention by the science and management community. In general, our overall knowledge of benthic habitats and communities in the Delaware Estuary is poor. What little we do know is limited to benthic species surveys, and some of these have pointed to the existence of interesting assemblages of worms and other fauna. The functional aspects of the benthic ecosystem are completely unknown. This is particularly notable because the importance of benthic-pelagic coupling processes has been well established and examined in many other estuaries, including those that do not have contaminant problems (as reported in Section 4.1.1, there is also very little known about the effects of toxics on benthic communities.)

Biological processes at the sediment-water interface are likely to be important for carbon balance, biogeochemical cycling, and the fate and effects of contaminants. What are the main nutrient cycling dynamics through benthic communities? How does sediment and water quality affect benthic organisms, and vice versa? What is the functional significance of oyster reefs and other communities of benthic suspension-feeders in governing water quality? What is the ecological significance of mysids and swarming amphipods that live near the bottom? What ecosystem services are rendered by healthy benthic communities, and are these functions impaired anywhere in the Estuary?

There is a fundamental need for identification of all natural resource assemblages in the Estuary, particularly those considered to be ecologically significant species and critical habitats. We must also ensure that suitable monitoring, assessment and management programs are in place or implemented to track their status and trends. These actions will promote continued development of appropriate indicators and measurable goals for the Estuary (Section 4.2.4).

4.1.4. *Ecological Flows*

Considerable attention was given to the overall water budget for the Estuary, including freshwater inflow, groundwater, salt water exchange, and the effects of diversion and dredging. Study and management of the water budget is complicated by the difficulty in differentiating between natural cycles that are associated with climate variation (e.g., *El Nino*, North Atlantic Oscillation, wet/dry years) and the effects of human management (e.g., flow regulation, channel deepening, diversions out of the watershed, groundwater withdrawals). Some forcing functions are unidirectional, such as sea-level rise.

Changes in the balance between saltwater and freshwater can have important direct effects on human activities. Infiltration of saltwater into the groundwater in southern New Jersey, is leading to salt contamination of wells for drinking water. While most of these changes in the salt balance of groundwater are being driven by groundwater withdrawals, a better understanding the water budget of the Estuary, and its likely response to rising sea level, will help water resources managers better predict and plan for such problems in the future.

The water budget is also critically important for the biological communities of the Estuary, and much discussion at the Conference centered on the importance of freshwater flow management in the watershed for ecological communities in the Estuary; hence, this topic is termed an “ecological flow” issue. One of the distinguishing characteristics of the Delaware Estuary compared to other large American estuaries is the size of the freshwater tidal region, considered one of the largest of its kind in the world. The main mixing zone between seawater and freshwater occurs in the middle of the estuary. Any further reduction in freshwater inflow, combined with rising sea level, is certain to shift the salinity gradient towards the upper estuary. Increased salinity in the middle and upper Estuary will impact all of the species and habitats that reside in those areas because most animals and plants in freshwater tidal marshes have very narrow physiological tolerance limits for salt exposure.

Oyster reefs and freshwater tidal marshes are both regarded as signature habitat types of the Delaware Estuary (Section 4.1.2). Oysters (*Crassostrea virginica*) could be impaired by increasing salinity because disease agents tend to be more virulent in dry years when bay salinities are higher than normal. Increasing salinity due to sea-level rise and freshwater withdrawal will exacerbate this tendency. This issue is of increased importance because the bay narrows appreciably just above the area of the oyster beds leaving little area for up-estuary movement of the resource. Freshwater tidal marshes contain high plant diversity and species of special interest such as wild rice (*Zizania aquatica*). These plants cannot tolerate saltwater. Being situated in the urban corridor of the Estuary where they are impacted by development and pollution, freshwater tidal marshes are vestigial compared to their historic acreage.

Key links between ecology and physical processes need resolution of the importance of: the magnitude and seasonal timing of freshwater flow location of the salt line; and, flow management and the interrelationship between flow regulation, natural flow variation, and other impacts (e.g. sea level rise); and, the effects of these physical processes on biota and key ecological processes in the Estuary.

4.1.5. *Physical-Chemical-Biological Linkages*

The ecological flows issue (Section 4.1.4) is an example of the complex interactions among physical (hydrodynamics), chemical (salinity), and biological (oysters and marsh grasses) elements of the system. The Conference participants discussed many issues that are poorly understood, and therefore represent challenges and needs for the science and management community. Although chemical and physical properties of water quality are being monitored in the Delaware Estuary, there is relatively little study and assessment of coincident biological interrelationships.

An additional example of a physical-chemical-biological interaction that must be better understood is the interrelationship between the sediment budget of the Estuary, sediment contaminants, and their biological fate and effects. The sediment budget has important implications for managing stormwater runoff, contaminant transport and fate, maritime exchange, deep-water dredging, and ensuring sufficient sediment to sustain tidal marsh accretion. The development of a regional sediment management plan is needed. This was also identified as a priority of the Ocean Commission Report (Chapter 12) ,and was highlighted by the recent disastrous effects of Hurricane Katrina, which drew national attention to the effects of sediment starvation on wetland loss rates in the Mississippi Delta

Another example of a physical-chemical-biological interaction that must be better understood is the interrelationship between sediment inputs, turbidity and light availability (physical traits), nutrient concentration and balance (chemistry), contaminant forms and concentrations (chemistry) and the relative production of autotrophs (phytoplankton) and heterotrophs (bacteria) that represent the base of the food-chain. An interesting trait of the Delaware Estuary is that eutrophication is rare in relation to other large American estuaries that have similar high nutrient inputs. One possible reason for this is that naturally high turbidity and low light conditions, possibly exacerbated by contaminant exposure and suboptimal nutrient balance, may inhibit algal blooms in the water column of the upper and middle estuary. More study by collaborative teams of experts and more broad-based monitoring is needed to develop a better understanding of these types of interactions.

4.1.6. *Food Web Dynamics*

The health of aquatic communities can be assessed in large part by characterizing, understanding and monitoring primary production, heterotrophic production, and trophic transfers and links that connect the base of the food chain to fish and shellfish production. At present, we have a patchy understanding of food web dynamics in the Delaware Estuary, and new technologies offer opportunities to monitor these elements.

Within the open water areas of the middle and upper Estuary there appears to be generally low primary production, including both benthic communities (e.g. submerged aquatic vegetation, microphytobenthos) and pelagic communities (phytoplankton), although exceptions may occur in some shallow areas. As noted above (Sections 3.6.3 and 4.1.5), this low primary productivity appears to result primarily from natural factors (e.g., high turbidity, depth). Compared to other large estuaries where eutrophication is common, the base of the food chain and overall food web dynamics of the Delaware Estuary may be governed to a much larger degree by allochthonous inputs of detrital material and associated decomposer organisms such as microheterotrophs.

How does the relative balance of autotrophic and heterotrophic activity vary seasonally and spatially within the Estuary? What are the relative contributions of different types of autotrophs and microheterotrophs to secondary production by metazoan consumers such as fish and shellfish? Key data gaps need to be filled to link the base of the food chain to fisheries production such as seasonal variation in the relative balance and the relative contribution to fishery production. An understanding of food web linkages and dynamics would allow better management of other species such as shorebirds. Migratory shorebirds stop along Delaware Bay to nourish themselves on the energy-rich eggs laid on sandy foreshores by horseshoe crabs. This interspecific trophic interaction between birds and crabs represents a case study for how an understanding of food web dynamics can inform management decisions and set environmental policy.

4.1.7. *Nutrients*

The concentrations, forms and relative ratios of various macronutrients (N, P) and micronutrients and minerals (silica, iron) are critically important for governing the structure and function of biological processes. Although nutrient-based TMDL's (total maximum daily loads) are being completed in some tributaries and eutrophication is not widespread in the Delaware Estuary, biological balance may be at risk in some areas due to localized eutrophication or to shifts in nutrient balance. Over the past 50 years, concentrations of nitrogen and phosphorus rose, but phosphorous was subsequently reduced as a result phosphorus detergent ban. Nitrogen inputs continue to rise. As a consequence, the relative balance of C, N and P appears to have undergone system-wide shifts over time and may be tilting toward a high N:P ratio.

Long-term shifts in nutrient balance are likely to affect food web dynamics, biogeochemical cycles, and living resources. Harmful algal blooms and impairment or alteration of marsh biodiversity and function are examples of nutrient balance effects that have been documented elsewhere. Future monitoring for nutrients should examine the forms, concentrations, and relative balance of the principle nutrients (e.g., N, P) and minerals (e.g., silica, iron) that can affect productivity.

4.1.8. *Ecosystem Functions*

Most quantitative assessment of biological resources within the Delaware Estuary focuses on standing stock, biodiversity, or health of individual resources or habitats. The ecological processes that link ecosystem components and characterize the vigor of the estuarine system are rarely studied and virtually never monitored. Key functional processes and dynamic exchange rates that occur in the ecosystem include rates of primary production, trophic transfer efficiencies, rates of denitrification, etc.

Importantly, many of these functions can be translated into economic value, particularly those that purify or improve water quality, or support resources that are exploited by people. The economic valuation of ecosystem goods and services by our estuarine environment will be difficult, but is nevertheless an important exercise. It enables a comparative analysis of the ecological and economic value of different resources and habitats and it also contributes to greater public appreciation and protectionism for our natural resources. Such a program would evaluate the worth (in dollars and cents) of a healthy Delaware Estuary and what each resource and habitat contributes. Answers to these questions would allow application of functional processes valuation for Natural Resource Damage Assessments, resources, habitats, species, and ecological links. This in turn would make a better case to the public about why the Delaware Estuary is important to them.

4.1.9. *Restoration and Enhancement*

Restorations and enhancement projects throughout the Estuary and watershed are currently underway to benefit biological communities and provide greater ecosystem services. Restoration and enhancement activities in the Delaware Estuary have targeted wetlands and oyster reefs, particularly because of their importance as essential fish habitats.

A fundamental science and management need is follow-up monitoring and assessment, leading to adaptive management practices. A frequent criticism of restoration activities, particularly those that result from mitigation to repair damages (e.g., through the NRDA process), is that there is rarely any long-term monitoring and maintenance to ensure that both the structure and function is restored. These are essential to ensure that habitats and resources are being restored over the long-term.

This need for follow-up monitoring and establishment of success criteria is not restricted to habitat issues. Restoration work directed at pelagic fish stocks, dam removal, maintenance of fish passages, and improvements to spawning substrates and refugia require long term monitoring for metrics of success to establish whether they have worked as planned, and to incorporate any lessons into similar future actions.

4.1.10. *Invasive Species*

Exotic species continue to be introduced to the Delaware Estuary. Some of these are more “invasive” that others *Phragmites australis* is perhaps the most significant invasive species because it has altered the landscape by out-competing other marsh grasses. Some of the fish species recently introduced into Delaware Estuary are regarded as voracious predators that can reproduce quickly, representing a potential threat to the balance of native food webs.

No integrated strategy exists to guide science, management and policy actions regarding invasive non-indigenous species. For example, it is widely known that the introduction of invasive species can occur through the seafood industry and aquarium trade, as well as via shipping related biological contamination such as in ballast water. No policy strategy has been developed and implemented to manage ballast water and cope with introductions of non-native species. There remains a need for greater monitoring for new invaders and to help control species that are on the verge of becoming invasive.. Lastly, there is also a need for more scientific study of the impacts of invasive species on the distribution and population dynamics of native species.

4.2 Operational Needs

The top six operational needs required to advance the scientific understanding and management capabilities of the Delaware Estuary are provided in Table 18.

Table 18. Top six operational needs for advancing science and management of the Delaware Estuary. Keywords are highlighted in bold font.

Top Six Operational Needs
1. Strengthen **Linkages Between Science and Management**
2. Develop a Comprehensive **Conceptual Framework** Describing the Ecosystem
3. Implement an **Ecosystem Management** Approach
4. Grow the **Monitoring** Infrastructure and Link to Improved **Indicators and Goals**
5. Improve **Data** Coordination, Compatibility, Quality, Sharing, Access and Archiving
6. **Educate** Public and Build **Identity** for Defining Traits and Issues

The needs listed in Table 18 are described more fully below.

4.2.1. *Science and Management Linkages*

One point broadly articulated among scientists and resource managers at the 2005 Delaware Estuary Science Conference was that policy-making and management of environmental resources should be rooted in science. In the past, linkages among science, management and policy, and connections to restoration and community-based activities, have been hampered by a lack of coordination and insufficient funding. In addition, science and management in the Delaware Estuary is complicated by a diverse landscape of academic institutions and agency types, which must adhere to geopolitical boundaries that are markedly different from watershed boundaries.

Nationally and internationally however, the trend in environmental science is toward greater interdisciplinary partnering. In the Delaware Estuary, continued weak interaction among scientists and science-interested people from academia, agencies and other institutions will result in the status quo (at best) with little advancement toward the needs identified in this White Paper. At the Science Conference and IOOS Workshop it was broadly recognized that the lack of coordination and linkages between scientists and managers is largely responsible for our patchy understanding of the workings and distinguishing characteristics of our Estuary. It is also believed to be a principal reason for the disparate level of national funding allocated to the study and restoration of the Delaware Estuary, compared to other large, well-populated estuaries. Lastly, the lack of an organized science community has left us ill-prepared to deal with emergency situations in the Estuary that are associated with environmental and human health crises.

For these reasons, we must place highest priority on bridging the gap between science, management and policy so that we can work together to change public perceptions about the national significance and distinguishing traits of the Delaware Estuary. This in turn will ultimately translate into greater resources for all constituents of the scientific community. Numerous suggestions were made to promote greater communication among scientists, managers and policy-makers, such as by initiating more joint, common-ground partnerships, taking care to use complementary cross-references to the public and officials, and working together to broaden monitoring efforts. A more well-coordinated science and management community would also strengthen our emergency preparedness and Homeland Security capabilities.

4.2.2. *Conceptual Framework*

The Delaware Estuary is markedly different from other large American estuaries in terms of its physical, chemical and biological character. Hence, the principal science and management challenges here are not necessarily the same as in other mid-Atlantic systems such as Chesapeake Bay. As yet, we have not formulated a distinct, comprehensive, conceptual framework that describes the overall structure, function and management challenges for our estuary.

A comprehensive, integrated and ecologically-based monitoring framework that is attuned to the unique aspects and challenges of our system would be a tremendous asset for establishing policy and guiding management decisions. By being comprehensive across riverine, estuarine and coastal areas, and by linking physical-chemical-biological components, the framework will help discern data gaps, guide efforts to adapt existing monitoring programs to be more broad-based and representative of the whole system, and monitoring would better link to environmental indicators and goal-setting for State of the Estuary assessments (e.g., DELEP 2003). In addition, if the unique essence and workings of the Delaware Estuary can be defined in a simple conceptual model understandable by the public, this should generate greater enthusiasm and support for our environmental programs. This, in turn, would ultimately help raise national awareness and increased resources with which to study and manage the Estuary.

4.2.3. *Ecosystem Management*

New approaches are needed that adopt methodologies to manage at the ecosystem scale, rather than resource by resource. Ecosystem management is an integrated approach that considers the entire ecosystem including humans. It is adaptive and manages human activities in a manner that promotes a balanced coexistence of healthy fully functioning ecosystems and human communities. Ecosystem management must be rooted in a comprehensive, ecologically-based conceptual framework that captures the structural and functional essence and dominant components of the Delaware Estuary

(Section 4.2.2). This framework will further include an integrated set of principles, goals, objectives and procedures that together seek to ensure the co-existence of healthy, fully functioning ecosystems and human communities.

4.2.4. *Monitoring, Indicators and Goals*

Improvement in our monitoring capabilities is a fundamental need. Environmental conditions in the Delaware Estuary are currently monitored with numerous programs, as exemplified in Table 19. For some aspects of water quality and living resources, we are fortunate in having long-term datasets for the Delaware Estuary; e.g., DRBC "Boat Run" and Rutgers oyster surveys, respectively. It is imperative that these programs be continued to maintain the integrity of long-term monitoring data, which is increasingly viewed as critical for assessing status and trends. Monitoring programs should be broad-based, capturing functionally dominant components of the physical, chemical and biological ecosystem.

New indicators are needed that can be used to gauge the status and trends of ecologically significant species or critical habitats in the Delaware Estuary and watershed, such as riparian corridors, wetlands and reefs. Development of indicators and goals that capture the important elements of a commonly accepted conceptual framework and link to monitoring activities would have enormous value for environmental managers and education and outreach activities. This would also lead to improved State of the Estuary reports (e.g., DELEP 2003) that better link to scientifically meaningful measures of environmental condition. By emphasizing desired future conditions, this would also strengthen efforts to improve forecasting capabilities and link science to policy outcomes. Indicators and goals should be appropriate and representative of the functional dominant resources or processes outlined in the conceptual framework, and monitoring efforts should link to these as well.

As discussed below, PDE and DRBC are currently working to strengthen coordination and further broaden existing monitoring activities. One important element of this will be efforts to improve the existing monitoring infrastructure, including more real-time monitoring and state of the art technology affixed to bridges, lighthouses, water intake structures (power plants), ferries and other movable systems. A monitoring system for basic measures (temperature, salinity, flow) could be initiated fairly cheaply. Multi-entity proposals are currently being developed to advance these interests as the Delaware Estuary Watershed to Ocean Observing System (DEWOOS).

4.2.5. *Data Issues*

From the conception of the Estuary Program and the CCMP, science has played an important role in determining courses of action, however the pursuit and management of scientific information has often occurred in an uncoordinated fashion leading to data gaps and datasets that are incomparable. A variety of data-related problems currently challenge scientists and managers. These include a lack of data coordination, integration, comparability, quality, archiving, and access. Specific examples and more thorough descriptions are provided in Section 3.

Table 19. Examples of monitoring programs in the tidal Delaware Estuary.

Program	Purpose
National Coastal Assessment (EPA)	Provide data on sediment contaminants, sediment toxicity, water quality, and biological components such as fish and benthic organisms
Estuary Boat Run (DRBC)	Assess compliance with water quality standards for conventional pollutants, metals and volatile organics; develop and calibrate water quality models for conventional and toxic pollutants
Total Maximum Daily Loads (TMDL)	Collect, analyze and assess air, ambient water, sediment and tributary samples for contaminants of concern for TMDL efforts
Automated Dissolved Oxygen Monitoring	Assess water quality standards and provide data to assess fishable/swimmable levels
Automated Specific Conductance Monitoring	Provide data to track salt front and regulate reservoir releases
Groundwater and Surface Water Flow Monitoring	Provide data for regulating river flows and groundwater usage
Groundwater and Surface Water Use Inventory	Monitor consumptive use of basin waters
Tidal Tributary Sampling Program	Assess compliance with water quality standards for conventional pollutants at 9 PA and 9 NJ tributaries
Sediment Surveys	Provide data on sediment concentrations of toxic pollutants for sediment quality models
National Status & Trends Mussel Watch (NOAA)	Provide data on temporal changes in levels of toxic chemicals in bivalve tissues at 8 lower estuary sites
Ambient Toxicity Surveys	Assess compliance with chronic whole effluent water quality standards
Fish Tissue Analysis	Assess impairment of fish consumption use by bioaccumulative pollutants

Data gaps are also widespread, particularly with regard to spatial coverage and long-term record-keeping. Better data coordination, through an IOOS-base network and other means, is becoming increasingly important as digital technologies and data management schemes become more diverse and central to managers.

A regional information node is needed for the Delaware Estuary, which could be operated and maintained by a web-linked partnership of agencies such as PDE, DRBC and IOOS. The information node would facilitate coordination and expansion of DEWOOS and would include web-accessible datasets and reports related to all natural resources throughout the Estuary, organized in a straightforward and comprehensive conceptual model (see above).

4.2.6. *Education and Public Identity*

Educational programs that lead to an improved understanding of the value of the Estuary for the public were identified as a critical operational need. Many facts about the Delaware Estuary that make it unique have received little national local, regional and national attention. It is still falsely assumed that the issues and ecology of the Delaware Estuary closely resemble those of Chesapeake Bay. Furthermore, some of the most notable physical, chemical and biological aspects of the Delaware Estuary continue to be unheralded and unmonitored. There is a need to educate all groups about the history of the system, and the basic working components of the current system.

5. A Blueprint for Addressing Science Needs

Considerable work is being done at present, but with little coordination. No one agency or group has been charged with providing comprehensive scientific and technical oversight that considers linkages among hydrodynamics, water quantity and quality, habitats and living resources, etc. There is a wide spectrum of differing missions, agendas and politics at the various academic, governmental, non-profit, corporate and public groups in the Estuary. For example, the Delaware Estuary is governed by multiple states and different federal sub-regions. The academic and resource management communities have often been disassociated, and although the Delaware Estuary supports considerable industry and is home to one of the largest port complexes in the country, few commercial interests are engaged in or are invited to participate in the scientific and technical community.

As widely discussed at the Science Conference, this lack of coordination has contributed to the following problems:

- Inefficient and poorly linked programs that are often in competition for limited resources, and/or are attending to vastly different needs and agendas;
- Failure to develop an integrated conceptual framework that captures the principal components that define the essence and workings of the system;
- Limited development of science-based environmental indicators;
- Inability to set meaningful environmental goals that bridge science and policy;
- Lack of public and national awareness for the importance and uniqueness of the system, and consequently;
- Poor overall support and funding for science and environmental resource management, compared to other large estuaries.

To help address these problems, The Partnership for the Delaware Estuary (PDE) intends to lead by facilitating and strengthening science coordination and marshalling resources to address these critical shortcomings. Building on the momentum from its 2004 reorganization and the 2005 Science Conference, PDE is now working with leading scientists and key partners such as the Delaware River Basin Commission, EPA, Delaware, New Jersey, Pennsylvania, and numerous federal partners to take numerous short- and long-term measures, as outlined below. These science-themed initiatives will figure prominently in a strategic planning effort being completed by PDE in 2006.

5.1 Science Coordinator

A Delaware Estuary Science Coordinator was hired to convene and attend science and technical conferences, foster dialogue among various scientists and institutions, attend and operate advisory committees and technical workgroups, and otherwise work with partners to identify and fill critical science needs.

5.2 Ecosystem Matrix

To ensure that science needs are addressed in a comprehensive and inclusive manner, PDE has developed a 141 cell matrix table that summarizes the principal habitats and ecosystem components of the Delaware Estuary (Table 20). In prioritizing needs and actions to be taken with regard to science, policy and restoration, the scientific community is encouraged to consider the context within this conceptual framework. Where possible, needs and actions should address as many matrix cells as possible, strengthen linkages and balance among cells, and work to fill data gaps and project inequity among cells where we know the least. By calculating the percentage of cells that are addressed, this matrix table can serve as a tool to gauge the comprehensiveness of a specific science and management action.

5.3 Science and Technical Advisory Committee (STAC)

There was broad consensus among the more than 250 scientists, managers and policy-makers at the Science Conference that PDE needs to reform the STAC to provide critical guidance and peer review for programmatic activities, help assemble ad hoc workgroups to address emerging issues, build on our comprehensive assessment of the Estuary's natural communities, and to guide development of thematic workshops and conferences that provide mechanisms for information exchange and networking. The first order of business for the STAC will be to provide specific recommendations for addressing the top science and management needs identified in Section 4.

5.4 Technical Workgroups

To move forward on specific science and management needs, the STAC will provide guidance and oversight for the formation and disbanding of technical workgroups (TWGs) on an ad hoc basis. Formation of new workgroups will be prioritized to address needs that are underrepresented by technical committees that already exist. As one example, a Wetlands Science Workgroup is planned to assess status and trends of wetlands and adjacent upland buffers. As one of the most identifiable environmental assets in the Estuary, tidal wetlands exemplify a resource that merits more proactive and coordinated scientific analysis, policy attention, and community awareness. Additional TWGs will be created and operated to address other top needs as resources allow. Where existing workgroups and committees are already actively working to address specific needs (e.g., Delaware River Basin Fish and Wildlife Management Cooperative, Toxics Advisory Committee), the STAC will contribute peer review where appropriate and strive to foster greater communication and networking among workgroups. All existing and new workgroups and committees will be charged with offering specific recommendations to the STAC, PDE and program partners on how best to address the top science and management needs identified in Section 4.

Table 20. A conceptual matrix framework summarizing the principal ecosystem and habitat components of the Delaware Estuary. The cell numbering is arbitrary and meant to give a unique reference point to every cell.

Conceptual Matrix for the Delaware Estuary Ecosystem																			
Number of Cells = 141			**Nontidal Watershed**					**Tidal Estuary**											
			Freshwater					**Freshwater** (<1 ppt)				**Brackish** (1-8 ppt)				**Bay** (>8 ppt)			
			Delaware River (above River Mile 133)		**Other Rivers and Streams** (below River Mile 133)			Approximately River Mile 82 to 133				Approximately River Mile 58 to 82				Approximately River Mile 0 to 58			
			Main Channel	Tributaries to Delaware River (e.g., Lehigh)	Schuylkill River & Its Tributaries	Christina River & Its Tributaries	Other Tributaries	Main Channel	Shallow Subtidal	Intertidal Edges, Shorelines	Wetlands	Main Channel	Shallow Subtidal	Intertidal Edges, Shorelines	Wetlands	Main Channel	Shallow Subtidal	Intertidal Edges, Shorelines	Wetlands
Aquatic	**Pelagic**	Physical	1a	2a	3a	4a	5a	6a	7a	8a	9a	10a	11a	12a	13a	14a	15a	16a	17a
		Chemical	1b	2b	3b	4b	5b	6b	7b	8b	9b	10b	11b	12b	13b	14b	15b	16b	17b
		Biological	1c	2c	3c	4c	5c	6c	7c	8c	9c	10c	11c	12c	13c	14c	15c	16c	17c
	Benthic	Physical	1d	2d	3d	4d	5d	6d	7d	8d	9d	10d	11d	12d	13d	14d	15d	16d	17d
		Chemical	1e	2e	3e	4e	5e	6e	7e	8e	9e	10e	11e	12e	13e	14e	15e	16e	17e
		Biological	1f	2f	3f	4f	5f	6f	7f	8f	9f	10f	11f	12f	13f	14f	15f	16f	17f
Terrestrial	**Tidal Buffers***									8g	9g			12g	13g			16g	17g
	Riparian Buffers**		1h	2h	3h	4h	5h												
	Watershed Uplands**		1i	2i	3i	4i	5i			8i	9i			12i	13i			16i	17i
Socioeconiomic			1j	2j	3j	4j	5j	6j	7j	8j	9j	10j	11j	12j	13j	14j	15j	16j	17j

** Tidal buffers refer to upland areas immediately adjacent to tidal wetlands and shorelines that are at an elevation of less than 2 m above mean high tide. These are areas most susceptible to sea level rise and most important for managing the landward migration of shorelines and wetlands.*

*** Terrestrial areas are distinguished as being either riparian zone habitat (here termed "riparian buffers") or watershed uplands, which is here taken to include forests, meadows, and developed lands. The width of the riparian buffer will depend on the data source, with preference for the most widely adopted standards.*

5.5 Website

The ability to share information in a timely manner is critical. Recognizing the need to develop a centralized more comprehensive information clearinghouse for the Estuary, PDE is redesigning its website, www.delawareestuary.org to meet that need. The redesign includes a comprehensive interactive section dedicated to the science needs and will provide a portal to other partners and Estuary related activities, i.e. IOOS, DRBC, etc.

5.6 Funding Mechanisms

To ensure propagation and self-sufficiency of these initiatives and to provide a mechanism for addressing specific technical and scientific needs, PDE is working to conceive and develop a sustainable new fund for science.

5.7 Science Conference

Recognizing the critical importance of bringing together the various science and resource management partners in the Estuary on a regular basis, the Partnership intends to host a Science Conference every two-three years. In addition, the White Paper will be updated every five years or as warranted. This will ensure that current information is exchanged and priority needs are refreshed on a predictable cycle.

5.8 Summary

This blueprint is designed to be science-based, adaptive and realistic. Nationally and internationally, the scientific community is being called upon to provide the basis for making informed decisions in environmental resource management and policy. Many of the challenges faced by resource managers and planners are complex, and effective environmental science is increasingly multidisciplinary and proactive. At the same time, we must overcome real world impediments such as tight budgets and lingering institutional cultures that focus on the study of specific fields using dated approaches.

The blueprint for addressing the science needs of the Delaware Estuary must therefore be realistic until the funding climate and scientific culture begin to undergo a paradigm shift. The approach being adopted by PDE and partners is to carefully prioritize science needs that are identified, fill key data gaps, and to provide unbiased peer review. Specific needs will be addressed using a flexible structure whereby technical workgroups of experts can be formed and disbanded as needs and resources dictate. Furthermore, an iterative process is planned whereby science needs are revisited, discussed, and re-parameterized every two years using the bi-annual science conference as a driver.

Looking to the future, a key ingredient to the success of this blueprint will be the continued active participation by all of the scientists and science-interested parties in the Estuary. We challenge the scientific community to continue to work together to define and redress critical science needs. A more unified scientific community will be better positioned to work together proactively to discuss current and emerging topics and strengthen our capability to respond to issues of special concern. The November 2004 oil spill provided a case study for how coordination of local scientists and scientific information could be improved.

To facilitate interaction, dialogue and information exchange, between conferences and meetings, PDE has created a new science hub at their website to provide a central point for continual contact. With increasing interaction and dialogue among members of the science and management community, we expect to build enthusiasm for a common conceptual framework that will highlight the distinguishing aspects of the Delaware Estuary. As this special character is increasingly translated to the public and elected officials, we expect the national identity of the Delaware Estuary to be strengthened, leading to greater parity in science funding for this vital system compared to other large estuaries in the United States.

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7. List of Acronyms

APFO	Ammonium Perfluorooctanoate (a.ka. "C-8")
C	Carbon
CCMP	Comprehensive Conservation and Management Plan
DBOS	Delaware Bay Observing System
DDT	DichloroDiphenylTrichloroethane (compound has been renamed)
DE	Delaware
DELEP	Delaware Estuary Program (currently is PDE)
DEWOOS	Delaware Estuary Watershed to Ocean Observing System
DO	Dissolved Oxygen
DOM	Dissolved Organic Matter
DRBC	Delaware River Basin Commission
EDC	Endocrine Disrupting Compound
EPA	Environmental Protection Agency
GIS	Geographic Information System
IBI	Index of Biotic Integrity
IOOS	Integrated Ocean Observing System
LIDAR	LIght Detection And Ranging
MACOORA	Mid-Atlantic Coastal Ocean Observing Regional Association
MSX	Multinucleated Sphere X (a haplosporidium)
N	Nitrogen
NCA	National Coastal Assessment
NJ	New Jersey
NOAA	National Oceanographic and Atmospheric Administration
NJDEP	New Jersey Department of Environmental Protection
NRDA	Natural Resources Damage Assessment
NS&T	National Status and Trends
NWQMN	National Water Quality Monitoring Network
P	Phosphorus
PA	Pennsylvania
PAH	Polycyclic Aromatic Hydrocarbon
PBDE	Polybrominated Diphenyl
PCB	Polychlorinated Biphenyl
PDE	Partnership for the Delaware Estuary
PFOA	Perfluorooctanoic Acid
PPCP	Pharmaceutical and Personal Care Product
PSEG	Public Service Electric Gas Company
SAV	Submerged Aquatic Vegetation
STAC	Science and Technical Advisory Committee
TAC	Toxics Advisory Committee
TBT	Tributyltin
TMDL	Total Maximum Daily Load
TWG	Technical Workgroup

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