EPA-SAB-14-xxx

The Honorable Gina McCarthy
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: SAB Review of the Draft EPA Report *Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence*

Dear Administrator McCarthy:

The EPA's Office of Research and Development (ORD) requested that the Science Advisory Board (SAB) review the draft report titled *Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence (September 2013 External Review Draft)* ("Report"). The Report is a review and synthesis of the peer-reviewed literature on the connectivity or isolation of streams and wetlands relative to large water bodies such as rivers, lakes, estuaries, and oceans. The Report was developed by ORD to summarize the current scientific understanding of connectivity to inform EPA and U.S. Army Corps of Engineers rulemaking related to the jurisdiction of the Clean Water Act.

In response to the EPA's request, the SAB convened an expert panel to review the Report. The SAB was asked to comment on the clarity and technical accuracy of the Report; whether it includes the most relevant peer-reviewed literature; whether the literature has been correctly summarized; and whether the findings and conclusions are supported by the available science. The enclosed report provides the SAB's consensus advice and recommendations.

The EPA Report is a thorough and technically accurate review of the literature on the connectivity of streams and wetlands to downstream waters. The SAB agrees with two of the three major conclusions in the Report. The SAB finds that the review of the scientific literature strongly supports the conclusions that streams and "bidirectional" floodplain wetlands are physically, chemically, and/or biologically connected to downstream navigable waters; however, these connections should be considered in terms of a connectivity gradient. The SAB recommends revisions to improve the clarity of the Report, better reflect the scientific evidence, expand the discussion of approaches to quantifying connectivity, and make the document more useful to decision-makers. The SAB disagrees with the conclusion that there is insufficient information available to generalize about the connectivity of wetlands in "unidirectional," non-floodplain settings. In that case, the SAB finds that the scientific literature supports a more definitive statement that reflects how numerous functions of non-floodplain wetlands sustain the physical, chemical, and/or biological integrity of downstream waters, although the degree of connectivity can vary widely. The SAB's major comments and recommendations are provided below.

- The Report often refers to connectivity as though it is a binary property (connected versus not connected) rather than as a gradient. In order to make the Report more technically accurate, the SAB recommends that the interpretation of connectivity be revised to reflect a gradient approach that recognizes variation in the frequency, duration, magnitude, predictability, and consequences of those connections. The SAB notes that relatively low levels of connectivity can be meaningful in terms of impacts on the chemical, physical, and biological integrity of downstream waters.

- The SAB recommends that the EPA consider expanding the brief overview of approaches to measuring connectivity. This expansion would be most useful if it provided examples of the dimensions of connectivity that could most appropriately be quantified, ways to construct connectivity metrics, and the methodological and technical advances that are most needed.

- The Report presents a conceptual framework that describes the hydrologic elements of a watershed and the types of connections that link them. The literature review supporting the framework is technically accurate and clearly presented. However, to strengthen and improve its usefulness, the SAB recommends that the framework be expressed as spatially continuous physical, hydrological (surface and subsurface), chemical, and biological flowpaths that connect watersheds. The water body classification system used in the Report (i.e., classification of waters according to landscape settings) should be integrated into the flowpath framework to show that continuous phenomena interact across landscape settings. In addition, the SAB recommends that each section of the Report be clearly linked to the conceptual framework.

- The SAB recommends that the Report more explicitly address the scientific literature on cumulative and aggregate effects of streams, groundwater systems, and wetlands on downstream waters. In particular, the Report should contain a discussion of the spatial and temporal scales at which streams, groundwater systems, and wetlands are functionally aggregated. The SAB also recommends that, throughout the Report, the EPA further discuss several important issues including the role of biological connectivity, biogeochemical transformation processes, and the effects of human alteration of connectivity.

- In the Report, the EPA has classified waters and wetlands as having the potential for either "bidirectional" or "unidirectional" hydrologic flows with rivers and lakes. The SAB finds that these terms do not adequately describe the four-dimensional (longitudinal, lateral, vertical, and temporal) nature of connectivity, and the SAB recommends that the Report use more commonly understood terms that are grounded in the peer-reviewed literature.

- The SAB commends the EPA for the comprehensive literature review in the Report, although additional citations have been suggested to strengthen it. To make the review process more transparent, the EPA should more clearly describe the approach used to screen, compile, and synthesize the information. The EPA should also note differences between the scientific terms and definitions used in the literature review and regulatory terminology.

- The SAB finds that the review and synthesis of the literature describing connectivity of streams to downstream waters reflects the pertinent literature and is well grounded in current science. The literature review provides strong scientific support for the conclusion that ephemeral, intermittent, and perennial streams exert a strong influence on the character and functioning of downstream waters and that tributary streams are connected to downstream waters. However, the EPA should recognize that there is a gradient of connectivity. The SAB also recommends that the literature review more thoroughly address hydrologic exchange flows between main channels and off-channel areas, the influence of stream connectivity on downstream water temperature, and the movement of organisms throughout stream systems to use critical habitats.

- The SAB finds that the review and synthesis of the literature on the connectivity of waters and wetlands in floodplain settings is somewhat limited in scope (i.e., focused largely on headwater riparian wetlands) and should be expanded. However, the literature review does substantiate the conclusion that floodplains and waters and wetlands in floodplain settings support the physical, chemical, and biological integrity of downstream waters. The SAB recommends that the Report be reorganized to clarify the functional role of floodplain systems in maintaining the ecological integrity of streams and rivers and that the Report more fully reflect the literature on lateral exchange between floodplains and rivers.

- The SAB finds that, in general, the review and synthesis of the literature on the connectivity of non-floodplain ("unidirectional") waters and wetlands is technically accurate. However, additional information on biological connections should be included. The SAB has provided numerous additional literature citations addressing the roles of multiple biological taxa in this regard, such as transporting propagules and nutrients and providing critical habitat.

- The SAB disagrees with the EPA's conclusion that the literature reviewed did not provide sufficient information to evaluate or generalize about the degree of connectivity (absolute or relative) or the downstream effects of wetlands in "unidirectional" non-floodplain landscape settings. The SAB finds that the scientific literature supports a more definitive statement about the functions of "unidirectional" non-floodplain wetlands that sustain the physical, chemical and/or biological integrity of downstream waters. In this regard, the SAB recommends that the EPA revise the conclusion to better articulate: (1) what is supported by the scientific literature and (2) the issues that still need to be resolved.

The SAB appreciates the opportunity to provide the EPA with advice on this important subject. We look forward to receiving the agency's response.

Sincerely,

NOTICE

U.S. Environmental Protection Agency
Science Advisory Board
Panel for the Review of the EPA Water Body Connectivity Report

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1. EXECUTIVE SUMMARY

The National Center for Environmental Assessment in the EPA Office of Research and Development (ORD) has developed a draft report titled *Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence (September 2013 External Review Draft).* The draft report (hereafter referred to as the "Report") is a review and synthesis of the peer-reviewed scientific literature on the connectivity or isolation of streams and wetlands relative to large water bodies such as rivers, lakes, estuaries, and oceans. The purpose of the Report is to summarize the current understanding of these connections, the factors that influence them, and the mechanisms by which connected waters affect the function or condition of downstream waters. The Report was developed by ORD to summarize the current scientific understanding of connectivity to inform EPA and U.S. Army Corps of Engineers rulemaking related to the jurisdiction of the Clean Water Act. The Report is a scientific review and, as such, it does not set forth legal standards for Clean Water Act jurisdiction.

The literature review and synthesis in the Report focuses on describing: (1) a conceptual framework that represents the hydrologic elements of a watershed, the types of physical, chemical and biological connections that link them, and the watershed climatic factors that influence connectivity at various spatial and temporal scales; (2) the downstream connectivity and effects of ephemeral, intermittent, and perennial streams; (3) the downstream connectivity and effects of waters and wetlands in floodplain settings; and (4) the downstream connectivity and effects of waters and wetlands in non-floodplain settings. Six case studies from the literature are included in the report to illustrate the connectivity of water bodies in different landscape settings and geographic regions.

The EPA asked the SAB to review the Report and comment on: the clarity and technical accuracy of the document; whether it includes the most relevant peer-reviewed literature; whether the literature has been correctly summarized; and whether the findings and conclusions in the Report are supported by the available science. This Executive Summary highlights the findings and recommendations of the SAB in response to the charge questions provided in Appendix A.

Overall Clarity and Technical Accuracy of the Report

The SAB was asked to provide its overall impressions of the clarity and accuracy of the Report. The SAB finds that the Report is an extensive review of the literature on the connectivity of streams and wetlands to downstream[1] waters that is generally thorough and technically accurate. However, the Report could be strengthened by careful editing to ensure that it is more clearly organized, concise, and written in a consistent style. Some terms and definitions are not used consistently throughout the document. The SAB has proposed a revised conceptual framework which describes the hydrologic elements of a watershed and the connections that link them, and recommends that it be used to integrate the entire Report. Each section of the document should be clearly linked to this framework. In addition, the key points in each chapter of the Report should be clearly stated at end of the chapter and the EPA

[1] In this SAB report, the term "downstream" is used to refer broadly to connectivity that is both downstream and downgradient. All water (e.g., surface water, hyporheic flows, and groundwater) flows downgradient toward lesser hydraulic head than at the point of origin or point of interest. For most surface water flows, downgradient is also downstream. Sometimes the term "downgradient" is used in this report to emphasize instances where hyporheic and groundwater flows are especially important.

should consider including in the Executive Summary a succinct table summarizing all of the key findings and the levels of certainty that could be associated with the findings. The EPA should also consider summarizing and displaying the conclusions in the Report in matrix form with brief characterizations of the temporal and spatial scales over which given functions or phenomena occur. In addition, the SAB recommends that the conclusions be more empirically and/or specifically described by providing a clearer indication of the breadth of support in the literature.

The Report is a science, not policy, document that was written to summarize the current understanding of connectivity or isolation of streams and wetlands relative to large water bodies such as rivers, lakes, estuaries, and oceans. Given the policy context, however, the Report could be more useful to decision-makers if it brought more clarity to the interpretation of connectivity, especially with respect to approaches for quantifying connectivity. The language used in the Report often suggests that connectivity is a binary property (connected versus not connected) rather than a gradient. The SAB recommends that the interpretation of connectivity be revised to reflect a gradient approach that recognizes variation in the frequency, duration, magnitude, predictability, and consequences of connections. Moreover, relatively low levels of connectivity can be meaningful in terms of impacts on the chemical, physical, and biological integrity of downstream waters. The SAB also recommends that the Report more explicitly address the cumulative effects of streams and wetlands on downstream waters and the spatial and temporal scales at which functional aggregation should be evaluated.

The literature review in the Report could be strengthened by including additional citations and more clearly describing the approach used to screen, compile, and synthesize the information and by including additional references provided by the SAB. The SAB finds that the case studies in the Report provide helpful illustrations of the connectivity of streams and wetlands in certain geographic areas to downstream waters. However, the case studies would be more useful if they were selected to represent geographically relevant examples of systems spanning the connectivity gradient. It also would be helpful to present the case studies more succinctly in text boxes throughout the document.

Clarity and Technical Accuracy of the Conceptual Framework in the Report

The SAB was asked to comment on the clarity and technical accuracy of the conceptual framework of watershed structure and function presented in the Report. The literature review supporting the conceptual framework is technically accurate but the SAB recommends some revisions to improve the clarity, accuracy, and usefulness of the framework. The SAB recommends clearly delineating the Report's scope in terms of the types of wetlands and water bodies covered and focusing on functional roles of floodplains and riparian areas irrespective of their classification as waters and wetlands under the Clean Water Act. Connectivity should be defined at the beginning of the Report. The SAB recommends that this definition be systems-focused and, as such, include connections within and among entire watersheds and underlying aquifers. Different descriptors of connectivity drawn from the literature on disturbance ecology (e.g., frequency, magnitude) also might be helpful. The SAB also recommends expanding the discussion in the Report on approaches to measuring or otherwise quantifying connectivity.

The SAB recommends that the conceptual framework in the Report be expressed as continuous physical, hydrological (surface and subsurface), chemical, and biological flowpaths connecting landscapes. The framework should illustrate the importance of climate, geology, and topographic relief on flow and transport and highlight the four-dimensional (longitudinal, lateral, vertical, and temporal) nature of connectivity. In the Report, the EPA discusses connectivity within a classification system based on discrete landscape settings (i.e., rivers and streams; waters and wetlands in floodplain settings; and waters and wetlands in non-floodplain settings). The SAB recommends that this classification system be mapped onto the flowpath framework to show that continuous phenomena interact across these discrete landscape settings. There should be more emphasis in the conceptual framework on the importance of groundwater mediated connectivity and biological connectivity. Additional layers of complexity also should be included in the conceptual framework to reflect important issues such as spatial and temporal scales and human alteration of the hydrological landscape.

In the conceptual framework, the EPA has classified waters and wetlands based on their potential to have "bidirectional" or "unidirectional" hydrologic flows with rivers and lakes. Some "unidirectional" wetlands are also called "geographically isolated wetlands." However, the terms "bidirectional" and "unidirectional" do not adequately describe the four-dimensional nature of connectivity and therefore should be replaced with more commonly understood terms that are grounded in the peer-reviewed literature (e.g., waters and wetlands in floodplain settings). The term "geographically isolated wetlands" is misleading because connectivity occurs along a gradient. Therefore, the SAB recommends that the EPA carefully define "geographically isolated wetlands" in terms of the literature, explain that the term does not imply functional isolation, and then further explain that "geographically isolated wetlands" will not be used as an organizational term in Report. In addition, the SAB recommends that a summary and synthesis of the conceptual framework be added to the end of Chapter 3 of the Report.

Ephemeral, Intermittent, and Perennial Streams: Review of the Literature

The SAB was asked to comment on whether the Report includes the most relevant literature on the connectivity and effects of ephemeral, intermittent and perennial streams and whether the literature has been correctly summarized. The Report contains an extensive review of the scientific literature describing the connectivity of streams to downstream waters. However, further discussion of the literature on several specific topics is warranted. The Report should be expanded to include a more complete discussion of temporal dynamics of connectivity of streams as well as the processes involved in hydrologic exchange flows between main channels and off-channel areas. The discussion of naturally occurring chemical constituents, contaminants, contaminant transformation processes, and the influence of stream connectivity on downstream water temperature also should be expanded. In addition, the Report should more thoroughly document the evidence that the biological integrity of headwater streams and downstream waters is affected by the movement of biota throughout the lotic system. Other important topics that should be further discussed include: the consequences of human alteration of headwater streams; aggregate and cumulative effects of headwater streams on downstream waters; the effects of streamside vegetation on stream ecosystems; the importance of reciprocal food-web linkages between streams and their adjacent riparian areas; the role of groundwater and sediments in determining connectivity; and the degree or strength of downstream connections.

Ephemeral, Intermittent, and Perennial Streams: Review of the Findings and Conclusions

The SAB was asked to comment on whether the conclusions and findings concerning the connectivity of ephemeral, intermittent, and perennial streams are supported by the available science. The Report concludes that these streams exert a strong influence on the character and functioning of downstream waters, and indeed and that all tributary streams are physically, chemically, and biologically connected to downstream waters. Strong scientific support has been provided for this overall conclusion and related findings. The SAB notes that there is a gradient of connectivity that is a function of the frequency, duration, magnitude, predictability, and consequences of physical, chemical and biological processes. The SAB recommends that the conclusions and findings concerning ephemeral, intermittent, and perennial streams be quantified when possible, related to the four dimensions of connectivity (longitudinal, lateral, vertical and temporal), and discussed with additional detail on biogeochemical transformations and biological connections. In addition, some hydrologic aspects of connectivity require additional detail; these include descriptions of key linkages and exchanges in tributary streams, such as groundwater-surface water interactions, and the role of transition areas between uplands and headwaters. Likewise, the Report should explain how hydrologic connectivity sustains both streams and aquifers, particularly in alluvial systems in the Southwest and in karst systems in the eastern United States. Selecting specific case studies to represent the gradient of connectivity and articulating the rationale for choosing the case studies would also help ensure that the keys points are well illustrated.

Waters and Wetlands in Floodplain Settings: Review of the Literature

The SAB was asked to comment on whether the Report includes the most relevant literature on the connectivity and effects of waters and wetlands in floodplain settings and whether the literature has been correctly summarized. The SAB finds that the literature review substantiates the Report's conclusion that floodplains and waters and wetlands in floodplain settings support the physical, chemical and biological integrity of downstream waters. That said, the literature review and synthesis on the connectivity and downstream effects of waters and wetlands in floodplain settings is somewhat limited in scope (i.e., focused largely on headwater riparian wetlands) and should further consider the frequency, magnitude, duration, predictability, and consequences of connectivity pathways. This section should be expanded to include the following topics: channel migration zones (which demonstrate the variable nature of connectivity of floodplains); the importance of lateral connections that support the biological integrity of downstream waters by creating a diversity of habitats for a wide array of species; and human impacts on connectivity. A more recent and diverse review of the biogeochemical implications of exchange flow (including the literature on the role of wetlands and floodplains as sources, sinks and transformers of nutrients and other chemical contaminants) should be included in the Report.

The SAB also recommends that the examples used in the Report be broadened to make it more representative of the United States. In particular, studies on peatlands in floodplain settings in northern tier states and Alaska, forested wetlands (including bottomland hardwoods), and coastal lowland wetlands in Hawaii could be incorporated. In addition, the functional role of floodplain systems in maintaining the ecological integrity of streams and rivers would be clearer if the literature on floodplain wetlands were reorganized. The text on low-order riparian areas and the effects of headwater, streamside areas on in-stream structure and function could be moved to the chapter of the Report that addresses ephemeral, intermittent, and perennial streams.

The SAB suggests that the term "bidirectional wetlands" be replaced with the term "waters and wetlands in floodplain settings" to reflect landscape position. The Report should also more explicitly discuss how floodplain environments are intimately linked to river systems both spatially and temporally by means of flood pulses. In this regard, the importance of the short-duration, high-intensity and long-duration, low-intensity events should be compared and contrasted. In addition, the Report should emphasize the effects of floodplains not only on river flows, but also on hydrological connections and processes affecting biota, chemistry and sediment movement through downstream as well as lateral, vertical and temporal dimensions.

Waters and Wetlands in Floodplain Settings: Review of the Findings and Conclusions

The SAB was asked to comment on whether the conclusions and findings concerning the connectivity of waters and wetlands in floodplain settings are supported by the available science. The Report concludes that "bidirectional" wetlands and waters in floodplain settings are physically, chemically and biologically connected with rivers through multiple pathways. There is strong scientific support for this overall conclusion. However, additional literature could be included in the Report to bolster the conclusion and the related findings. Many of the conclusions and findings concerning waters and wetlands in floodplain settings are drawn from literature related to non-floodplain riparian wetlands (i.e., within headwater riparian zones).

A discussion of river-floodplain systems as integrated ecological units would be a useful addition to the Report, and the science of larger river (i.e., high-order) floodplain systems is a good starting point. The discussion of the findings and conclusions concerning waters and wetlands in floodplain settings should further address a number of other issues, including: the temporal dimension of connectivity of these waters and wetlands; the role of these waters and wetlands in storing and transforming chemical constituents; the role of biological connectivity (including food webs); quantification of groundwater linkages, the effects of human alteration of connectivity; and the importance of considering aggregate/cumulative downstream effects of these waters and wetlands. In addition, the SAB recommends that consistent terminology be used throughout the report to describe floodplain wetlands.

Waters and Wetlands in Non-floodplain Settings: Review of the Literature

The SAB was asked to comment on whether the Report includes the most relevant literature on the connectivity and effects of waters and wetlands in non-floodplain settings and whether the literature has been correctly summarized. In general, the EPA's review and synthesis of the literature on the downstream connectivity and effects of wetlands and waters in non-floodplain settings is technically accurate. The SAB recommends that the EPA consider reviewing and adding some additional literature. In particular, the SAB recommends reviewing publications that analyze bulk exchange of materials by biota, movement of nutrients by biota, introduction of disease vectors, and the provisioning of habitat essential for biological integrity and completion of life cycles of downstream species. Numerous additional literature citations addressing the role of multiple biological taxa have been provided by the SAB for the EPA's consideration. The review of the literature should also be expanded to include quantitative tools such as surface water quantity and quality modeling, sediment transport modeling, groundwater quantity and quality modeling, and biological/habitat/landscape modeling. These tools are used by hydrogeologists, watershed scientists and engineers to assess the structure and function of non-floodplain wetlands. The term "unidirectional wetlands" as used in the report is misleading because it implies one-way hydrologic flows when, in fact, connectivity can have many spatial and temporal dimensions. The SAB recommends that the terms "unidirectional" and "geographically isolated" waters and wetlands be replaced in the report; the term "non-floodplain waters and wetlands" is suggested as an alternative. The SAB also recommends that the EPA frame the discussion about the temporal and spatial scales and gradients of various connections between and among floodplain wetlands and non-floodplain wetlands and downstream waters by considering the frequency, magnitude, duration, predictability, and consequences of connectivity pathways. The Report also should recognize that all aquatic habitats have some degree of connection, although such connections may not be relevant if they do not have important effects on the physical, chemical, and/or biological integrity of downstream waters. In addition, the Report should discuss the importance of assessing non-floodplain wetland connectivity and connectivity pathways in terms of aggregated wetland complexes and the legacy effects of human disturbances.

Waters and Wetlands in Non-floodplain Settings: Review of the Findings and Conclusions

The SAB was asked to comment on whether the conclusions and findings concerning the connectivity of waters and wetlands in non-floodplain settings are supported by the available science. The Report concludes that the literature reviewed does not provide sufficient information to evaluate or generalize about the degree of connectivity (absolute or relative) or the downstream effects of wetlands in non-floodplain settings. The SAB disagrees with this overall conclusion. To the contrary, the SAB finds that the scientific literature provides ample information to support a more definitive statement (i.e., numerous functions of non-floodplain waters and wetlands have been shown to benefit the physical, chemical, and biological integrity of downgradient waters). Thus, the SAB recommends that the EPA revise the conclusion to focus on what is supported by the scientific literature and articulate the specific knowledge gaps that must be resolved (e.g., degree of connectivity, analyses of temporal or spatial variability). The SAB also recommends that the Report explicitly discuss the pathways by which non-floodplain waters and wetlands can be connected to downstream waters and state that the evaluation of connectivity should be based on the frequency, magnitude, duration, predictability, and consequences of water, material, and biotic fluxes to downstream waters and their impact on the physical, chemical, and/or biological integrity of those waters.

The SAB recommends several additional revisions to improve the findings concerning non-floodplain waters and wetlands. Reference to specific studies should be synthesized rather than individually reported, as they are intended to summarize general themes arising from the diverse literature. The key findings should be more explicitly presented and clearly explained in the text of the Report. In addition, the key findings should address: the biological functions and biological connectivity of non-floodplain wetlands; differences between natural and manmade wetlands; the importance and temporal dynamics of spatial proximity as a determinant of connectivity; and the importance of cumulative or aggregate impacts of non-floodplain wetlands.

2. INTRODUCTION

The National Center for Environmental Assessment in the EPA Office of Research and Development (ORD) has developed a draft report titled *Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence (September 2013 External Review Draft).* The draft report (hereafter referred to as the "Report") is a review and synthesis of the peer-reviewed scientific literature on the connectivity or isolation of streams and wetlands relative to large water bodies such as rivers, lakes, estuaries, and oceans. The purpose of the Report is to summarize the current understanding of these connections, the factors that influence them and the mechanisms by which connected waters affect the function or condition of downstream waters. The Report was developed by ORD to summarize the current scientific understanding of connectivity to inform EPA and U.S. Army Corps of Engineers rulemaking related to the jurisdiction of the Clean Water Act. The Report is a scientific review and, as such, it does not set forth legal standards for Clean Water Act jurisdiction.

The literature review and synthesis in the Report focus on describing: (1) a conceptual framework that represents the hydrologic elements of a watershed, the types of physical, chemical, and biological connections that link them, and the watershed climatic factors that influence connectivity at various spatial and temporal scales; (2) the downstream connectivity and effects of ephemeral, intermittent, and perennial streams; (3) the downstream connectivity and effects of waters and wetlands in floodplain settings; and (4) the downstream connectivity and effects of waters and wetlands in non-floodplain settings. Six case studies from the literature are included in the report to illustrate the connectivity of water bodies in different landscape settings and geographic regions.

The EPA asked the SAB to review the Report and comment on: the clarity and technical accuracy of the document, whether it includes the most relevant peer-reviewed literature, whether the literature has been correctly summarized, and whether the findings and conclusions in the Report are supported by the available science. In response to the EPA's request, the SAB convened an expert panel to conduct the review. The Panel held a public meeting on December 16-18, 2013 and teleconference meetings on April 28, May 2, and June 19, 2014 to deliberate on the charge questions and develop a consensus report. A large number of public comments were received for the SAB's consideration (Docket EPA-HQ-OA-2013-0582). During Panel deliberations a number of issues identified in the public comments were raised for discussion. The Panel's draft report was reviewed and discussed by the chartered SAB at a teleconference on [insert date]. This report provides the findings and recommendations of the SAB in response to the EPA charge questions (Appendix A). The SAB recommendations are highlighted at the end of each section of this report.

3. RESPONSES TO EPA'S CHARGE QUESTIONS

3.1. <u>Overall Clarity and Technical Accuracy of the Draft Report</u>

Charge Question 1. Please provide your overall impressions of the clarity and technical accuracy of the draft EPA Report, "Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence."

The EPA's Report is an extensive review of the literature that is generally thorough and technically accurate. That said, the Report could be improved with additional effort to: (1) ensure consistency and continuity in style and organization throughout the document; (2) improve the usefulness of the document to decision-makers; (3) strengthen the literature review in several key places; (4) provide further detail and clarification of concepts in some parts of the document; and (5) restructure the case studies. Each of these points is discussed below.

3.1.1 Style and Organization of the Draft Report

There are stylistic differences among the chapters of the Report, and the writing needs to be reworked for consistency and continuity so that it is written in a single voice. There also is a strong need to check for consistent use of terms and definitions among the chapters, subchapter sections, and the glossary. To prevent confusion, the EPA should avoid using words that may denote particular legal or regulatory meanings (e.g., significant, adjacent) unless a definition is provided. The Report is quite long and is repetitive in places, with the main points easily lost in the volume of material presented. Superfluous or redundant information should be removed, being careful that only concise text supporting the key findings is included. A technical editor could provide great support for this process.

Several organizational changes will improve the readability of the Report. First, each section of the Report should be clearly linked to and consistent with the conceptual framework. Second, each paragraph and/or subsection of the Report should have parallel structure where main points are clearly articulated at the end – perhaps even in bold or underlined text. Third, key points should be stated simply and directly at the end of each chapter. Fourth, the authors should consider including in the executive summary a succinct table that summarizes the key findings and levels of certainty of each finding within the Report. The report of the Intergovernmental Panel on Climate Change (IPCC 2007) is an excellent model for this approach.

Key Recommendations

- The Report should be edited to ensure that it is written in a consistent style and each section should be clearly linked to the conceptual framework.

- Terms and definitions should be used consistently throughout the Report and, to avoid confusion, caution should be exercised when using words that may have legal or regulatory meanings.

- Key points should be clearly stated at the end of each chapter and the EPA should consider including in the Executive Summary a succinct table summarizing the key findings and level of certainty associated with each.

3.1.2. Improving the Usefulness of the Report to Decision-Makers

Although the Report is a science, not policy, document, the SAB recognizes that it was written to inform the EPA's efforts to clarify the jurisdiction of the Clean Water Act. As such, the Report could be written in a more strategic manner that provides greater insight on complex or nuanced issues to be addressed in evaluating connectivity. For example, throughout the Report there could be greater focus on the literature that addresses various aspects of quantifying the frequency, duration, magnitude, predictability, and consequences of connectivity. The authors might consider an approach similar to that used in the report of the Intergovernmental Panel on Climate Change (IPCC 2007), which would provide an estimate of the relative certainty of connectivity or a downstream effect. As written, the Report uses language that often suggests that connectivity is a binary property – something either present or absent, rather than a gradient. Many of the public commenters remarked that the binary perspective in the Report implies that any connectivity must significantly affect the biological, physical, or chemical integrity of downstream[1] waters. Although connectivity is known to be ecologically important even at the lower end of the gradient, the frequency, duration, predictability, and magnitude of connectivity will ultimately determine the consequences to downstream waters.

The SAB also finds that the Report would be strengthened if it contained: (1) additional review of the scientific literature that quantifies the frequency, duration, predictability, and magnitude of hydrologic, chemical, and biological connections for each type of "water" and consequences of that connectivity for the physical, chemical, and biological integrity of downstream waters, with key uncertainties made explicit, and (2) a more explicit discussion of the cumulative effects of streams and wetlands on downstream waters (i.e., multiple streams and/or wetlands considered in aggregate) including a discussion of the spatial and temporal scales at which the functional aggregation should be evaluated.

Key Recommendations

- As further discussed in Section 3.8.1 of this report, the SAB recommends that the interpretation of connectivity be revised so as not to sound like a binary, categorical distinction (connected versus not connected) but rather a gradient whereby the consequences to downstream waters are determined by the frequency, duration, predictability, and magnitude of connections.

- The Report should explain how the definitions used for rivers, streams, and wetlands differ from those in the Clean Water Act and associated regulations and discuss any implications this might have for interpreting the conclusions.

3.1.3. Strengthening the Literature Review

The literature review in the Report can be strengthened by clarifying what was considered as peer-reviewed literature, the kinds of evidence used to support the findings and conclusions in the Report, and

[1] In this SAB report, the term "downstream" is used to refer broadly to connectivity that is both downstream and downgradient. All water (e.g., surface water, hyporheic flows, and groundwater) flows downgradient toward lesser hydraulic head than at the point of origin or point of interest. For most surface water flows, downgradient is also downstream. Sometimes the term "downgradient" is used in this report to emphasize instances where hyporheic and groundwater flows are especially important.

the number and types of studies selected for review. The approach used for screening, compiling, and synthesizing information should be made explicit. In particular, the "weight of evidence" approach used to evaluate multiple references should be described in more detail. The extent to which an exhaustive literature review was performed should be clearly stated in the Report. The SAB has provided numerous additional references for the EPA's consideration, and other references have been suggested in written comments from the public.

The SAB also finds that the EPA could better highlight gaps in the understanding of certain wetland and stream systems and/or geographic areas by including in the Report a table that shows the distribution of the scientific literature for various regions of the United States.

Key Recommendations

- The literature review in the Report should clearly describe the approach used to screen, compile, and synthesize the information and indicate: (1) what was considered to be peer-reviewed literature; and (2) the number and types of studies selected for review.

- EPA should consider including in the Report additional information from references provided by the SAB and members of the public.

3.1.4. Additional Detail and Clarification of Text Needed in the Report

As further discussed in other sections of this SAB report, the following topics in the EPA Report need clarification and/or additional detailed information:

a) *The importance and relevance of different spatial and temporal scales.* The EPA should discuss the relevant spatial and temporal scale for assessing connectivity in different water systems and the spatial scales and time frames over which wetlands are functionally aggregated. Understanding the spatial and temporal scales at which connectivity affects the physical, chemical, and biological integrity of downstream waters is central to evaluating and predicting connectivity and its consequences. The relevant scale of connectivity may be clarified by considering the most important consequences or problems over particular temporal and spatial scales.

b) *The extent to which biological connections among water systems affect the integrity of downstream waters.* The movement of birds, mammals, and other fauna (e.g., amphibians), among systems can mediate important material transfers to downstream waters. This movement can also be a critical source of organisms necessary to support viable populations and functions that contribute to ecological integrity of downstream waters. Biological connectivity should be evaluated across complete annual and full life cycles, as well as through food web interactions. Literature references concerning biological connectivity are provided in Appendix B and in other sections of this report.

c) *The necessity of adopting watershed, riverscape, riverine landscape, and groundwater basin perspectives to understand connectivity*. Viewing systems as part of these larger basins, riverscapes and watersheds permits a greater understanding of interactions and feedbacks with floodplain and riparian vegetation, groundwater and subsurface waters, and other surface water features that can ultimately impact downstream waters.

d) *The importance of considering water bodies in aggregate (e.g., groups of tributaries, floodplains, floodplain wetlands and non-floodplain wetlands) for evaluations of connectivity.*

e) *The role and temporal dynamics of groundwater, sediments, and chemical and biological parameters in establishing connectivity of water bodies.*

f) *The influence of human alterations on connectivity.* For example, human alterations that could affect connectivity in ways that impact the integrity of downstream waters can include directly eliminating, restoring, or altering connectivity via roads, agricultural tiles, dams, pumping groundwater, irrigation, channelization, and other manmade infrastructure (piped streams, stormwater pipes). Certain systems, such as those sustained by human wastewater effluents, are more closely tied to human alterations than others. Functions associated with these human-altered systems and their natural counterparts should be evaluated using the scientific literature.

g) *Approaches to assess or measure connectivity*. It would be useful to provide examples of the various dimensions of connectivity that are most appropriately quantified, ways to construct connectivity metrics (e.g., retrospective or prospective analyses, model simulations, spatial analyses), and the scientific, methodological, and technical advances most needed to understand and estimate connectivity

3.1.5. Restructuring the Case Studies

The SAB finds that the case studies in the Report provide helpful illustrations of connectivity between downstream waters and geographically specific types of systems. That said, case studies could be even more helpful if they were selected and organized to illustrate different points along the gradient of connectivity (i.e., less to more connected) and examples of different types of water bodies, including at least one where intermittent connectivity is important. As further discussed in Sections 3.3.9 and 3.5.6 of this report, it would be useful to include case studies representing a greater range of geographic regions and systems such as Southwest arid, Midwest mesic, arctic permafrost, human-modified systems, forested wetlands, and bottomland forests. As discussed in Section 3.2.5 of this report, comparisons among geographic regions could be accomplished by using climate, geology, and relief, which vary regionally and form the basis of the concept of Hydrologic-Landscape Regions (i.e., HLRs), as a framework for the case studies.

An alternative approach would be to present case study summaries as brief textboxes to clearly and simply articulate key points, with reference to the expanded versions in appendices, if deemed necessary. The rationale for selecting different case studies and the key points being illustrated by each should be explicitly stated early in the text. If expanded in the appendices, each case study could have a conceptual model diagram showing the surface and subsurface flowpaths illustrating the connectivity between/among systems.

Key Recommendations

- The rationale for selecting different case studies and the key points illustrated in each should be clearly stated early in the text.

- The EPA should consider distilling case studies into brief summaries presented in text boxes that: (1) provide short, clear illustrations of where different systems lie along the gradients of connectivity, and (2) highlight differences in the ecologically relevant temporal and spatial scales. The reader also should be able to see how the case studies align with hydrological, chemical, and biological flowpaths connecting watersheds (discussed in Section 3.2 of this SAB report). If expanded case studies are desired, these should be presented in the appendices. Case studies could serve to highlight areas of certainty in the EPA's conclusions as well as knowledge gaps.

- The EPA should consider including case studies of a greater range of geographic regions.

3.2. Conceptual Framework: An Integrated, Systems Perspective of Watershed Structure and Function

Charge Question 2. Chapter 3 of the draft Report presents the conceptual basis for describing the hydrologic elements of a watershed; the types of physical, chemical, and biological connections that link these elements, and watershed climatic factors that influence connectivity at various temporal and spatial scales (e.g., see Figure 3-1 and Table 3-1). Please comment on the clarity and technical accuracy of this Chapter and its usefulness in providing context for interpreting the evidence about individual watershed components presented in the Report.

The SAB finds that the literature review in Chapter 3 of the Report is technically accurate and readable, although it could be strengthened with technical editing. However, the conceptual framework needs to be revised and clearly articulated at the beginning of the chapter. As further discussed below, the SAB finds that the following revisions are needed to improve the clarity, accuracy, and usefulness of the conceptual framework in the Report: (1) connectivity should be clearly defined at the beginning of Chapter 3; (2) the scope of the Report (i.e., the types of waters and wetlands covered) should be clearly defined at the beginning of Chapter 3; (3) the conceptual framework should be expressed as hydrological, chemical, and biological flowpaths; (4) certain terms (e.g., "unidirectional" and "bidirectional") used in the Report should be replaced with more commonly understood terminology from the peer-reviewed literature; (5) additional layers of complexity (including a functional framework, spatial and temporal scales, the influence of human activities, the use of Hydrologic Landscape Regions, aggregate and cumulative effects, and map resolution) should be represented in the conceptual model; and (6) a summary and synthesis of the conceptual framework should be added at the end of Chapter 3.

3.2.1. Conceptual Framework

A typical conceptual framework is a concise tool used to make conceptual distinctions and organize ideas. The best conceptual frameworks draw simple analogies and are easy to remember. Although Chapter 3 of the Report certainly includes a great deal of information that supports a conceptual framework, the framework should be strengthened and made more explicit (see Section 3.2.3 below). In addition, the SAB recommends that the Chapter be retitled "An Integrated Systems Perspective of Watershed Structure and Function" to better reflect the content, which includes both the conceptual framework and attendant details that support the remainder of the Report.

3.2.2. Defining Connectivity and Isolation

Because "connectivity" and "isolation" can be defined in many ways, the Report must concisely define them at the beginning of Chapter 3. Currently, only connectivity is defined, but long after much of the conceptual framework has been presented and discussed (page 3-28). The definition of connectivity also should be extended to the entire landscape (i.e., not just to waters and wetlands but to entire watersheds and underlying aquifers) through a broader vision of local- to landscape-scale physical, chemical, and biological exchanges. The definition and discussion of connectivity at the beginning of Chapter 3 should be brief, with the many details and nuances addressed later. SAB concerns associated with EPA's definition and use of the term "geographically isolated wetlands" have been previously noted and are further discussed below.

The definition of connectivity used in the Report seems to follow that of Pringle (2001, 2003); i.e., the transfer of matter, energy, and/or organisms within or between elements of the landscape. The scientific literature shows that connectivity is a scalable quantity ranging continuously from fully connected to completely isolated, rather than a binary condition of either connected or isolated. The Report should articulate that connectivity is spatially and temporally scale dependent, and all elements of the landscape are connected when considered at sufficiently long temporal scales. Moreover, elements that appear isolated at one time (e.g., a dry season) might otherwise be connected at another time (e.g., during an intense rainstorm, during a wet season). This point could be expressed in a simple conceptual figure in Chapter 3, and then again as more specific figures in chapters on each water and wetland type covered in the Report (see, for example, Figure 3 in Section 3.7.3 of this report.)

If connectivity is defined as the condition resulting in a transfer of matter, energy, and/or organisms within or between elements of the landscape, which is scalable ranging from fully connected to fully isolated, then one might infer that true isolation requires absolutely no transfer of matter, energy, and/or organisms within or between elements of the landscape. This condition might be so rare as to be negligible, rendering the term isolation almost useless.

The definitions of connectivity and isolation might be clarified by drawing more upon the literature on quantitative metrics of connectivity, Ali and Roy (2010) and Larsen et al. (2012) and references therein, or alternatively from the literature on disturbance ecology (see Stanley et al. 2010 and references therein). Larsen et al. (2012) review many definitions of connectivity and associated metrics in hydrology and ecology beginning with the conceptual definition of Pringle (2001) and extending to more precise definitions that are more amenable to quantification. For example, Larsen et al (2012) define connectivity as transport or dispersal potential along a given direction in a patchy or complex landscape, which can be quantified by a directional connectivity index that varies between zero and one. A complementary viewpoint is apparent from the literature of disturbance ecology, given that disturbances change the physical, chemical, and/or biological environment and are commonly quantified in terms of physical measures of the disturbance itself (e.g., frequency, magnitude, duration). Predictability and the rate of change are often part of this definition (e.g., Resh et al. 1988; Poff 1992). By adding these details, connectivity and isolation could be viewed conceptually along a continuum ranging from fully connected to completely isolated, with a transition somewhere in between that varies case-by-case and is defined by whether or not a perturbation is outside the normal range and relevant to the biota.

Key Recommendations

- Connectivity and isolation should be defined and discussed at the beginning of Chapter 3 of the Report.

- The definition of connectivity in the Report should be extended to the entire landscape through a broad vision of local- to landscape-scale physical, chemical, and biological exchanges.

- The definition of connectivity and isolation could be clarified by connecting to literature on quantitative metrics of connectivity and disturbance ecology.

3.2.3. Measuring or Otherwise Quantifying Connectivity

The Report should discuss approaches to measuring or otherwise quantifying connectivity. Such approaches should recognize that connectivity is, in part, determined by the extent to which impacts to one water body will affect chemical, physical, and/or biological integrity of downstream waters. In addition, multiple dimensions of connectivity should be described as sources and mechanisms of transport and transformation (i.e., fluxes of water, material, biota) and associated ecological functions (e.g., lag, refuge, and transformation) manifest along multiple flowpaths (e.g., via surface water, the hyporheic zone, and groundwater). Moreover, assessments should occur at spatial and temporal scales that permit evaluation of the cumulative effects of connectivity over time and the aggregate effects of connectivity over space. Therefore, the EPA should consider expanding the brief overview of approaches to measuring connectivity that is provided on pages 6-6 and 6-7 of the Report. This expansion would be most useful if it provided examples of the dimensions of connectivity that are most appropriately quantified, ways to construct connectivity metrics (e.g., retrospective or prospective analyses, model simulations, spatial analyses), and the most needed methodological and technical advances.

Insights from Hydrologic Systems

Future efforts to quantify connectivity can be informed by the wide variety of conceptual models and quantitative tools that have been developed to evaluate the connectivity of both surface and subsurface hydrological systems in different settings, including non-floodplain wetlands. The standard approach involves first characterizing the surface and subsurface elements of landscapes. Important elements include climate, geology, topographic relief, and the amount, distribution and types of waters and wetlands. These elements can then be integrated to create a flowpath network that describes connectivity (Heath 1983; ASTM 1996; Kolm et al. 1996; Winter et al. 1998). This approach has been extended to biological connectivity and hydrogeomorphic (HGM) wetland classifications (e.g., Kolm et al. 1998). Of course, the approach to quantifying hydrologic connectivity is not identical across systems, and careful attention must be given to identifying the most appropriate techniques (Healy et al. 2007; Bracken et al. 2013) and metrics (Lexartza-Artza and Wainwright 2009; Ali and Roy 2010; Wainright et al. 2011; Larsen et al. 2012).

The Report also can draw on examples related to water quantity and quality modeling (Appel and Reilly 1994; Sun et al. 1997; Harbaugh 2005; Parkhurst et al. 2010; Cunningham and Schalk 2011), integrated surface water groundwater modeling (Markstrom et al. 2008; Ely and Kahle 2012; Huntington and Niswonger 2012; Woolfenden and Nishikawa 2014), sediment transport modeling (Nelson et al. 2003;

McDonald et al. 2005), and watershed and biological/habitat/landscape modeling (Kinzel et al. 1999; Kinzel et al. 2005; Hunt et al. 2013). Approaches have also been developed to quantify linkages due to groundwater movement and storage (Heath 1983) and the effects of "flood pulses" (Kolm et al. 1998). Likewise, the role of chemical movement and storage to groundwater systems in floodplains has been quantified by flow and transport modeling (Winter et al. 1998; Markstrom et al. 2008; Woolfenden and Nishikawa 2014) as well as with steady-state and transient analyses that simulate temporal changes (Appel and Reilly 1994; Winter et al. 1998; Nelson et al. 2003; Conaway and Moran 2004; Harbaugh 2005; McDonald et al. 2005; Markstrom et al. 2008; Huntington and Niswonger 2012).

A growing number of studies are using graph-theory-based indices of connectivity to better understand aquatic systems. These studies should be considered in developing the discussion of approaches to quantify connectivity. For example, Van Looy et al. (2013) used the Integral Index of Connectivity to quantify connectivity and habitat availability in a dendritic river network across varying spatial scales. Wainwright et al. (2011) demonstrated how responses of river systems to vegetation removal, runoff, and erosion were better predicted by measures of structural and functional connectivity. Other metrics integrate hydrological and ecological connectivity using the Directional Connectivity Index and connectivity-orientation curves, which effectively quantified physical-biological feedbacks in the Everglades (Larsen et al. 2012). Malvadkar et al. (2014) recently examined numerous metrics drawn from graph-theory, including Betweenness Centrality, Integral Index of Connectivity, Coincidence Probability, Eigenvector Centrality, Probability of Connectivity, and Influx Potential.

Connectivity also can be described using six metrics commonly used in hydrology and disturbance ecology – frequency, magnitude, timing, duration, rate of change, and predictability (e.g., Resh et al. 1988; Poff 1992; Poff et al. 1997). These can be defined in hydrological, chemical, or biological terms. For example, in hydrological terms, frequency describes how often a flow of a particular magnitude occurs, magnitude is the amount of water moving past a fixed location per unit time, duration is a measure of how long such a flow persists, and the rate of change is how quickly one flow gives way to another. These first five metrics comprise the components of the natural flow regime (Poff et al. 1997). The last metric, predictability, takes all of these into account (e.g., predictability of a given flow can be indicated by the presence or absence of flow-dependent biota).

The temporal and spatial predictability of connectivity is especially important to quantify when assessing potential for downgradient effects in systems without permanent or continuous flowpaths (e.g., Poff and Ward 1989; Lytle and Poff 2004; Poff et al. 2006). Predictability refers to the regularity at which certain flows occur. Some mechanisms of connectivity are predictable (e.g., migration of anadromous fish and waterfowl, spring flood pulses and late summer low flows, seasonal peaks of aquatic insect emergence), whereas others are less so (e.g., flood events from storms, short-term and/or stochastic movement of organisms, nutrient spiraling dynamics). Predictable events can profoundly shape systems. For example, sequential and predictable seasonal flooding and drying events over an annual cycle are formative processes of physical, chemical, and biological attributes of streams in Mediterranean biomes, including parts of the western United States (Gasith and Resh 1999). Large seasonal waterfowl migrations can move nutrients, plants (seeds), and invertebrates between wetlands and downgradient waters (e.g., Figuerola et al. 2003; Green et al. 2008). A predictability axis could be folded into the current "gradient of connectivity" framework suggested by the SAB (Figure 3 in Section 3.7.3 of this report)

Key Recommendations

- The Report should discuss approaches to measuring or otherwise quantifying connectivity. This could be done by expanding the brief overview of approaches to measuring connectivity that is provided on pages 6-6 and 6-7 of the Report.

- Approaches to measuring or otherwise quantifying connectivity could be drawn from both the hydrological and disturbance ecology literature.

3.2.4. Defining the Scope of the Report

The SAB finds that the scope of the Report, with respect to the types of waters and wetlands covered, needs to be clearly defined and discussed at the beginning of Chapter 3. As a synthesis of the scientific literature, the Report appropriately includes discussion of the relevant literature on processes that occur across landscapes to connect various waters and wetlands, relying on science-based and ecological (i.e., Cowardin et al. 1979) rather than regulatory definitions of waters and wetlands. That said, the Report is unclear about the degree to which its definitions of waters and wetlands include broader portions of the landscape (e.g., whether wetlands or rivers include their floodplains), and this could be clarified with discussion of functional roles of landscape elements. Many public commenters have expressed concern about the potential expansion of the scope of jurisdiction of the underlying Clean Water Act – from “three-parameter” to “one-parameter” waters and wetlands[2]. These concerns could be addressed in a separate section outlining the scope of the Report immediately after the section defining connectivity. The Report should discuss the functional role of floodplains and riparian areas (i.e., the riverine landscape) regardless of their regulatory status. However, it should be made clear that this discussion does not imply an expansion of the definition of waters and wetlands under the jurisdiction of the Clean Water Act. The SAB recognizes that the Report is a scientific and not a policy document, but finds that ignoring this distinction only serves to create unnecessary confusion and concern among the readership.

Key Recommendations

- The scope of the Report should be clearly delineated, with special attention paid to defining the types of wetlands and water bodies covered.

- The Report should consider the functional role of floodplains and riparian areas (i.e., the riverine landscape) irrespective of their classification as waters and wetlands under the Clean Water Act (see discussion in Section 3.5.2 of this report).

3.2.5. Revising and Defining the Terminology Used in the Report

With regard to the discrete categories of systems discussed in the Report (i.e., rivers and streams, waters and wetlands in floodplain settings, and waters and wetlands in non-floodplain settings), the SAB finds

[2] The “one parameter” wetland classification system (Cowardin et al., 1979) classifies an area as a wetland if it has one or more of the following three attributes: (1) the area supports predominantly hydrophytes at least periodically; (2) the land has substrate that is predominantly undrained hydric soil; or (3) the land has nonsoil substrate that is saturated with water or covered by shallow water at some time during the growing season of each year. The “three parameter” classification system (33CFR 328.3(b); USACE 1987) requires that an area have all three of these attributes to be classified as a wetland.

that "bidirectional" and "unidirectional" are misleading terms. The Report uses these terms to describe wetlands and open waters with: (1) the potential for non-tidal, "bidirectional" hydrologic flows with rivers and lakes; or (2) the potential for "unidirectional" hydrologic flows to rivers and lakes. The four-dimensional nature of connectivity (longitudinal, lateral, vertical, and temporal) is a foundational aspect of freshwater ecology (e.g., Ward 1989). "Bidirectional" and "unidirectional" hydrologic flow certainly describes a key difference among wetland and open water systems. Indeed, in some landscape settings, there are two-way fluxes of water and water-borne materials between the landscape and the rivers and streams, while in other landscape settings there are only one-way fluxes of water and water-borne materials from the landscape to the rivers and streams. Although this is an important difference, it does not adequately characterize the four-dimensional fluxes in both landscapes. The key difference in the respective settings is landscape position, with some waters and wetlands having flood-pulse exchanges with rivers and streams and other waters and wetlands not having flood-pulse exchanges with rivers and streams. Therefore, the SAB recommends that the terms "unidirectional" and "bidirectional" be changed to terms reflecting a commonly understood classification system that is grounded in the literature. This is important not only for communication purposes but also because it is consistent with the peer-reviewed, literature-based focus of the Report. One possibility is that, after defining the term "floodplain" at the beginning of the report, "bidirectional" wetlands could be called *waters and wetlands in floodplain settings* and "unidirectional" wetlands could be called *waters and wetlands in non-floodplain settings*.

Use of the term "geographically isolated wetlands" in the Report is problematic. "Geographically isolated wetlands" technically means "wetlands isolated in space" but the term is defined in the Report to mean "wetlands surrounded by uplands." These are very different definitions. The SAB acknowledges that the term "geographically isolated wetlands" has been established in the literature, and is commonly used (e.g., Tiner 2003a,b). However, as discussed in other sections of this SAB report, at sufficiently large spatial and temporal scales, all waters and wetlands are connected. More important are the degree of connection (e.g., frequency, magnitude, timing, duration) and the extent to which those connections affect the chemical, physical, and biological integrity of downstream waters. A final point is that the term "geographically isolated wetlands" does not fit into the current conceptual framework in the Report because the Report explicitly states that geographically isolated wetlands can occur in both floodplain settings and non-floodplain settings. The SAB therefore recommends that the EPA carefully define "geographically isolated wetlands" in terms of the literature, explain that the term "geographically isolated wetlands" does not imply functional isolation, and then further explain that "geographically isolated wetlands" will not be used as an organizational term in Report. The SAB further recommends that the EPA then remove the term from later sections of the Report or, at the very least, ensure that the term is used consistently and not interchangeably with other terms, as it has been on occasion in the section of the Report on "unidirectional" wetlands.

Key Recommendations

- The terms "bidirectional" and "unidirectional" should be replaced in the Report with more commonly understood terms that are grounded in the peer-reviewed literature. The SAB suggests that "bidirectional" wetlands be called "waters and wetlands in floodplain settings" and "unidirectional" wetlands be called "waters and wetlands in non-floodplain settings."

- The term "geographically isolated wetlands" is misleading because it implies functional isolation and does not directly map onto the organizational terminology in the Report. The EPA should draw upon the literature to carefully define "geographically isolated wetlands," explain that the term does not imply functional isolation, and will not be used as an organizational term in Report.

3.2.6. Use of a Flowpath Framework

Chapter 3 of the Report contains detailed information about river system characteristics, the effects of streams and wetlands on downstream waters, and factors influencing connectivity. However, the conceptual framework is not explicit, which makes it difficult to categorize and organize this detailed information. Thus, the SAB recommends that a conceptual framework be established and discussed at the beginning of Chapter 3. This conceptual framework could be expressed as continuous hydrological (surface and subsurface), chemical, and biological flowpaths connecting watersheds from "ridge to reef," (i.e., highlands to lowlands) and therefore connecting waters and wetlands to downgradient waters. The flowpath framework should highlight the four-dimensional nature of connectivity, because four-dimensional connectivity scaled in a habitat-to-catchment context is a foundational aspect of freshwater ecology (e.g., Ward 1989). The flux and transformation of water, materials, and organisms – which fundamentally control the integrity of downgradient freshwater ecosystems – occur at varying rates primarily determined by climate, geology, topographic relief, and biology and are expressed in terms of surface water and groundwater storage and flow through the landscape (e.g., uplands, wetlands, lakes, rivers, and floodplains). Therefore, these flowpaths are inherently four-dimensional (i.e., longitudinal, lateral, vertical, and through time).

The flowpath framework could be briefly presented and discussed in the context of a revised Figure 1-1 (currently on page 1-2 of the Report), which could be moved to the beginning of Chapter 3 and expanded to include at least some representation of hydrological, chemical, and biological flowpaths. In the revised figure, each representative type of flowpath could be color-coded (e.g., blue for hydrological, red for chemical, and green for biological). The revised Figure 1-1would thus become Figure 3-1. In the conceptual framework, hydrological flowpaths should be expressed in terms of both surface water and groundwater flowpaths, with the latter including the potential for groundwater connections to cross watershed boundaries (McDonnell 2013). Chemical flowpaths should be expressed as largely following hydrological flowpaths, with subtle differences such as the typically tight nutrient spiraling transitioning to increasingly open spiraling from the headwaters to the outlet (Newbold et al. 1981). Chemical flowpaths also could be expressed as sometimes following biological flowpaths, with examples including marine-derived nutrients being transported to headwater streams by anadromous fish and nutrients being transported between waters and wetlands by birds that eat in one location and defecate in another (Helfield and Naiman 2001). Biological flowpaths should be expressed as aquatic, terrestrial, and aerial flowpaths connecting watersheds internally "ridge to reef" and "reef to ridge" and including the potential for biological connections to cross watershed boundaries (Skagen et al. 2008). Taken to the extreme, the revised Figure 1-1 could become almost infinitely complex and equally incomprehensible, so it is important to clearly state that this is a conceptual framework with representative rather than complete flowpaths.

Groundwater connectivity, in particular, could be better represented in the Report. The U.S. Geological Survey (USGS) has published numerous reports and learning tools on groundwater connectivity, including examples of flowpath frameworks expressed in block diagrams (Heath 1983, 1984; Winter et al. 1998), that contain flows through floodplains. Care should be taken not to imply that bedrock is impermeable because groundwater flows through bedrock are important flowpaths that connect hydrologic landscapes over long distances and often across watershed boundaries (e.g., Roses et al. 1996).

An important next step is to state how the revised conceptual framework is used in the Report. Connectivity should be discussed as a continuous phenomenon. However, the SAB recognizes that the EPA has chosen to discuss landscape settings discretely in the Report, with separate sections for "rivers and streams," "waters and wetlands in floodplain settings," and "waters and wetlands in non-floodplain settings." This approach is workable as long as the discrete classification is mapped onto the continuous conceptual framework. The integration of the discrete classification and continuous framework could be achieved by adding two panels to the revised Figure 1-1 described above, using the same base block diagram. In the second block diagram, all flowpaths could be removed and the classification system showing the three landscape settings (i.e., rivers and streams, waters and wetlands in floodplain settings, and waters and wetlands in non-floodplain settings) could be added. Then, in the third block diagram, the first and second block diagrams could be merged, clearly showing that the continuous phenomena (i.e., the hydrological, chemical, and biological flowpaths) interact across the discrete landscape settings (i.e., connect rivers and streams, waters and wetlands in floodplain settings, and waters and wetlands in non-floodplain settings to one another at the landscape scale).

Suggested editorial or technical corrections have been identified in the line-by-line preliminary written comments provided by SAB Panel members. Hillslope hydrology is discussed independently here because it is so central to the flowpath framework connecting all parts of the watershed, with water flowing from the "ridge to the reef" and potentially passing through or otherwise interacting with waters and wetlands along the way. The EPA Report should clearly describe the following four pathways through which water flows across the landscape:

1) Infiltration-Excess Overland Flow: This is the overland flow that occurs when the rainfall rate exceeds the infiltration rate, resulting in excess rainfall running overland despite a below-surface water table. This flow is also known as Hortonian overland flow because it was first described in the literature by Horton (1945).

2) Saturation-Excess Overland Flow: This is the overland flow that occurs when the water table rises to the surface, so that all additional rainfall runs overland. This is also known as Dunne's mechanism because it was first described by Dunne and Black (1970).

3) Interflow: This is rapid lateral flow in the unsaturated zone of soil and rock. Interflow commonly occurs because above a low-permeability layer there are interconnected macropores that intercept and channel rainfall as would a subsurface pipe (e.g., Beven and Germann 1982).

4) Saturated Groundwater Flow: This is the normal saturated groundwater flow, where infiltrating rainfall reaches the water table and then flows laterally along with the general flow in the aquifer.

The Report should further explain how areas contributing runoff expand and contract, changing the way that landscapes connect through storms and seasons (Dunne and Black 1970). The expansion of runoff-producing areas in non-floodplain settings can intermittently or ephemerally change the extent of headwater streams (e.g., Dunne 1978; Van der Kwaak and Loague 2001; Rains et al. 2006, 2008). This type of variability suggests that connectivity should be discussed within a continuum of runoff producing mechanisms. As previously noted, the EPA elected to discuss landscape settings discretely, focusing on rivers and streams, waters and wetlands in floodplain settings, and waters and wetlands in non-floodplain settings; however, the lines delineating these landscape categories are conceptual and without scientific consensus.

The Report focuses primarily on the site and subregional scales, perhaps due to cost of and access to data and model results. This tends to either ignore or at least downplay the potential significance of regional-scale hydrologic connectivity, especially as it relates to groundwater. This is a problem because regional groundwater flows commonly interact with the surface environment at sinks and springs. For example, the Floridan aquifer underlies all of Florida as well as portions of Mississippi, Alabama, Georgia, and South Carolina and commonly interacts with the surface environment through sinks, springs, and outcrops (see Sun et al. 1997 and references therein). To provide a better understanding of groundwater connectivity, and the way that groundwater connectivity might vary spatially, the SAB recommends that the EPA also consider using the ASTM D5979-96 *Standard Guide for Conceptualization and Characterization of Ground Water Systems* (ASTM 1996; Kolm et al. 1996). To better characterize regional-scale groundwater connectivity, the SAB recommends that the EPA also consider using findings from the U.S. Geological Survey Regional Aquifer Systems Analysis (RASA) Program. An understanding of regional groundwater flow systems is critical to the understanding of four-dimensional hydrologic connectivity on both the local and regional scales. Understanding groundwater flow in unique hydrogeologic settings, including the Floridan aquifer system (karst systems), the High Plains aquifer system (semi-arid systems), and the Snake River Plain aquifer system (volcanic bedrock systems), is especially important. These and other unique hydrogeological settings are covered by the RASA Program (Sun et al. 1997).

The SAB recommends that biological connectivity be better defined, illustrated with examples from a broader range of taxa, and described in the context of consequences to downstream waters. As written, the Report emphasizes the importance of hydrological connectivity, but organismal movement can connect waters and wetlands across uplands and between watersheds in unique and important ways. Indeed, many organisms meet life-history requirements by moving among habitats (i.e., their life cycles cannot be completed without these habitats) that are often dispersed throughout watersheds (e.g., Schlosser and Angermeier 1995; Falke and Fausch 2010). Habitats that are seasonally dry or even dry for several years in a row can be critical to the biological integrity of downgradient waters because a wide range of species (e.g., fish, amphibians, reptiles, birds, mammals, and invertebrates) use them to complete certain annual or life-cycle stages (Falke and Fausch 2010). When these upstream, lateral, and disconnected aquatic habitats are degraded or destroyed, populations decline and species can become threatened or endangered (or otherwise imperiled), or are extirpated (Fausch and Bestgen 1997). Ignoring these connections can result in the listing of new threatened and endangered species, not only for highly imperiled vertebrate groups like amphibians, but also invertebrates like mussels that are transported by fish (as glochidia, their larval stage) throughout watersheds.

Key Recommendations

- The conceptual framework should be fully described at the beginning of Chapter 3. The framework should have a flowpath focus showing that watersheds are connected from "ridge to reef," and that waters and wetlands in the landscape are therefore connected to downgradient waters by hydrologic (surface and subsurface), chemical, and biological flowpaths.

- The conceptual framework in the Report should generally express the importance of climate, geology (surface and subsurface), topographic relief, and biology on flow and transport. The resulting three-dimensional structure should show potential surface, near surface, and subsurface pathways, which then can be analyzed in terms of hydrological, chemical, and biological connectivity in four dimensions (i.e., with the temporal dimension included).

- The discrete-landscape classification system should be mapped onto the revised conceptual framework in the Report, with explicit acknowledgment that the classification system serves only as a communication tool.

- Groundwater mediated connectivity, including regional groundwater mediated connectivity across watershed divides, should be better defined, and described in the context of connectivity between waters and wetlands and downgradient waters.

- Biological connectivity should be better defined, illustrated with examples representing a broader range of taxa, described in the context of consequences to downstream waters, and recognized as supporting the biological integrity of connected waters.

3.2.7. Layers of Complexity in the Conceptual Framework

Once the EPA has described the flowpath framework and explained how the framework is used in the Report, additional layers of complexity (focusing on the issues discussed below) should be represented in the conceptual model. The SAB recognizes that some of these issues are already addressed in various parts of the Report. In those cases, the SAB recommends expanding upon or moving the discussion to the section of the Report that outlines the major concepts underlying the conceptual framework.

Functions

The SAB recommends layering water and wetland function on the flowpath framework. The Report should indicate that each water and wetland performs functions broadly categorized as source, sink, lag, transformation, and refuge, and that the degree to which each function is performed is dependent upon landscape position and related connectivity. The importance of including this in the discussion of the conceptual framework is to explain up front that some hydrological, chemical, and biological functions are enhanced by connectivity while others are enhanced by relative isolation. This is an important point, one that is implicit throughout the Report and explicit in the section on “unidirectional” wetlands. Including a functions layer in the conceptual framework will help clarify the later discussion of functions that are enhanced by connectivity or relative isolation.

Spatial and Temporal Scales

Spatial and temporal scales are critical aspects of connectivity and its role in maintaining the chemical, physical, and biological integrity of downgradient waters. However, spatial and temporal scales vary by flowpath type and flowpath characteristics (Figure 1). An illustration similar to Figure 1, focused on the spatial and temporal scale of connectivity, should be included in the Report, with a particular focus on the differences in the spatial and temporal scales of surface water and groundwater connectivity as it relates to the chemical, physical, and biological integrity of downgradient waters. Similar figures could also be created for chemical and biological connectivity.

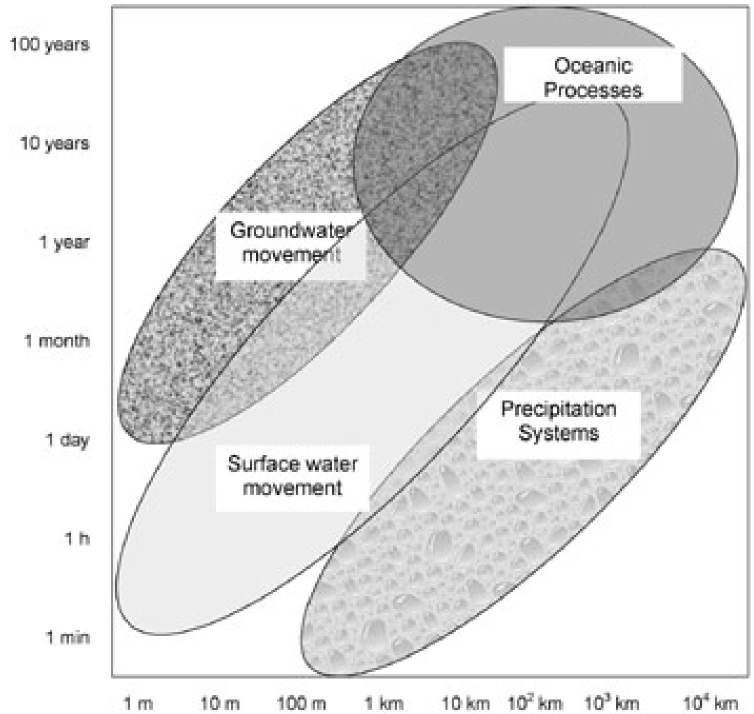

Figure 1. Schematic of selected atmospheric, surface, and subsurface hydrologic processes and their temporal and spatial scales of occurrence. (Source: U.S. Global Change Research Program 2001)

The Report should carefully discuss how connectivity is a function of spatial and temporal scale. For example, a complex of depressional wetlands might appear connected at the complex scale but might nevertheless be collectively isolated at the watershed scale. Alternatively, a depressional wetland might appear isolated in the dry season but connected by surface water for long duration during the wet season (e.g., Rains et al. 2008).

The Report should clearly state that low-frequency events affecting the chemical, physical, and biological integrity of downgradient waters can be particularly important if the effects are essential, long-lived, and/or cumulative. Excellent examples can be found in the stream and river literature, though similar examples for other types of waters and wetlands (e.g., Winter and Rosenberry 1998; Winter 2000) can be found. Low-frequency, high-magnitude flows connect channels to the furthest reaches of the floodplains (Poff et al. 1997), thereby controlling species composition and abundance in forests (Darst and Light 2008) and aquatic habitats in the floodplain (Light et al. 1998) and transporting large clasts and/or woody debris that otherwise cannot be transported by more-frequent, lower-magnitude flows (Wolman and Miller 1960). Long-lived effects are exemplified by debris flows, which are low-frequency events that nevertheless can be important mechanisms that connect headwaters to rivers, serving as important sources of sediment to downgradient waters (Benda et al. 2005). Though such debris flows occur infrequently, the consequences can be long lived, and can play important roles in controlling the structure and function of downgradient waters over the scale of decades (Leibowitz et al. 2008). Important cumulative effects are exemplified by ephemeral flows in arid landscapes, low-frequency events that may nevertheless provide most of the subsidies to downgradient waters (Izbicki 2007).

The SAB recommends that the Report compare and contrast the temporal scales of connectivity in the East and the Southwest. In the East, precipitation is weakly seasonal and the weighted-average flux of materials, energy, and/or water-borne organisms is therefore likely greatest in response to moderate-frequency rainfall events; in the Southwest, precipitation is strongly seasonal and the weighted-average flux of materials, energy, and/or water-borne organisms is therefore likely greatest in response to low-frequency rainfall events. The latter are no less important to the integrity of the downgradient waters, even though their frequency and duration may be negligible in comparison. Therefore, the importance of the connectivity is not just a function of the frequency or duration of the connection but, rather, the relative magnitude of the connection. Consider, for example, a river with total annual flow of 200,000 m^3, 150,000 m^3 of which originates as ephemeral flows in headwater streams. In this case, these headwater streams, though infrequently connected to the river, would nevertheless be critical to the maintenance of the chemical, physical, and biological integrity of that river.

One way to conceptualize this point in the Report is by developing a matrix of relative likelihood × relative consequence (e.g., Figure 2), which would facilitate a discussion of spaces occupied by given waters and wetlands. Such a figure would help readers understand the regional context of the spatial and temporal scale of connectivity.

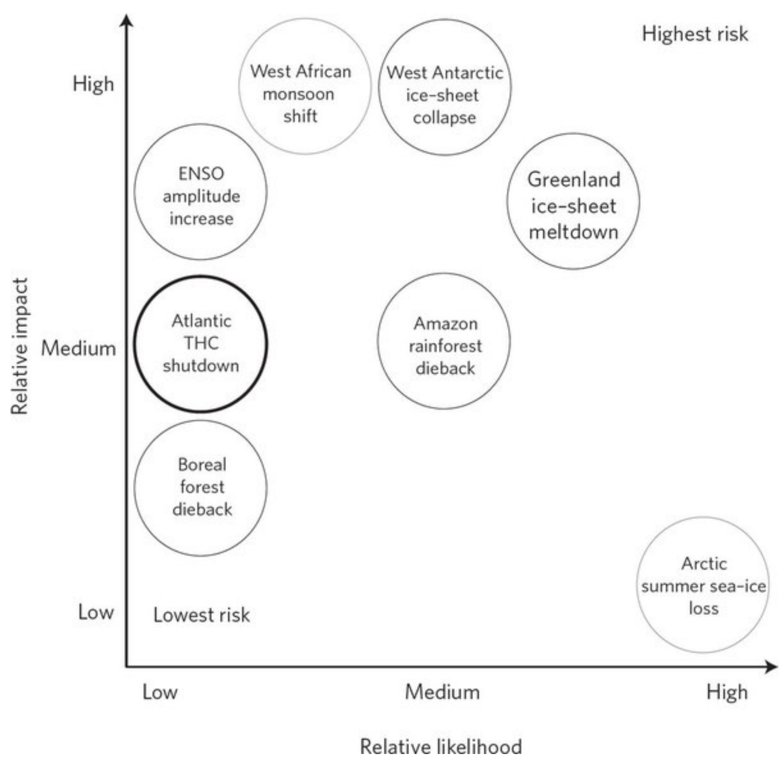

Figure 2. Relative likelihood × relative impact of global-scale phenomena. (Source: Lenton 2011. Reprinted by permission from Macmillan Publishers Ltd: Nature Climate Change 1(4):201-209, copyright 2011.)

Human-Altered Systems

There are few, if any, ecosystems unaltered by humans. The role that these alterations play in the conceptual framework should be addressed explicitly in the Report. Waters and wetlands are "connected" in the sense that they are integrated into the broader hydrological landscape and therefore can play important roles in maintaining the chemical, physical, and biological integrity of downgradient waters. They perform a variety of functions (which are broadly classified in the Report as source, sink, lag, transformation, and refuge functions) at rates that are a characteristic of where these waters and wetlands are located on the gradient of connectivity. Therefore, downgradient waters might suffer consequences if the degree of connectivity is altered by human activities. Alterations can be of three types: some can directly decrease connectivity, such as dams (Ward and Stanford 1983) and groundwater pumping that lowers local water tables and causes surface-water connections to cease (Haag and Pfeiffer 2012); some can directly increase connectivity, such as ditches (Min et al. 2010) and tile drains (Randall et al. 1997); and some can indirectly change the frequency, magnitude, timing, duration, and/or rate of change of connectivity, such as impervious surfaces in the contributing watershed (Walsh et al. 2012). Each of these types of human alterations affect connectivity, modify the surface water network, and therefore impact the chemical, physical, and biological integrity of the downgradient waters.

Regionalization

The SAB finds that the conceptual framework in the Report is not amenable to considering connectivity in a regional context, especially for regions with unique conditions such as the permafrost regions of Alaska. This issue was identified by a number of public commenters. The EPA therefore should consider expressing forcings of connectivity in terms of Hydrologic-Landscape Regions (HLRs; Wolock et al. 2004), or an equivalent system (e.g., Wigington et al. 2013). This would not represent a large departure from the approach used in the Report because HLRs are fundamentally a function of climate, geology, and topographic relief, which are already recognized as central controls on watershed hydrology. Using HLRs to consider flow and transport functions would ground the discussion to consistent terminology. Use of terminology in the Report is currently inconsistent, sometimes referring to climate, geology, and relief, sometimes to climate and watershed characteristics, and other times focusing only on climate. Using the HLRs also would ground the discussion in the Report to peer-reviewed literature, which could then serve as a means to discuss regionalization and the reality that generalizations about chemical, physical, and biological phenomena are limited to particular environmental settings (i.e., context dependent). Associated with this issue is the fact that much more is known about connectivity in some settings than others. The Report could be improved by explicitly recommending that HLRs be used to better understand the relevance of the findings in the document to their respective regions.

Aggregate or Cumulative Effects

The aggregate or cumulative effect of many waters and wetlands on the chemical, physical, and biological integrity of downstream waters is sufficiently important to merit its own subsection in the Report. Mainstem rivers integrate and accumulate the materials, energy, and organisms that flow by surface-water and/or groundwater flowpaths from numerous waters and wetlands. This is an important concept because the individual effect of any single water or wetland on downstream waters might be negligible, but the cumulative effects of many similarly situated waters and wetlands on downstream waters might nevertheless be important. For example, the degradation of a single small, headwater stream in the watershed might have a negligible effect on the physical, chemical, and biological integrity of downstream waters, but the aggregate or cumulative effect of the degradation of all small, headwater streams would have a large effect on downstream waters (Alexander et al. 2007).

Cumulative effects can be defined as an emergent property of all headwater streams in the watershed (i.e., a river network statistical attribute). A measurable effect on the integrity of downstream waters may not be detected if only a small number of headwater streams within a watershed were impacted, whereas there could be substantial and possibly cascading effects on downstream waters were a larger number of headwater streams impacted. Moreover, the extent of downstream effects reflects a convolution – both in space and time – of each headwater stream's time-varying flux of mass, materials, and organisms. For example, in a watershed with a 200-year recurrence interval of debris flows on headwater streams, the probability of a debris flow on any given headwater stream in a given year is 0.5% - likely a negligible effect on fish habitat in downstream waters in a given year. However, at the watershed scale, there are hundreds of headwater streams, which means that the annual probability of a debris flow in the group of headwater streams is much higher and more likely to substantially affect downstream fish habitats. Studies have been published on these kinds of cumulative effects, such as the aggregate effects of individually occurring debris flows in headwater streams controlling the long term sediment flux and storage in higher order channels (Benda and Dunne 1997a,b) and the cumulative effects of wetlands on watershed hydrology (e.g., Johnston et al. 1990). Therefore, any evaluation of changes to individual waters and wetlands must consider past and future (e.g., as a consequence of climate change) alterations of other waters and wetlands in the watershed. The SAB recommends that the EPA review the following additional studies on the cumulative and aggregate effects of streams and wetlands on downstream waters: Ahmed (2014); Bedford and Preston (1988); Benda et al. (2003); Brinson (1988); Dietch et al. (2013); Dunne et al. (2001); Gabet and Dunne (2003); Johnston (1994); Lancaster and Casebeer (2007); Reid (1998); Squires and Dube (2013); and Schindler (2001).

Map Scale

The important issue of map resolution, mentioned throughout the Report, needs to be more clearly and thoroughly presented in a separate section, or perhaps in a figure comparing the results of using different technologies. A related topic that could be addressed in the Report is the increasing availability of light detection and ranging (LiDAR) digital elevation models (DEM) and thus the increasing ability to create more accurate water and wetland maps; this illustrates how new technologies may influence the scientific understanding of connectivity.

The Report should clearly indicate that many existing databases do not include small streams and thus do not represent the full extent and magnitude of the river and stream network. For example, Meyer and Wallace (2001), estimating stream extent in a North Carolina watershed using maps with different resolution, found 0.8 km of stream channel on a 1:500,000 scale map and 56 km of stream channel on a 1:7200 scale map. The increasing availability of high resolution DEM, including the USGS National Elevation Dataset (NED) 10 m DEM (USGS 2014) and more robust flow routing algorithms means that more accurate stream maps are becoming increasingly available. Thus the ability to predict (and discern) hydrological, chemical, and biological connections between small and large streams is increasing rapidly. Mapping scale also applies to wetlands in non-floodplain settings. Frohn et al. (2009, 2012), Lane et al. (2012), and Martin et al. (2012) tried to map geographically isolated wetlands (i.e., wetlands surrounded by uplands) but found that currently available spatial data were inadequate for the task, in large part due to the limitations of the scale and/or accuracy of the maps used to determine whether or not a wetland was surrounded by upland. Hence, the assessment of the degree of connectivity will be determined in some part by the database and/or data collection technology used for the analysis.

Key Recommendations

- After describing the structure and use of the flowpath framework, additional layers of complexity should be developed with particular focus on the following issues:

  - Water and wetland function should be represented on the flowpath framework. EPA should indicate that each water and wetland performs functions broadly categorized as source, sink, lag, transformation, and refuge, with the degree to which each function is performed being dependent upon landscape position and related connectivity.
  - Spatial and temporal scales should be addressed in the discussion of connectivity and its effects on the chemical, physical, and biological integrity of downstream waters. The Report should discuss the potential importance of low-frequency events.
  - The role that human alterations play in the conceptual framework should be addressed explicitly.
  - The EPA should consider expressing forcings of connectivity in terms of Hydrologic-Landscape Regions (HLRs) to help readers understand the regional relevance of findings in the Report.
  - The aggregate or cumulative effect of many waters and wetlands on the chemical, physical, and biological integrity of downgradient waters is sufficiently important to merit its own subsection in the Report.
  - The important issue of map resolution is mentioned in several parts of the report, but it should be more clearly and thoroughly presented in a separate section.

3.2.8. Summary and Synthesis of the Conceptual Framework

Chapter 3 of the Report ends abruptly, without summary or synthesis of the conceptual framework. The SAB recommends that the EPA consider moving Figure 6.1 (The role of connectivity in maintaining the physical, chemical, and biological integrity of water) to the end of Chapter 3. The figure could then be used as a means of summarizing and synthesizing the conceptual model and explaining how the model guides the way that the EPA is thinking about and presenting evidence of connectivity between waters and wetlands and downgradient waters. This figure succinctly shows the role played by connectivity in maintaining the chemical, physical, and biological integrity of downgradient waters and hence would serve this purpose well.

Key Recommendation

- A summary and synthesis of the conceptual framework should be added to the end of Chapter 3 of the Report using what is currently Figure 6.1 to frame the discussion.

3.3. <u>Ephemeral, Intermittent, and Perennial Streams: Review of the Literature</u>

Charge Question 3(a). Chapter 4 of the draft Report reviews the literature on the directional (downstream) connectivity and effects of ephemeral, intermittent, and perennial streams (including flow-through wetlands). Please comment on whether the Report includes the most relevant published literature with respect to these types of streams. Please also comment on whether the literature has been *correctly summarized. Please identify any published peer-reviewed studies that should be added to the Report, any cited literature that is not relevant to the review objectives of the Report, and any corrections that may be needed in the characterization of the literature.*

Chapter 4 of the Report is an extensive review of the literature that describes the connectivity of headwater streams to downstream waters. The Report documents the current scientific understanding that there are numerous ways headwater streams are connected to downstream ecosystems and that these connections can be essential in promoting the physical, chemical, and biological integrity of downstream ecosystems. The connections between headwaters and downstream ecosystems are well established as a foundational concept in stream ecology.

The EPA's review is based on pertinent literature and is strongly grounded in current science. However, the SAB provides a number of recommendations to improve the literature review in Chapter 4 of the Report. The SAB has identified additional references to relevant peer-reviewed literature that the EPA should consider citing in the Report.

3.3.1. Hydrologic Exchange Flows between Main Channels and Off-Channel Areas

The SAB recommends that the literature review in Chapter 4 of the Report be expanded to include the description of exchanges between main channels and off-channel surface and shallow subsurface waters located at channel margins (e.g., pools, recirculating eddies, subsurface hyporheic flow paths) and in upstream or off-channel areas that may become connected during wet periods (e.g., variable source areas or off-channel sloughs or riparian areas). The Report should include a more complete discussion of the soil-water processes involved (e.g., processes that establish temporary sinks for chemical constituents, provide water to riparian vegetation, or facilitate contaminant transport) and more attention should be given to spatial and temporal variability that could affect connectivity of streams. The revised text also should include broader discussion of associated biogeochemical transformations that change the form and mobility of dissolved chemicals that affect downstream water quality. The discussion should go beyond solely discussing nitrate removal to include phosphorus removal and examples of fate and transport of contaminants such as toxic metals and organic contaminants. A discussion also is needed of the geomorphological control of soil moisture and patch diversity that impacts riparian plant communities (Stromberg 2001). The review should also describe how surface-subsurface water interactions affect stream temperature and habitat for fish and other organisms, particularly when surface water flows diminish but subsurface flow is present. The following references (and others that are similar) should be considered for inclusion in a broader discussion of hyporheic processes: Buffington and Tonina (2009); Karwan and Saiers (2012); Poole et al. (2006); Sawyer et al. (2011); Stonedahl et al. (2010); and. Stromberg (2001). As further discussed in Section 3.5 of this report, the material on the physical and chemical influence of riparian areas (Sections 5.3.1 and 5.3.2 of the EPA Report) is more appropriately located in Chapter 4 of the EPA Report.

Key Recommendations

- The review of hydrologic exchange flows between main channels and off channel areas should be expanded in the Report to include the topics summarized above.

- Additional references recommended by the SAB, and others that are similar, should be considered for inclusion in a broader discussion of hyporheic processes.

3.3.2. Naturally Occurring Chemical Constituents, Contaminants, Contaminant Transformations, and Sediment Transport

The EPA should expand the discussion in the Report of naturally occurring chemical constituents other than nutrients (i.e., nitrogen and phosphorus), contaminants, and contaminant transformations, and sediment transport. The Report needs a more thorough characterization of upslope (surface and subsurface) effects of geology, soils, and hydrology (e.g., sediment transport) on overall water chemistry (e.g., conductivity, alkalinity, pH, major cations) and the consequences of altering these upslope processes on downstream water chemistry and associated ecological responses. The role of nutrient spiraling as a demonstration of connections between headwaters and downstream ecosystems is covered in the Report. However, the Report could be strengthened if more attention were given to the important transformations that affect mobility, toxicity, and time lags of storage or degree of removal that occurs and how it affects downstream loading of nutrients and contaminants. The Report also should further discuss both sediments and sediment-bound contaminants and their downstream movement and effects on downstream waters.

The review and synthesis of the literature on connectivity of streams should also be expanded to provide information on the physical, chemical, and biological effects and quantification of sediment transport as related to surface water connectivity. This review should include the geology and sedimentology literature on three types of sediment: dissolved, suspended and bedload (based on type of movement and size).

The following references (and others that are similar) should be considered for inclusion in the discussion of naturally occurring chemical constituents, contaminants and contaminant transformation processes: Baker et al. (2000); Bourg and Bertin (1993); Conant et al. (2004); Doyle et al. (2003); Ensign et al. (2008); Findlay (1995); Fuller and Harvey (2000); Harvey and Fuller (1998); Harvey et al. (2013); Hedin et al. (1998); Kim et al. (1992); Kim et al. (1995); Kimball et al. (1994); Lautz and Fanelli (2008); Malcolm et al. (2005); and O'Connor and Harvey (2008).

Key Recommendations

- The review of the literature on connectivity of streams should be revised to include discussion of contaminants and naturally occurring chemical constituents other than nutrients (i.e., nitrogen, phosphorus) and to consider nutrient and contaminant transformation processes and the effect of these processes on downstream water quality, if known.

- Additional references recommended by the SAB, and others that are similar, should be considered for inclusion in the discussion of naturally occurring chemical constituents, contaminants and contaminant transformation.

3.3.3. Factors that Influence Stream Temperature

Stream temperature is an important component of ecosystem integrity because it controls many ecosystem properties and processes. Upslope factors affect the relative contributions of surface, shallow and deeper subsurface waters to channel flow and can affect stream temperature and downstream connectivity. The SAB recommends that discussion of this topic be expanded to (1) discuss the treatment of the direct and indirect effects of upstream/upslope riparian shading, channel morphology, and channel network topology on stream temperature; (2) expand the discussion of how environmental alterations in channels and upslope areas influence connectivity, and thus, stream temperature dynamics; (3) directly address interactions between stream temperature and downstream connectivity; and (4) more explicitly describe the effects of hyporheic flow and storage and resulting lag and attenuation effects that buffer temperature extremes within streams. The discussion of these latter subsurface hyporheic effects should include a comparison to direct groundwater discharge in terms of their effects on stream temperature dynamics (Callahan et al. in press). The following references (and others that are similar) should be considered for inclusion in the discussion of factors that influence stream temperature: Arrigoni et al. (2008); Hester et al. (2009); and Sawyer et al. (2012).

Key Recommendations

- The discussion of upslope factors that influence stream temperature should be expanded to include hyporheic flow and storage, a comparison to groundwater effects on stream temperature, upstream/upslope riparian shading, channel morphology; channel network topology, and environmental/human alterations in upslope areas and channels.

- The Report should explicitly discuss interactions between stream temperature and downstream connectivity.

- Additional references recommended by the SAB (and others that are similar) should be considered for inclusion in the discussion of factors that influence stream temperature.

3.3.4. Clarifying the Temporal Dynamics of Flow-Related Aspects of Connectivity

The Report lacks a succinct yet comprehensive paragraph that covers the temporal dynamics of connectivity for headwater streams (e.g., headwaters that connect perennial, intermittent, and ephemeral channels with their variable source areas) and effects on the transport of materials and sediments and on the physical, chemical, and biological integrity of downstream waters. Connections that are highly variable in time can also be important to biota and influence the biological integrity of downstream waters, such as when fish or amphibians breed in habitats that are dry most of the year or for several years. The timescale of these temporally variable connections (i.e., connected at certain times) could range from seasons, years, or decades to centuries. In addition, some aspects of connectivity occur over relatively short times frames and are highly stochastic but can represent important connections to downstream ecosystems. For example, major erosion or woody debris fluxes that occur infrequently during high runoff events may represent major sources of sediments or large wood to downstream ecosystems.

Chapter 4 of the Report would benefit from a separate section on the temporal dynamics of connectivity. The SAB recommends that the report characterize the temporal dynamics of streamflow (i.e., magnitude, frequency, duration, and timing) that explicitly connect these ecosystems to downstream waters. For example, the report correctly describes how headwater streams can contribute a large fraction of the water in downstream ecosystems over an annual cycle, even though they are periodically dry. However, the report should explore the effect of short duration connections on downstream ecosystems. More discussion and additional literature citations should be included to describe how even short duration and highly episodic flow connections and longer duration periods of dry conditions can be important to downstream ecosystems. The SAB also recommends that the Report be revised to explicitly recognize the important role of variable hydraulic residence times in river networks and their effects on the storage and transformation of organic matter and nutrients in downstream waters.

In addition, the Report should discuss how natural or human-caused interruptions of flow affect the temporal dimensions of connectivity. In many streams that experience flow regulation, groundwater capture, or any rapid longitudinal change in discharge, riverine habitat can become discontinuous and aquatic and riparian communities can lose connectivity. For example, in the arid Southwest, the San Pedro and Santa Cruz Rivers include long reaches of ephemeral flow bounded by intermediate-to-perennial sections. In the volcanic terrains of the Snake River Plain in Idaho or the Hawaiian Islands and karst regions of central Kentucky, stream flow can be captured by bedrock aquifers. These streams, defined as “interrupted” (Meinzer 1923; Hall and Steidl 2007), can be strongly or very weakly connected depending upon a variety of biological and physical factors; the Report should discuss ways commonly used to spatially and temporally characterize the impacts to riverine habitat of natural and human interruption of flow.

Overall, the SAB recommends that the report include a clear discussion of how intermittent and ephemeral streams are connected in space and time to downstream ecosystems and the consequences of these connections for physical, chemical, and biological integrity. The following references (and others that are similar) should be considered for inclusion in the Report to illustrate the ways in which intermittent and ephemeral streams are connected to downstream ecosystems and the effects of time-varying flow connections: Brooks et al. (2006); Constantz (2008); Harvey et al. (2012); Levick et al. (2008); McDonough et al. (2011); O'Connor et al. (2012); RWRD (2002); and Walker et al. (2005).

Key Recommendations

- The Report should include a new section that explicitly examines the temporal dynamics of connectivity for headwater streams (e.g., headwaters that connect perennial, intermittent, and ephemeral channels with their variable source areas) and effects on the transport of materials and sediment on the physical, chemical, and biological integrity of downgradient waters. The new section should note that it is the effect of flows that determines their importance to downstream connectivity.

- The Report should be revised to explicitly recognize the important role of variable hydraulic residence time in river networks and its effects on the storage and transformation of organic matter and nutrients in downstream waters.

- The Report should include discussion of how human alterations affect the temporal dimensions of connectivity, e.g., via water withdrawal or augmentation and effluent-dependent or effluent-dominated stream flow.

- Additional references recommended by the SAB (and others that are similar) should be considered for inclusion in the Report to illustrate the ways in which intermittent and ephemeral streams are connected in space and time to downstream ecosystems and the effects of time-varying flow connections.

3.3.5. Strengthening the Review of Biological Connectivity of Ephemeral, Intermittent, and Perennial Streams

As mentioned in Section 3.2.6, the Report should be revised to more thoroughly document evidence that biota move throughout aquatic and riparian systems (e.g., in upstream, lateral, and downstream waters) to use critical habitats and that these movements have strong and important effects on biological integrity. A more thorough treatment of biological connectivity would strengthen Chapter 4 of the Report. The following key points should be included in the Chapter:

a) Organisms require habitats that are dispersed throughout watersheds (i.e., their populations cannot persist without these habitats), and many species move among these habitats during their life cycles (e.g., Fausch et al. 2002; Kanno et al. 2014).

b) Some species maintain populations in downstream waters, but move upstream or laterally to use habitats that are dry seasonally and in some cases are dry several years in a row. Thus, these intermittent or ephemeral habitats often can be critical to the biological integrity of downstream waters (Falke and Fausch 2010).

c) A wide variety of downstream mobile species move among aquatic habitats dispersed throughout watersheds, including ephemeral or intermittent streams, requiring them to meet critical needs during different stages of life and/or annual cycles.

d) Data from comparative studies and experiments show that some animal populations decline or are extirpated when upstream, lateral, and disconnected habitats are degraded or destroyed, or the connections are lost (e.g., owing to constructed barriers, Fausch and Bestgen 1997). Thus, connectivity to these habitats is key to the biological integrity of downstream waters. Dam and dam-removal literature may be helpful to illustrate this point.

e) A failure to recognize the importance of biological and habitat connections can result in the listing of new threatened and endangered species, especially for highly imperiled vertebrate groups like amphibians, but also highly imperiled groups of invertebrates like mussels whose larvae are transported throughout watersheds by their fish hosts (Vaughn 2012; Schwalb et al. 2013).

Key Recommendation

- The Report should more thoroughly document evidence that biota move throughout the lotic system (e.g., in upstream, lateral, and downstream waters) in order to use critical habitats and that these movements have strong and important effects on biological integrity of downstream waters, as detailed in the points above.

3.3.6. Review of the Human-Modified Headwater Stream Literature

The current version of the report generally excludes the many studies that have been conducted in human-modified stream ecosystems. This literature (e.g., Blann et al. 2009) should be included in the Report in order to provide information about the consequences of alterations of headwater systems to the physical, chemical, and biological integrity of downgradient waters. Many headwater stream ecosystems are altered by land-use change and human activity that often disrupts connectivity. Consideration of appropriate temporal scales and disturbance ecology could help the Report provide direction on discrimination between short-term, erosional features like rills and gullies, which are initiated by human or natural disturbance, and longer-term, integrated headwater channels with more ecologically effective connectivity to downstream waters. Poesen et al. (2003) and Schumm et al. (1987) provide information on the transition from gullies to headwater streams. The SAB finds that there are many insights to be gained about the importance of connectivity to downstream waters when connections are either severed or enhanced. Including additional information from this large area of research will provide more examples of the importance of connectivity, and the SAB recommends that information about human-modified systems be included in the report.

The SAB recommends that the Report authors consider including examples from at least some of the following human alterations affecting the connectivity of streams: agricultural ditches and tile drains, urban lined channels and buried streams, removal of riparian trees, cattle grazing, gravel mining, channel diversions, low-head dams, grade control structures, roads, stream restoration, accelerated erosion, sediment transport and storage, stream restoration, and effluent dominated streams. The following references (and others that are similar) could be considered for inclusion in the Report to illustrate the effects of human alterations to headwater streams: Booth (1990); Bull and Scott (1974); Chin and Gregory (2001); Croke et al. (2005); Doyle et al. (2000); Graf (2006); Gregory (2006); Faulkner (2004); Horner et al (2001); Lautz and Fanelli (2008); Montgomery (1994); Paul and Meyer (2001); Schumm et al. (1984); Thompson et al. (2008); Wemple et al. (1996, 2001); Wigmosta and Perkins (2001); Williams and Wolman (1984); and Wohl (2005).

Key Recommendations

- The Report should be revised to include information about the consequences of human alteration of headwater systems on their connectivity and concomitant effects on the water quantity and quality and biota of downstream ecosystems.

- Additional references, including those recommended by the SAB, should be considered for inclusion in the Report to illustrate the effects of human alterations to headwater streams.

3.3.7. Aggregate and Cumulative Effects of Headwater Streams on Downstream Ecosystems

The SAB recommends that a new section on the aggregate and cumulative effects of headwater streams on downstream ecosystems be added to Chapter 4 of the Report. This new section should draw upon the large body of literature on cumulative watershed effects of land use, based on both modeling and empirical approaches. In addition, the existing section on watershed modeling should be improved by expanding the discussion to include results from models beyond just the SPARROW (SPAtially Referenced Regressions On Watershed attributes) model and encompass the numerous modeling and empirical approaches that have been used. In addition, the Report could draw upon examples from literature that investigates the movement of sediments through watersheds to examine aggregate and cumulative effects on downstream waters. The following references (and others that are similar) should be considered for inclusion in the Report to document the aggregate and cumulative effects of headwater streams on downstream ecosystems: Alexander et al. (2009); Böhlke et al. (2009); and Helton et al. (2011).

Key Recommendations

- A new section on aggregate and cumulative effects of headwater streams on downstream ecosystems should be added to Chapter 4 of the Report. Additional references recommended by the SAB should be considered for inclusion in the new section.

- The findings of the modeling and empirical studies on the cumulative effects of land use on the physical, chemical, and biological integrity of downgradient waters should be summarized in the Report.

- The modeling section of the Report should be expanded to include results from a broader set of models.

3.3.8 Connections to the Adjacent Riparian Landscape

The Report focuses primarily on the connections among components of the aquatic system, including not only hydrologic connections but also those made by organisms that walk, crawl, or fly between water bodies. However, the physical, chemical, and biological integrity of downstream waters also depends on the presence of intact headwaters, and the integrity of these headwater ecosystems depends on critical connections between streams and the adjacent riparian landscape. Given this, the SAB finds that more emphasis could be placed on the importance of these connections to the integrity of downstream waters.

For example, the positive ecological effects of streamside vegetation are not limited to riparian wetland function, but include effects of inputs of leaf litter and terrestrial insects on downstream food resources, effects of woody debris on channel morphology, sediment and organic matter storage, hydrologic retention, and modulation of stream temperature. These benefits occur along the entire longitudinal stream profile, but are especially important to headwater streams. The SAB recommends that the Report be revised to expand the discussion of the effects of streamside vegetation on stream ecosystems. Some information about this topic is already provided in Section 5.3.1.3 of the Report. This information should be moved to Chapter 4, which discusses the physical, chemical, and biological connections of low-order streams and riparian areas.

The SAB also recommends adding information to address the importance of food-web connections from riparian zones to streams that support aquatic organisms. Organisms that define the biological integrity of downstream waters are embedded in food webs and these food webs transcend aquatic-terrestrial boundaries. Following are key points that should be included:

a) Streams receive organic matter in the form of leaves, wood, and other plant litter from riparian vegetation, and these supply essential carbon and nutrients to biota ranging from microbes to invertebrates, which in turn feed larger invertebrates, fish, amphibians, reptiles, birds, and mammals (e.g., Wallace et al. 1997; Baxter et al. 2005).

b) Streams also receive terrestrial invertebrates, which are used directly as prey by fish and amphibians, either in the same reach, or after flowing downstream from headwaters into reaches that support these predators (e.g., Nakano and Murakami 2001; Wipfli and Baxter 2010).

c) These linkages between riparian zones and streams are critical to maintaining the biological integrity of the Nation's waters. Data from comparative studies and experiments support the generalization that cutting off these connections can cause emigration or extirpation of organisms that rely on food web connections between streams and riparian zones (Fausch et al. 2010).

Overall, these food webs integrate key connections across aquatic and terrestrial landscapes and therefore provide a useful framework through which to view the role of riverine landscapes in connectivity among aquatic ecosystems.

Key Recommendations

- The Report should be revised and additional references should be added to expand the discussion of the effects of streamside vegetation on stream ecosystems.

- The SAB recommends adding information to the Report to document the importance of reciprocal food-web connections between riparian zones and streams on the integrity of the ecosystems that are connected to downstream waters

3.3.9. Clarifying How Case Studies Were Selected

As previously discussed, the SAB recommends the addition of text that clarifies how case studies were selected. In addition, a case study that focuses on human-dominated systems should be added to the Report in order to include information about the effect of human-dominated systems on downstream waters. For example, the Rio Grande case study on arid rivers provides excellent examples of human-modified systems and its description of human effects could be expanded. Other examples include the Baltimore and Central Arizona Long Term Ecological Research Projects (Cary Institute of Ecosystem Studies 2014; LTER Network 2014). The SAB notes that the San Pedro River example in the Section 4.8.4 of the EPA Report is never mentioned or interpreted in other parts of the Report.

Key Recommendations

- The Report should discuss the rationale used to select the case studies.

- The Report could contain a case study that illustrates the downstream effects of human-modified systems. The Baltimore and Central Arizona Long Term Ecological Research Projects are good examples.

3.3.10. Clarifying the Report Findings Concerning the Strength or Degree of Downstream Connectivity

The SAB recommends that the Report text be revised to address the strength or degree of downstream connectivity. In particular, the Report needs a more focused discussion of the relative strength/degree of connectivity of intermittent and ephemeral streams, including streams with evaporative losses, and their variable source areas. This could be achieved through a discussion of the frequency, duration, magnitude, predictability, and consequences of surface and subsurface connections. It is important to note that subsurface flows often persist after surface flows wane; further, these subsurface flows may provide important connectivity functions from ephemeral and intermittent streams to downstream waters. In addition, as previously mentioned, even ephemeral and intermittent streams and short duration surface water connections in source water areas may have substantial effects on the chemical and biological integrity of downstream waters. The SAB recommends that the following references (and others that are similar) be considered for inclusion in the Report to document the strength or degree of downstream connectivity: Goodrich et al. (2004); Graf (1988); Hernandez et al. (2000); Larsen et al. (2012); Osterkamp et al. (1994); and Stratton et al. (2009).

Key Recommendations

- The SAB recommends that the degree/strength of downstream connections be highlighted or discussed in each major subsection of Chapter 4 (e.g., for subsections on temperature, chemical, and biological connections). In particular, the SAB recommends that the Report contain a more focused discussion of the relative strength/degree of connectivity of intermittent and ephemeral streams to downstream waters.

- Additional references recommended by the SAB (and others that are similar) should be considered for inclusion in the Report to document strength or degree of downstream connectivity.

3.4. Ephemeral, Intermittent, and Perennial Streams: Review of the Findings and Conclusions

Charge Question 3(b). Conclusion (1) in section 1.4.1 of the draft Report Executive Summary discusses major findings and conclusions from the literature referenced in Charge Question 3 (a) above. Please comment on whether the conclusions and findings in section 1.4.1 are supported by the available science. Please note alternative wordings for any conclusions and findings that are not fully supported.

Conclusion 1 in Section 1.4.1 of the Report states that: "*The scientific literature demonstrates that streams, individually or cumulatively, exert a strong influence on the character and functioning of downstream waters.*" The Report further states that: *"All tributary streams, including perennial, intermittent, and ephemeral streams, are physically, chemically, and biologically connected to downstream rivers via channels and associated alluvial deposits where water and other materials are concentrated, mixed, transformed, and transported."* The SAB finds that the Report provides strong scientific support for these conclusions and findings. However, the EPA should recognize that there is a gradient of connectivity that is a function of the frequency, duration, magnitude, predictability, and consequences of physical, chemical, and biological processes. The SAB strongly supports the current emphasis in this Section of the Report on the importance of considering cumulative impacts and recommends minor but nevertheless important changes in the conclusions and findings in Section 1.4.1.

The Report should be revised so that the conclusions and findings in Section 1.4.1 are clearly linked to the foundational concept that connectivity is expressed in four dimensions (i.e., three-dimensional space, plus time) within the context of a catchment. The SAB recommends that the conclusions emphasize not only hydrologic linkages, but also include biogeochemical transformations and diverse biological connections. The text in Section 4.6 of the Report, "Synthesis and Implications," (p. 4-35) could be improved through the use of bullets to highlight the main findings as well as underscore the key stream functions (sources, sinks, refuges, transformations, and lags; Table 4.1) and their effect on downstream waters. The SAB recommends adding connectivity itself to Table 4.1, perhaps using both hydrological and biological connections as examples. In addition, the Report's five key functions and linkages (six if connectivity is included) should be reiterated succinctly and consistently across the relevant Report chapters. These are Sections 4.6, "Streams: Synthesis and Implications" (p. 4-35); Section 1.4.1, "Key Findings" (p.1-7); and Section 6.1, "Major Conclusions" (p. 6-1). At present, these summaries vary in content, length, writing and presentation style, and number of literature citations; the summary should not include reference to literature already cited in the Report. Most importantly, these inconsistencies obscure the Report's conclusions.

Key Recommendations

- The conclusions in Section 1.4.1 of the Report should be clearly linked to the foundational concept that connectivity is expressed in four dimensions (i.e., three dimensional space plus time) within the context of a catchment.

- The conclusions in Section 1.4.1 should emphasize not only hydrologic linkages, but also include biogeochemical transformations and diverse biological connections.

- Bullet points should be used to highlight main findings in the text on "Synthesis and Implications."

- Different types of connectivity (e.g., hydrologic, biological) should be added to Table 4.1 of the EPA report. In addition, the EPA Report should explain that not all connectivity in the watershed is hydrologic, and that biological connectivity should be mentioned as an example.

- The Report's key functions and linkages should be succinctly and consistently summarized across all the relevant Report chapters.

3.4.1. Recommendations to Strengthen the Findings and Conclusions Concerning Ephemeral, Intermittent, and Perennial Streams

The SAB recommends that the Report be revised to strengthen the findings and conclusions concerning ephemeral, intermittent, and perennial streams by addressing the specific issues discussed below.

Connectivity, Boundaries and Linkages

The SAB recommends that the statements in the Report that support conclusions about the connectivity of streams should be stated in quantitative terms wherever possible (For example: "of X studies, X% support the conclusion of connectivity.")

The SAB also recommends that the text of the Report be revised to provide better definition of boundaries (e.g., transitions between uplands and headwaters) and acknowledge where boundaries are difficult to define. The report should also better define and emphasize key linkages and exchanges that influence connectivity (e.g., groundwater-surface water interactions, flooding or other episodic events, and the influence of riparian zones) and how these linkages influence biota and food webs and vice versa. For example, the first sentence in Section 4.6, "Streams: Synthesis and Implications," should be revised to state "A substantial body of evidence unequivocally demonstrates connectivity *above and below ground.*" The conclusions should also reiterate how these linkages and exchanges influence physical, chemical, and biological connectivity with downstream systems.

The SAB finds that neither connectivity linkages that occur during flooding, nor the lack thereof during droughts, are well-recognized in the conclusions. Although drought is a natural disturbance, its effects can be exacerbated by human activities (e.g., water extraction, wetland drainage) with impacts on connectivity. In addition, the SAB recommends that text be added to the Report to explain hydrologic connectivity where surface water sustains aquifers in some environments, and aquifers sustain streams in other environments. Alluvial systems in the southwest and karst systems in the eastern United States could be used as examples. In addition, the perennial streams in the Colorado Plateau and the Rocky Mountain and High Plains systems could be used as specific examples of aquifers sustaining streams. Floodplains locally and regionally may function in one or both directions, particularly with spring runoff/flooding (groundwater recharge and water table rise) versus fall baseflow (groundwater discharge and water table lowering).

Ephemeral Streams

The Report concludes that existing evidence supports a sufficient link between ephemeral streams and downstream systems. This conclusion could be strengthened in three ways: (1) by adding text that describes spatial and temporal variation in linkages of ephemeral streams with downstream waters; (2) by summarizing existing evidence of the frequency, predictability, and duration of these connections; and (3) by identifying where further research is needed. For example, the Report currently emphasizes the important role of variable source areas (e.g., swales) in downstream connectivity; this role should be reiterated in the conclusions. In addition, the conclusions in the Report should emphasize that dynamic groundwater-surface water connections not only maintain the ecological integrity of ephemeral streams, but also connect them structurally and functionally to downstream waters, whether or not the upstream channels are perennial. Finally, the SAB recommends that the conclusions concerning ephemeral streams be strengthened by clarifying how and when ephemeral headwaters provide critical habitat and corridors for biota commonly connected to habitats associated with downstream rivers.

Chemical Connectivity and Nutrients

The SAB finds that the summary of chemical functions that has been included in the Report could be strengthened by adding details about how headwater streams influence sediment-bound nutrients, dissolved organic matter (DOM), and contaminants; the text now focuses primarily on nitrogen, with detailed examples provided only for nitrate as it related to denitrification.

The SAB also finds that Chapter 4 of the Report is currently too focused on headwaters as hotspots for uptake and transformation of nitrogen; more breadth across solutes should be added. The text should also be revised to include nutrient removal processes in the discussion on the importance of nutrient spiraling because both assimilatory and dissimilatory processes are important. Currently, the text focuses on the role of denitrification processes in removing nitrate-N from streams.

Treatment of Uncertainty

The SAB recommends that the EPA consider summarizing and displaying the Report's conclusions in matrix form. A well-designed matrix would better communicate: the evidence underlying each conclusion, the uncertainty for a given conclusion across different functions (i.e., source, sink, refuge, lag, and transformation), and the confidence in conclusions across different system types (e.g., streams versus adjacent wetlands). The SAB also recommends including in the Report brief characterizations of the temporal or spatial scales over which given functions or phenomena occur and their sizes, intensities, and effects. Use of graphical methods to convey the level of confidence in the Report's conclusions, e.g., similar to those in the Intergovernmental Program on Climate Change report (IPCC 2007) would also help to better communicate findings.

Case Studies and Context

The SAB finds that it is difficult to discern the intended illustrative points of the Report's case studies within the broader discussion of streams in Chapter 4. The case studies should be presented earlier and the SAB suggests that text boxes should be used to present the findings of case studies within the main body text. The longer case studies would have more impact if the key points of each were highlighted. In addition, the SAB also finds that some case study conclusions appear to be overreaching; for example, real-world management scenarios can contrast greatly with the situations described in the case study for arid streams.

For the summary conclusions in case studies, the SAB recommends that the EPA consider distinguishing flow-, geology- and climate-dependent conclusions that integrate with the broader more general conclusions provided elsewhere. As previously mentioned, the SAB finds that conclusions for the case studies could be improved by being explicit about how human activities alter (both increase and decrease) above- and below-ground connectivity of streams with downstream waters, ideally through the use of specific examples (e.g., perhaps using the Report's existing case studies). The SAB notes that each case study has its own unique bulleted list of conclusions, which makes it difficult to draw conclusions across the case studies or to relate individual case studies to the Report's general conclusions.

Consistent Statement of Conclusions throughout the Text

The SAB also notes that it is essential that descriptions of functions and linkages in the Report be consistently and succinctly stated in Section 4.6 "Streams: Synthesis and Implications" (pages 4-35 and 4-36) and Section 1.4.

Key Recommendations

- Statements in the Report that support conclusions about the connectivity of streams should be expressed in quantitative terms wherever possible. Descriptions of functions and linkages should be consistently and succinctly stated in Section 4.6 (pages 4-35 and 4-36) and Section 1.4.

- The SAB suggests that the EPA consider summarizing and displaying the Report's conclusions in matrix form, including brief characterizations of the temporal or spatial scales over which given functions or phenomena occur, and their sizes, intensities, and effects.

- The EPA's report should analyze the scientific literature and discuss how differences in flows affect connectivity emphasizing key linkages and exchanges that influence the magnitude and frequency of connectivity such as groundwater-surface water interactions, flooding or other episodic events, and the influence of riparian zones and also how these linkages influence biota and food webs and vice versa. The conclusions in the Report should then reiterate how these linkages and exchanges influence physical, chemical, and biological connectivity with downstream systems.

- The conclusions concerning ephemeral streams should be strengthened by: (1) adding text that describes spatial and temporal variations in linkages of ephemeral streams with downstream waters; (2) summarizing existing evidence of the frequency, duration, and predictability of these connections; (3) identifying where further research needed; and (4) clarifying how and when ephemeral headwaters provide critical habitat and corridors for biota to move among and within their habitats associated with downstream waters.

- Text should be added to the Report to explain how hydrologic connectivity in both directions can sustain aquifers. Alluvial systems in the southwest and karst systems in the eastern United States should be used as examples that influence the physical, chemical, and biological integrity of downgradient waters.

- The summary of chemical functions that has been included in the Report should include details about the ways that headwater streams influence sediment-bound nutrients, dissolved organic matter (DOM), and contaminants.

3.5. <u>Waters and Wetlands in Floodplain Settings: Review of the Literature</u>

Charge Question 4(a). Section 5.3 of the Report reviews the literature on the directional (downstream) connectivity and effects of wetlands and certain open waters subject to non-tidal, "bidirectional" hydrologic flows with rivers and lakes. Please comment on whether the Report includes the most relevant published peer-reviewed literature with respect to these types of wetlands and open waters. Please also comment on whether the literature has been correctly summarized. Please identify any published peer-reviewed studies that should be added to the Report, any cited literature that is not relevant to the review objectives of the Report, and any corrections that may be needed in the characterization of the literature.

The SAB generally finds that literature on the connectivity of waters and wetlands in floodplain settings included in the Report is fairly limited in scope (i.e., focused largely on headwater riparian wetlands) and should consider the gradient of connectivity that is a function of the frequency, duration, magnitude, predictability, and consequences of these connections. That said, the literature substantiates the conclusion that, in an overwhelming number of cases, floodplains and waters and wetlands in floodplain settings support the physical, chemical, and biological integrity of downstream waters. Additional emphasis, discussion, and reorganization of the information presented (and in some cases review of more recent and diverse literature) is needed to address the significance of multi-dimensional connectivity.

3.5.1. Structure of Section 5.3 of the Report

Chapter 5 of the Report addresses the physical, chemical, and biological connections of wetlands to rivers. Section 5.3 focuses on wetlands in riparian and floodplain settings and covers a wealth of topics. The Section could be strengthened by reorganizing the information presented, incorporating key literature that is now missing and, as with other sections, by technical editing of both the text and glossary.

The SAB recommends that Section 5.3 of the Report be reorganized to clarify the functional role of floodplain systems in maintaining the ecological integrity of streams and rivers. Much of the text in Section 5.3 is focused on headwater riparian zones and the importance of headwater, streamside areas to in-stream structure and function. As written, Section 5.3 of the Report is 16 pages in length, with only 6 pages that focus specifically on floodplain dynamics. The SAB recommends that the material on low-order stream riparian areas be moved from Section 5.3 to Chapter 4 of the Report, which discusses the physical, chemical, and biological connections of low-order streams and riparian areas (see also recommendations in Section 3.3.8 of this SAB report). In particular, the material in Sections 5.3.1 and 5.3.2, which focus on the physical and chemical influence of riparian areas, is more appropriately located in Chapter 4. Chapter 4 already includes discussions of the role of riparian forests in regulating water temperature and providing inputs of large woody debris, but leaves the discussion of other functions, such as ability of these areas to act as nutrient sinks and transformers, to Chapter 5. Consolidating the entirety of the literature review on the dynamics of low-order stream riparian areas into Chapter 4 would help organize and clarify the text. This will leave the emphasis of Section 5.3 on the structure and function of larger river systems, particularly floodplains and their lateral dimensions. This will also require editing throughout the report for consistency so that the use of headwater riparian terminology is separated from discussion of waters and wetlands in floodplain settings as much as possible.

The EPA should consider reorganizing the information on the different taxonomic groups (plants and phytoplankton, vertebrates, and invertebrates) that are described in Sections 5.3.3.1-5.3.3.3 of the Report to integrate the functional attributes of floodplains as habitats, rather than addressing each group separately, textbook style (Amoros and Bornette 2002). The EPA should also consider reviewing the following additional selected references on fauna in waters and wetlands in floodplain settings: Brooks et al. (2013); Baxter et al. (2005); Bestgen et al. (2006); Bestgen et al. (2007); Bottom et al. (2005); Fausch (2010); Flecker et al. (2010); McIntyre et al. (2007); Mion et al. (1998); Modde et al. (2001, 2005); Spinola et al. (2008); and Zelasko et al. (2010).

Key Recommendations

- Section 5.3 of the Report should be reorganized by moving the text on low-order riparian areas and the role of headwater, streamside areas on in-stream structure to Chapter 4 of the Report. Section 5.3 should focus on the functional role of floodplains in higher-order rivers and the literature review should more fully reflect the physical, chemical and biological linkages between floodplains and downstream waters (i.e., lateral exchange between floodplains and rivers followed by downstream transport) within riverscape (Wiens 2002) and riverine landscape (Ward et al. 2002; Thorp 2006) perspectives.

- EPA should consider reorganizing the information on the different taxonomic groups (plants and phytoplankton, vertebrates, invertebrates) that are described in Sections 5.3.3.1-5.3.3.3 of the Report to integrate the functional attributes of floodplains as habitats, rather than addressing each group separately.

- Additional references on fauna in waters and wetlands in floodplain settings have been recommended by the SAB and should be considered for inclusion in the Report.

3.5.2. Terminology in Section 5.3 of the Report

A broad view of the ecological and functional roles of floodplains, irrespective of their regulatory status, allows a more representative cross section of the literature to be included. This approach is consistent with including a wide range of wetlands (Cowardin et al. 1979) rather than exclusively those meeting the federal regulatory definition. The Report should contain a statement that the text refers to riverine landscape settings in their entirety, with its characteristic four-dimensions of connectivity (Ward 1989); however, the SAB also recommends that the authors clearly indicate these areas are covered in the report because of functional linkages and not policy goals.

As previously mentioned, the SAB recommends that "bidirectional" wetlands on floodplains be called "waters and wetlands in floodplain settings. "Unidirectional" wetlands as defined in the EPA Report are discussed in Sections 3.7 and 3.8 of this SAB report. This change in terminology is needed to acknowledge the multi-dimensional flux of water and materials between floodplains and riparian areas and their associated rivers and streams. Consistent use of these terms is important for clarity, as the inconsistent uses of "riparian/floodplain wetlands," "riparian areas," or "floodplains" in some sections of Chapter 5 is confusing. The definitions of "Riparian Area," "Riparian Wetland," "Floodplain," "Floodwater," and "Floodplain Wetland" in the glossary of the Report should also be revised to be consistent.

Key Recommendations:

- The Report should discuss the functional role of floodplains and riparian areas regardless of their regulatory status. However, it should be made clear that this discussion does not imply an expansion of the definition of waters and wetlands under the jurisdiction of the Clean Water Act.

- The terms "unidirectional" and "bidirectional" wetlands should be revised to reflect the landscape position of the water body and/or wetland in question. Thus, it is suggested that "bidirectional" wetlands be called "waters and wetlands in floodplain settings."

- The definitions of "Riparian Area," "Riparian Wetland," "Floodplain," "Floodwater" and "Floodplain Wetland" in the glossary of the Report should align with the ways the terms are used in the text.

3.5.3. Spatial and Temporal Connectivity of Floodplain Environments to River Systems

Spatial and temporal connectivity between the stream and floodplain are the primary determinants of physical and biological processes occurring within both the stream and the floodplain (e.g., Junk et al. 1989). Thus, Section 5.3 of the Report should include a new subsection that explicitly discusses how floodplain environments (including the terrestrial components thereof) are functionally linked to river systems, both spatially and temporally, for example, by means of the lateral "flood pulse" for surface water connections, and vertical connections to alluvial aquifers. The more current, integrated view of "riverscapes" (Wiens 2002) and "riverine landscapes" (Ward et al. 2002, Thorp et al. 2006) as a mosaic of patches that are shaped by the four components of connectivity at the habitat, floodplain, and river corridor scales, as well as disruptions caused by drought, could also be addressed in the new subsection. This riverine landscape perspective (Ward et al. 2002; Thorp et al. 2006) can provide the organizational backbone of the subsection, stressing higher order river structure and function while recognizing that there exist gradients of floodplain development along the drainage network. Although the flood pulse concept is acknowledged in the Report as a fundamental paradigm in river ecology (p. 5–6, line 5; page 6–4, lines 1-2), the conceptualization and hydrologic characterization of floodplain wetlands in either spatial or temporal dimensions remain undeveloped. The Report also recognizes the extension of the flood pulse concept to include “flow pulses” (Tockner et al. 2000) but does little to recognize how riverine landscapes (including floodplains and the wetlands within them) function through storm–related changes in flow, seasonal variation in water abundance and river discharge, and longer–term changes related to climate shifts and precipitation regimes. The references to “flood pulse” in the Report are limited, relating to flood attenuation in the main channel (p. 5–6, lines 5, 29; Table 5–3, page 5–38), or the influence of the flood pulse on biological entities (e.g., page 5–20, lines 16, 22, 29).

Short-duration, high-intensity flood events for surface waters and long-duration, low-intensity lateral discharge for groundwater need additional emphasis, including descriptions of the influence of the flooding on residence time of surface water, seasonal exchanges with groundwater, chemical and biological linkages, and ecosystem processes. For example, effects of low-frequency, high-intensity flood events on downstream waters chiefly affect physical connectivity, including water storage, peak flow attenuation, and sediment and wood transport and/or deposition. This occurs on a decadal or centennial return interval and the spatial scale of this type of flood event tends to be extensive, dictated largely by topography, and covering all available habitats. At the other end of the spectrum, the effects of high-frequency, low-intensity forms of connectivity (such as hyporheic groundwater flow) may drive biological or biogeochemical functions, including nutrient and contaminant transformation and organic matter accumulation. The spatial scale of this type of connectivity depends on whether groundwater discharge in the floodplain is discrete (e.g., an alluvial spring) or diffuse, and whether it travels through the floodplain as channelized flow or in the hyporheic zone. The role of groundwater movement and storage, including the effects of flood pulses on the hydrologic differences between, for example, “slope” (primarily groundwater fed) and “riverine” (primarily surface water fed) wetlands (per the hydrogeomorphic classification scheme; Brinson 1993), and the role of chemical/contaminant movement and storage related to groundwater systems in floodplains, have been quantified via flow and transport modeling using both steady-state and transient analysis to simulate temporal changes.

Finally, the potential for drought to disrupt connectivity by reducing water availability and disrupting hydrologic connectivity should be acknowledged. Drought has both direct and indirect effects, including the loss of available habitat, changes in water quality, and alterations in the strength and structure of species interactions (Lake 2003). Climate change is expected to exacerbate the impacts of drought by increasing the frequency and intensity of low flows (van Vilet and Zwolsman 2008).

Placing floodplain wetland environments into the context of the “riverine landscape” requires a perspective that considers how lateral flows caused by flood events influence the expansion of and linkages among these environments. The Report should clearly articulate the “bidirectional” nature of fluxes of water, materials, and biota to and from the river channel, as well as the temporal pattern of flows relative to the flood pulse. The manner in which the riverine landscape view fits within the conceptual framework can be illustrated by highlighting in Section 5.3 of the EPA Report the effects of floodplains not only on river flows, but also on chemistry, sediments, and biota of downstream waters. The SAB provides a number of specific recommendations to more clearly articulate the importance of lateral flows. Flood-forecasting methods can be used as a means to quantify the strength of connectivity (spatial and temporal) between floodplains and rivers. Hydrological measures of flood frequency and floodplain inundation can provide estimates of water residence time (or hydroperiod) on floodplains, with implications for fluxes of biota and biogeochemical processing of nitrogen (N), phosphorus (P), and other constituents. The results of flood forecasting are measures of vertical and lateral connectivity. Flood forecasting analyses require that recurrence intervals be explicitly defined, for example making estimates over a reasonable range of overbank flows (2 years out of 3, to 10-yr and 100-yr events), to establish variability in the time scales of connectivity. Such analyses would focus much needed attention on magnitude-frequency relationships.

The EPA should consider incorporating into the Report examples of floodplain classification systems (e.g., Nanson and Croke 1992) that address floodplain geomorphological and functional diversity and emphasize the continuum of floodplains along stream networks. Describing the ways in which floodplain/channel geomorphology and the duration of flooding or saturation shape the degree of connectivity between floodplains and downstream waters also would be useful. The SAB also recommends addressing flood frequency-floodplain inundation science as a means to estimate the degree of connectivity. Channel migration zones (Rapp and Abbe 2003; Brummer et al. 2006), which describe the movement of channels within floodplains and their valley floors over time, explain the variable nature of connectivity (in space and time) of floodplains and the waters/wetlands that they contain. In one year a floodplain can exist on one side of the channel and the next year, following a large flood, the active channel may have migrated 100 meters to the opposite side, stranding the former floodplain and creating new floodplains on that side. Thus floodplains, including wetlands, are temporally variable and transient, and connectivity could include what has been referred to as the “channel migration zone.” Some states have promulgated regulations about how to define and protect (regulate development of) channel migration zones that are non-floodplain portions of the valley floor.

The Report should emphasize the importance of floodplain connections and processes - such as sediment movement, erosion and deposition - that operate through downstream, lateral, vertical and temporal dimensions. Additional literature should be reviewed and cited in Section 5.3 of the Report to demonstrate that lateral connections create a diversity of lotic, semi-lotic and lentic habitats within the riparian zone, supporting a wide array of taxa (e.g., fish, amphibians, birds, mammals) and high levels of diversity. The SAB has provided some references (cited below) that address the role of wetlands and off-channel waters on floodplains that are spawning grounds and fish nurseries during high-water seasons for species that ultimately populate downstream fisheries and include several endangered fishes (e.g., Modde et al. 2001; 2005; Bestgen et al. 2007).

The SAB also recommends that a broader range of examples of waters and wetlands in floodplain settings be used in the Report to make it more representative of the United States as a whole. For instance, the EPA could incorporate studies on peatlands in floodplain settings that have “bidirectional” flows, as in northern tier states and Alaska, and coastal lowland wetlands of Hawaii that serve as barriers to sediment and nutrient loading to seagrass and coral reef habitat (e.g., Bruland 2008).

The SAB recommends that the EPA consider reviewing the following selected references (and others that are similar) to document how the hydrologic phenomenon of the flood pulse links rivers to the floodplain (and consequently to wetlands within them): Alford and Walker (2013); Anderson and Lockaby (2012); Benke et al. (2000); Bunn et al. (2006); Ellis et al. (2001); Galat et al. (1998); Granado and Henry (2014); Heiler et al. (1995); Henson et al. (2007); Hudson et al. (2012, 2013); Magana

(2013); Nanson and Croke (1992); Opperman et al. (2010); Power et al. (1995a,b); Powers et al. (2012); Rooney et al. (2013); Schramm and Eggleton (2006); Sullivan and Rodewald 2012; Sullivan and Watzin (2009); Thorp et al. (2006); Tockner et al. (2000); Toth and van der Valk (2012); and Valett et al. (2005).

The SAB also recommends that the EPA consider reviewing the following references that provide information concerning quantification of groundwater mediated linkages of waters and wetlands in floodplain settings: Appel and Reilly (1994); Kolm (1998); Winter et al. (1998); Nelson et al, (2003); Conaway and Moran (2004); Harbaugh (2005); McDonald et al. (2005); Markstrom et al. (2008); Huntington and Niswonger (2012); and Woolfenden and Nishikawa (2014).

Key Recommendations:

- Section 5.3 of the Report should contain a new subsection that explicitly discusses how floodplain environments (including the terrestrial components thereof) are intimately linked to river systems, both spatially and temporally, by means of the “flood pulse” and recent extensions thereof. The “riverine landscape” framework should be employed as the conceptual backbone of the new subsection, stressing dynamic lateral connections between the floodplain (surface and groundwater) and downstream waters, recognizing the full range of temporal and spatial variability (e.g., short duration, high-intensity floods for surface waters; long-duration, low-intensity lateral discharge for groundwater; drought.)

- Section 5.3 of the Report should emphasize the effects of floodplains not only on river flows, but also on hydrological connections and processes affecting biota, chemistry, and sediment movement through downstream as well as lateral, vertical and temporal dimensions. Flood-forecasting methods could be used as a means to quantify the strength of connectivity (spatial and temporal) between floodplains and rivers.

- The EPA should consider incorporating into the Report examples of floodplain classification systems to address the geomorphological and functional diversity of floodplains, and to place emphasis on the continuum of floodplains along stream networks. Channel migration zones could be used to demonstrate the variable nature of connectivity (in space and time) of floodplains and the waters/wetlands that they contain.

- Additional literature should be reviewed and cited in Section 5.3 of the Report to demonstrate how lateral connections create a diversity of lotic, semi-lotic and lentic habitats, supporting a wide array of taxa (e.g., fish, amphibians, birds, mammals) and high levels of diversity. More emphasis is needed in Section 5.3 of the Report on these biotic exchanges.

- The range of examples of waters and wetlands in floodplain settings in the Report could be broadened to make it more representative of the United States as a whole. For instance, the EPA could incorporate studies on peatlands in floodplain settings that have “bidirectional” flows, as in northern tier states and Alaska and coastal lowland wetlands of Hawaii.

- The EPA should consider reviewing and including in the Report additional references recommended by the SAB to document how the hydrologic phenomenon of the flood pulse links rivers to the floodplains.

3.5.4. Chemical Linkages

Wetlands and floodplains serve as sources, sinks and transformers of nutrients and other chemical contaminants, and have a significant impact on the physical, chemical, and biological integrity (including ecosystem productivity) of downstream waters. The primary driver of chemical linkages is ecosystem biogeochemistry, which involves the exchange or flux of materials between living and non-living components. These fluxes involve interaction of complex physical, chemical, and biological processes in various components of the ecosystem. Biota (plants, microbes, and fauna) can be considered as exchange pools that are small in size and undergo rapid turnover and cycling. Abiotic components of wetlands and floodplains (e.g., soil), which are large in size, undergo slow turnover and provide long-term storage similar to a reservoir. The amount of a given constituent in these pools depends on its residence time. It is important to acknowledge these issues in the Report.

The SAB recommends that the authors of the Report provide a more recent and diverse assessment of the biogeochemical implications of exchange flows. This can be accomplished by enhancing the review of the literature on the role of wetlands and floodplains as sources, sinks, and transformers of materials including: nutrients, metals, organic contaminants, and sediments. The Report sections on microbial nitrogen processing (denitrification), phosphorus cycling, and sediments (including legacy sediments and associated chemicals) could be strengthened with an expansion of the literature reviewed. The review on nitrogen processes in Section 5.3.2.2 of the Report is of particular concern due to its very heavy reliance on a single paper by Vidon et al. (2010), cited 20 times in that section, on the fate and fluxes of nitrogen in riparian areas. There is an extensive literature on this subject and while the Report correctly characterizes nitrogen transformations in a general sense, there are many key references that could be included. For example, the Report should be updated to provide a more recent and diverse assessment of biogeochemical implications of “hot-spots and hot-moments” in nitrogen fluxes that are associated with hydrologic exchanges between surface and subsurface waters, and the residence time of water in those locations (e.g., McClain et al. 2003; Groffman et al. 2003). This information may best be located in Chapter 4 with the review of low order riparian zones. The SAB also recommends that, in general, the literature findings in this section (as in much of the Report) be more quantitative and not reported by simple qualitative statements; for example, rather than stating that nitrogen levels increased or decreased, the Report should indicate the percent concentration change. The SAB notes that, depending on hydrologic connectivity and water residence time, floodplain soils exhibit a range of redox conditions, which then regulate biogeochemical cycling of key nutrients, metals, and organic compounds.

The Report should indicate that changing climatic conditions may stimulate or alter rates, fluxes and storage pools of key elements (carbon, nitrogen phosphorus, and sulfur) involved in biogeochemical processes and services provided by wetlands. For example, accelerated decomposition of organic matter can potentially increase nutrient generation, which may lead to increased nutrient/contaminant loading to adjacent water bodies. Important inorganic elements in wetlands are mobile and thus their concentrations may increase upon flooding and drainage cycles, water withdrawals, sea level rise, and increases in temperature. The bioavailability of many inorganic elements required for key biological processes (e.g., plant growth and decomposition) will respond to these changing conditions. Drainage also increases enzyme and microbial activities, which facilitates oxidation of organic matter and leads to subsidence and loss of organic soils. Many studies have shown that oxidation of organic matter in wetlands is dependent on water-table depth, temperature, nutrient loading, vegetation communities and release of nutrients. “Bidirectional” exchange of particulate organic matter (POM) and dissolved organic matter (DOM) in floodplains can be an important source of organic matter to streams and rivers. Further treatment of the residence time of water could also be considered. Water residence time is a critical concept that can have significant biological impacts, which can be particularly relevant to downstream waters. Powers et al. (2012) point out that aquatic ecosystem components that have relatively high nutrient processing rates may not contribute substantially to total ecosystem retention unless enabled by hydrological connections.

The SAB recommends that the EPA consider including in the Report the following references on biogeochemistry: Aitkenhead-Peterson, et al. (2003); Fowler (2004); Bridgham et al. (2001); Bridgham et al. (2006); Buresh et al. (2008); Fennessy and Cronk (1997); Freeman et al. (20004a,b); Hefting et al.(2004); Osborne (2005); Qualls and Richardson. (2003); Reddy et al. (1999); Reddy et al. (2005, 2011); Strack et al. (2008); and Wetzel (1990, 2002).

Key Recommendations:

- The discussion of the chemical implications of exchange flows should include literature on the biogeochemistry of wetlands and floodplains, and their role as sources, sinks, and transformers of materials including: nutrients, metals, organic contaminants, and sediments (additional references are provided in Sections 3.5.4 and 3.5.8 of this SAB report).

- The Report could further discuss how changing climatic conditions may stimulate or alter rates, fluxes and storage pools of key elements (carbon, nitrogen phosphorus, and sulfur) involved in biogeochemical processes and services provided by wetlands (additional references are provided in Section 3.5.4 and 3.5.8 of this SAB report).

- The Report sections on nitrogen processing (denitrification), phosphorus cycling, and sediments (including legacy sediments and associated chemicals) should be strengthened by expanding the literature reviewed. In particular, Section 5.3.2.2 of the Report should be updated to provide a more recent and diverse assessment of biogeochemical implications of “hot-spots and hot-moments” in nitrogen fluxes that are associated with residence time and hydrologic exchanges between surface and subsurface waters (see references in Section 3.5.4). The discussion about water residence time also could be expanded given its significant impacts on downstream water chemistry and biology (additional references are provided in section 3.5.8 of this SAB report).

- The Report should make quantitative, rather than simple qualitative, statements whenever possible; (e.g., nitrogen levels increased by 25%).

3.5.5. Export versus Exchange

Floodplains as well as waters and wetlands in floodplain settings are shaped by repeated inundation, saturation, erosion and deposition of sediment, and movement of biota. Water and materials flow laterally between floodplains and rivers (i.e., downstream waters), moving onto the floodplain in periods of high flows and back to the channel as floods recede. As mentioned previously, the Report does not clearly articulate the multi-dimensional nature of connectivity between the floodplain and channel. The SAB recommends strengthening the focus of the Report on the fluxes of water, materials and biota to emphasize how exchange flows respond to the temporal progression of the flood pulse.

Key Recommendation

- There should be a stronger focus in the Report on the multi-directional fluxes of water, materials and biota to emphasize how exchange flows respond to the temporal progression of the flood pulse.

3.5.6. Case Studies

The SAB finds that the report would benefit from more discussion of forested wetlands, including bottomland hardwoods, given their ecological importance, rate of loss, and unique attributes. These wetlands represent a significant portion of remaining United States wetlands. A case study could address this gap and illustrate the role of bottomland forests on river biogeochemistry and flood storage.

Key Recommendation

- It would be useful to include in the Report a case study illustrating the role of forested wetlands (including bottomland hardwoods) in river biogeochemistry and flood storage.

3.5.7. Human Impacts and Aggregate Effects on Waters and Wetlands in Floodplain Settings

The manner in which human activities impact the connectivity of waters and wetlands in floodplain settings is an important issue that should be addressed in the Report. An example of such an impact is channel incision or levee construction that breaks the link between floodplain waters and wetlands with downstream waters. Alterations that reduce the connectivity of floodplains and waters and wetlands in floodplain environments provide some of the clearest demonstrations of the functional role of these areas with respect to downstream waters (for example, through degraded water quality as urban and agricultural runoff increases, leading to downstream sediment and nutrient enrichment). A key approach to this analysis is to provide examples of the aggregate effects of watershed land use change and floodplain impacts on downstream waters in terms of flooding, biodiversity, and materials flux (Barksdale et al. 2013). The water quality benefits of riparian areas and floodplains should also be highlighted in the Report by explicitly pointing out that their destruction exacerbates nutrient runoff from agricultural lands by reducing or eliminating nutrient uptake, dentrification, and sedimentation of adsorbed phosphorus. The EPA should consider reviewing the following references on human impacts to waters and wetlands in floodplain settings: Dudley and Platania (2007); and Verhoeven et al. (2006).

Key Recommendations

- The Report should address how human activities impact the connectivity of waters and wetlands in floodplain settings. Additional references recommended by the SAB should be considered for inclusion in the Report.

- The Report should highlight how the destruction of riparian areas and floodplains can impair water quality by exacerbating nutrient runoff from agricultural lands, reducing or eliminating nutrient uptake, dentrification, and sedimentation of adsorbed phosphorus.

3.6. <u>Waters and Wetlands in Floodplain Settings: Review of the Findings and Conclusions</u>

Charge Question 4(b). Conclusion (2) in section 1.4.2 of the Report Executive Summary discusses major findings and conclusions from the literature referenced in Charge Question 4(a) above. Please comment on whether the conclusions and findings in section 1.4.2 are supported by the available science. Please suggest alternative wording for any conclusions and findings that are not fully supported.

3.6.1. Scientific Support for the Findings and Conclusions Concerning Waters and Wetlands in Floodplain Settings

The SAB finds that there is strong scientific support for the conclusion that floodplain water bodies and wetlands are connected to downstream waters through multiple pathways (including hydrological, chemical, and biological connectivity). However, as further discussed below, the SAB recommends that additional literature be included in the Report to bolster these findings, particularly as related to chemical and groundwater connectivity. The EPA should also recognize that there is a gradient of connectivity between wetlands and waters in floodplain settings and downstream waters that is a function of the frequency, duration, magnitude, predictability, and consequences of physical, chemical, and biological processes. In addition, the SAB notes that the key findings and conclusions presented in Section 1.4.2 of the executive summary of the Report should be directly related to and parallel the information presented in Section 5.3 on Floodplain Wetlands. Any conclusions presented in Section 1.4.2 of the executive summary should also align with conclusions presented in Sections 5.5, the wetlands synthesis and implications discussion, and 6.1, the discussion of major conclusions.

The SAB recommends that the EPA Report discuss river-floodplains as integrated ecological units, following riverscape (*sensu* Wiens 2002) and riverine landscape (*sensu* Ward et al. 2002; Thorp 2006) perspectives. Currently, many of the conclusions in the Report are drawn from literature related to non-floodplain riparian zones (i.e., headwater riparian wetlands), which potentially undermines the ability to speak to connectivity between waters and wetlands in floodplain settings and downstream systems. Thus, the SAB recommends replacing the current riparian focus with a discussion focused on the science of larger river (i.e., high-order) floodplain systems, and moving the riparian focus to Chapter 4, where the focus can largely remain on the dynamics of low-order streams.

Key Recommendations

- There is strong scientific support for the conclusion that waters and wetlands in floodplain settings are highly connected to downstream waters through multiple pathways including hydrological, chemical, and biological connectivity. However, a broad discussion of river-floodplain systems as integrated ecological units should replace the current headwater riparian focus and be included in Section 5.3 of the Report. The riverine landscape framework (Ward et al. 2002; Thorp et al. 2006) should be employed as the conceptual backbone of the section. Additional literature should be included in the Report to bolster findings as related to chemical and groundwater connectivity.

- Key findings and conclusions presented in Section 1.4.2 of the executive summary of the Report should be directly related to the information presented in Section 5.3 on Floodplain Waters and Wetlands. Conclusions presented in Section 1.4.2 of the executive summary should also align with conclusions presented in Sections 5.5, the wetlands synthesis and implications discussion, and 6.1, the discussion of major conclusions.

3.6.2. Additional Recommendations for the Findings and Conclusions for Waters and Wetlands in Floodplain Settings

The SAB recommends that the EPA address the following issues in the discussion of the findings and conclusions for waters and wetlands in floodplain settings.

Inconsistent Terminology

As previously mentioned, the Report's use of terms should remain consistent both within the key findings and conclusions sections as well as throughout Section 5.3. The terms "riparian areas," "riparian and floodplain areas," and "riparian/floodplain waters" are used inconsistently in Tables 5.1 and 5.3. The SAB encourages consistent use of these (and other) terms and suggests providing clarification of the differences among them in the definitions. The SAB notes that the glossary definitions in the Report distinguish between "riparian areas" and "riparian wetlands" as well as among "floodplain," "floodwater," and "floodplain wetland." "Upland" is also defined in the glossary as: *(1) Higher elevation lands surrounding streams and their floodplains. (2) Within the wetland literature, specifically refers to any area that is not a water body and does not meet the Cowardin et al. (1979) three-attribute wetland definition.* These are examples of the use of multiple definitions that, while not incorrect, are sufficiently different to potentially cause confusion. Most importantly, the SAB suggests that "bidirectional" wetlands be called "waters and wetlands in floodplain settings" and that headwater riparian terminology be disentangled from this section to the degree possible. The terminology used in the key findings and conclusions of the Report should align with the glossary definitions and the conceptual framework.

Temporal Component

As previously mentioned, the key findings and conclusions in the Report should recognize the temporal dimension of waters and wetlands in floodplain settings relative to downstream connectivity, consistent with the four-dimensional nature of the conceptual framework set forth in Chapter 2. Water residence times and the transient nature of floodplains should be key points. This temporal perspective, combined with an emphasis on developing and illustrating the strength of connectivity, could be done using the well-developed science of flood forecasting (probability) as a function of vertical and lateral connectivity. Incorporating discussion of flood frequency-floodplain inundation science into the Report might prove to be effective for highlighting how hydrologists estimate the degree of connectivity. Brief reference to the flood-pulse and riverine landscape concepts, discussed within the conceptual framework (Chapter 2), would reinforce the functional significance of regular or episodic floodplain inundation.

Discussion of "channel migration zones", which describe the movement of channels within floodplains over time as a result of large floods (Rapp and Abbe 2003, Brummer et al. 2006, Washington Department of Ecology 2011), would further address the lateral connectivity of rivers to their valley floors and the variable nature of connectivity in both space and time. The role of groundwater movement and storage should also be highlighted. This discussion should include the effects of flood pulses on the hydrologic differences between slope and riverine wetlands and the role of chemical/contaminant movement and storage related to groundwater systems in floodplains. These effects have been quantified by flow and transport modeling using both steady-state and transient analysis to simulate temporal changes.

Overall, the EPA's conclusions concerning connectivity of waters and wetlands in floodplain settings should reflect the main message of a new spatial and temporal subsection in Section 5.3, as recommended in Section 3.5 of this SAB report.

Further Quantification of Key Conclusions

The key conclusions for waters and wetlands in floodplain settings should be more empirically and/or more specifically described. Whenever possible, the degree of and/or strength of evidence for connectivity should be quantified (e.g., of X studies, X% support the conclusion of connectivity).

Chemical Linkages (including biogeochemical cycling)

The role of waters and wetlands in floodplain settings in storing and transforming chemical constituents, including the biogeochemical implications of exchange flows, should be expanded under Key Finding (d) in Section 1.4.2 of the Report. This may require additional literature review (in Section 5.3) to incorporate literature on floodplain wetlands and water bodies rather than relying on headwater riparian examples. Changes to nutrients (both N and P) and sediments should be easily documented. There is ample literature on the improved water-quality function of wetlands, and this is the rationale for constructed wetlands. Additionally, there is an opportunity to link the discussion of the role of wetlands and other water bodies in storing and transforming chemical constituents to the regulation and management of chemical contaminants.

Biological Linkages Including Food Webs

The role of biological connectivity between waters and wetlands in floodplain settings and downstream systems should be further highlighted in the key findings and conclusions. In particular, the SAB encourages the EPA to highlight the point that waters and wetlands in floodplain settings and downstream systems are intimately linked through biological connections (including integrated wetland-river food webs) across a range of spatial and temporal scales. In this regard, the Report should explicitly discuss linkages to downstream waters. For example: "Floodplain wetlands can provide critical nursery habitat for fish*, which then disperse into downstream waters, becoming part of river food webs and serving as a biological vector of nutrients*." There also may be an opportunity to mention the importance of waters and wetlands in floodplain settings to species that are economically important or listed as endangered, but this would have to be first developed in the body of the Report.

Export versus Exchange

As previously discussed, an "exchange" versus "export" framework (i.e., reciprocal exchanges between waters and wetlands in floodplain settings and downstream waters) should be used in the Report. In this way, the EPA can clearly indicate that multi-directional biological, chemical, and hydrological transfers characterize the connections between the two systems.

Case Studies

The SAB finds that the case studies in the Report are useful. However, the findings from the case studies should be more explicitly linked to the overall conclusions in Section 1.4 of the Report. As previously mentioned, the SAB finds that the Report would benefit from more discussion of forested wetlands, including bottomland hardwoods, given their ecological importance and their rate of loss. The SAB recommends that key information from case studies be presented in side boxes, with more detailed information included as appendices.

Human Impacts

In some cases, human alteration of connectivity provides the clearest demonstration of how waters and wetlands in floodplain settings are functionally linked to adjacent waters. Thus, the conclusions in the Report could be strengthened by explicitly mentioning how human activities (impairment as well as restoration) alter connectivity of waters and wetlands in floodplain settings with downstream waters. Mention should be made of alterations that both increase connectivity, such as ditches, and decrease connectivity, such as levees and water extraction activities that reduce the water table. Again, using the flood frequency-lateral connectivity argument, this might represent a strong opportunity to illustrate how diking has clearly diminished connectivity both in individual river segments as well as in the aggregate. Many floodplains along stretches of rivers, if not entire rivers, may be affected by diking. Other modifications should also be considered, including routine dredging/channelization, which can severely impair (or eliminate) floodplain function.

Aggregate/Cumulative Effects

The importance of considering waters and wetlands in floodplain settings in the aggregate should be underscored in the key findings and conclusions of the Report. For example, these sections could briefly illustrate how floodplain storage in the aggregate (e.g., floodplains in dozens to hundreds of individual channel reaches) yields many ecological services, including flood attenuation.

Key Recommendations

- The key findings and conclusions in the Report should better recognize the temporal dimension of waters and wetlands in floodplain settings relative to downstream connectivity, consistent with the four-dimensional nature of the conceptual framework set forth in Chapter 2. Water residence times and the transient nature of floodplains should be key points. The well-developed science of flood forecasting (probability) as a function of vertical and lateral connectivity may be particularly useful in developing this temporal perspective.

- The role of waters and wetlands in floodplain settings in storing and transforming chemical constituents (i.e., their biogeochemical functions) should be expanded under Key Findings in Section 1.4.2 of the Report. The role of biological connectivity between waters and wetlands in floodplain settings and downstream waters should also be further highlighted in the key findings and conclusions.

- The importance of considering waters and wetlands in floodplain settings in the aggregate, as well as the ways in which human activities (impairment as well as restoration) alter connectivity of waters and wetlands in floodplain settings with downstream waters, should be underscored in the key findings and conclusions of the Report.

- Report language referring to floodplain waters and wetlands should remain consistent both within the key findings and conclusions sections as well as throughout Section 5.3. The terminology used in the key findings and conclusions of the Report should align with the glossary definitions and the conceptual framework. The findings from the case studies in the Report should be explicitly linked to the overall conclusions.

- The key conclusions for waters and wetlands in floodplain settings should be more empirically and/or more specifically described. Wherever possible, the degree of and evidence for connectivity should be quantified (e.g., of X studies, X% support conclusion of connectivity).

3.6.3. Alternative Wording for Findings and Conclusions

The SAB recommends the following specific revisions to clarify the conclusions in Section 1.4.2 of the Report:

- Section 1.4.2 should consistently refer to "waters and wetlands in floodplain settings."

- Section 1.4.2 should indicate that waters and wetlands in floodplain settings form integral components of river food webs.

- The text in finding (c) should indicate that waters and wetlands in floodplain settings can reduce flood peaks by storing and subsequently releasing floodwaters.

- The example in finding (d) appears to be an agricultural best management practice. A more relevant example may be provided from the text on page 5-7.

- In finding (e) the lead sentence emphasizes ecosystem function but the body of the paragraph describes biological connectivity. Finding (e) should discuss the importance of waters and wetlands in floodplain settings to birds, and how birds can spatially integrate the watershed landscape.

3.7. <u>Waters and Wetlands in Non-floodplain Settings: Review of the Literature</u>

Charge Question 5(a). Section 5.4 of the draft Report reviews the literature on the directional (downstream) connectivity and effects of wetlands and certain open waters, including "geographically isolated wetlands," with potential for "unidirectional" hydrologic flows to rivers and lakes. Please comment on whether the Report includes the most relevant published peer-reviewed literature with respect to these types of wetlands and open waters. Please also comment on whether the literature has been correctly summarized. Please identify any published peer-reviewed studies that should be added to the Report, any cited literature that is not relevant *to the review objectives of the Report, and any corrections that may be needed in the characterization of the literature.*

The SAB finds that the review and synthesis of the literature on the downstream connectivity and effects of "unidirectional" wetlands and open waters in non-floodplain settings is, technically accurate. As previously mentioned, the SAB recommends the authors reconsider use of the terms "unidirectional" and "geographically isolated wetlands" and suggests replacing them with the term "non-floodplain wetlands." The SAB finds that the focus on surface water hydrologic connections in Section 5.4 of the Report and elsewhere does not adequately account for important groundwater and non-hydrologic biological exchanges that can strongly influence the integrity of downstream waters. As also previously discussed, the SAB recommends that the Report be reorganized to reflect the types of connections between wetlands and downstream waters via surface water, shallow subsurface flowpaths, shallow or deep groundwater flowpaths, or through the movement of biota, with specific attention paid to the magnitude, duration, frequency, predictability, and consequences of these connections. Throughout the Report, landscape position, spatial scale, and temporal scale should be considered in the evaluation of the degree of connectivity, given that regional context (e.g., geology, climate, landforms, and surficial sediments) is a major driver of linkages. Consideration of landscape position and scale will likely provide further justification for treating wetland complexes as aggregates rather than as individual units based on geographic distribution. Likewise, human alterations of watersheds may change the types of connections to downstream waters as well as the magnitude, frequency, duration, predictability, and consequences of the connections, and the SAB recommends that the Report be revised to acknowledge the role of humans in these changes. In addition the Report should discuss the differences between manmade wetlands and those found in natural settings.

3.7.1. Summary of the Literature on Non-floodplain Wetlands

The Report captures the most relevant peer-reviewed literature on non-floodplain "unidirectional" wetlands" and "geographically isolated wetlands." However, the SAB recommends adding additional citations on biological connections (e.g., Naiman et al. 1994; Polis et al. 1997), many of which are referenced throughout this SAB report. Additional evidence from the large and growing literature on biological exchanges between non-floodplain wetlands should also be included in the Report. In particular, the SAB recommends including literature addressing: the bulk exchange of materials via biota, e.g., energy (Lowe et al. 2005; Norlin 1967; Mason and MacDonald 1982; Polis et al. 1997; Sabo and Power 2002; Baxter et al. 2005; Spinola et al. 2008; Pearse et al. 2011); the movement of nutrients by biota (McColl and Burger 1976; Johnston and Naiman 1987; Davis 2003; Vrtiska and Sullivan 2009); the introduction of disease vectors (Blanchong et al. 2006); and the provisioning of habitat essential for biological integrity and completion of life cycles of downstream species (Brooks et al. 1998; Miyazano et al. 2010; Julian et al. 2013).

In addition, the SAB recommends that the EPA review and, if needed, add to the Report the following selected references that are particularly pertinent to the discussion of non-floodplain wetlands: Brunet and Westbrook (2012); Conly et al. (2001); Fang and Pomeroy (2008); Gray et al. (1984); Hayashi and Van der Kamp (2000); Hayashi et al. (2003); Shaw et al. (2012); Spence (2007); Spence and Woo (2003); Stichling and Blackwell (1957); Van der Kamp et al. (2003, 2008); Winter and LaBaugh (2003); Woo and Rowsell (1993); and Yang et al. (2010).

Key Recommendations

- The literature review in Section 5.4 of the Report is technically accurate; however, the SAB has recommended additional literature references that should be considered for inclusion in the Report to address: bulk exchange of materials via biota, the movement of nutrients by biota, the introduction of disease vectors, and the provisioning of habitat essential for biological integrity and completion of life cycles of downstream species.

- The literature review should address the relative degree of connectivity for various non-floodplain wetlands.

3.7.2. Clarification of Terms in Section 5.4 of the Report

The SAB finds that the term "unidirectional wetlands " as used in the Report implies the presence of only one-way hydrologic flows, when in fact, connectivity can have many physical, chemical, and biological dimensions far beyond surface and shallow subsurface hydrologic flowpaths. As previously discussed, the SAB recommends that the draft Report's "uni- and bi-directional" terminology be replaced by terms that better describe landscape position. In this case, "bidirectional wetlands" could be redefined as those within riparian and floodplain settings, and "unidirectional wetlands" as those not within riparian zones and floodplains (i.e., non-floodplain settings). The influence of floodplain and non-floodplain wetlands on downstream connectivity can then be explained in the context of their landscape settings and with respect to the conceptual framework, as described below.

Key Recommendation

- The SAB recommends that the terms "unidirectional" and "geographically isolated" wetlands be replaced in the Report and suggests using the term "wetlands in non-floodplain settings."

3.7.3. Recommended Conceptual Framework for Synthesizing Types and Gradients of Connectivity

As discussed in Section 3.2 of this report, the SAB recommends the EPA Report be revised to use the multiple flowpath conceptual framework that describes the multiple dimensions of connectivity. The five functions used to describe connectivity in the Report (i.e., source, sink, refuge, lag, transformation) are differentially affected by the types and characteristics of connections. The framework recommended by the SAB is envisioned as a potential way to map the five functions across different regional settings in order to assess the consequences and relative extent of hydrologic, biological, and beneficial chemical flowpaths provided by non-floodplain wetlands to downstream waters.

Similarly, the SAB recommends that a second conceptual model be developed and used to frame the discussion about the type and gradient of various connections between and among floodplain wetlands and non-floodplain wetlands and downstream waters (or "bidirectional" and "unidirectional wetlands," respectively, using the Report's original nomenclature). Figure 3 illustrates a conceptual model that the SAB finds to be useful in this regard.

The multiple dimensions of connectivity to downstream waters include connections provided by surface waters, deep and shallow subsurface groundwater, and movement of biota. Each dimension of connectivity should be arrayed as a gradient, as illustrated in Figure 3. This approach could be used to synthesize findings from the literature in terms of the degree of connectivity pathways (e.g., magnitude, duration, frequency[3]) rather than just the presence of any connection. The SAB finds that such an analysis is possible and would be useful for summarizing the effects of such connections in semi-quantitative terms.

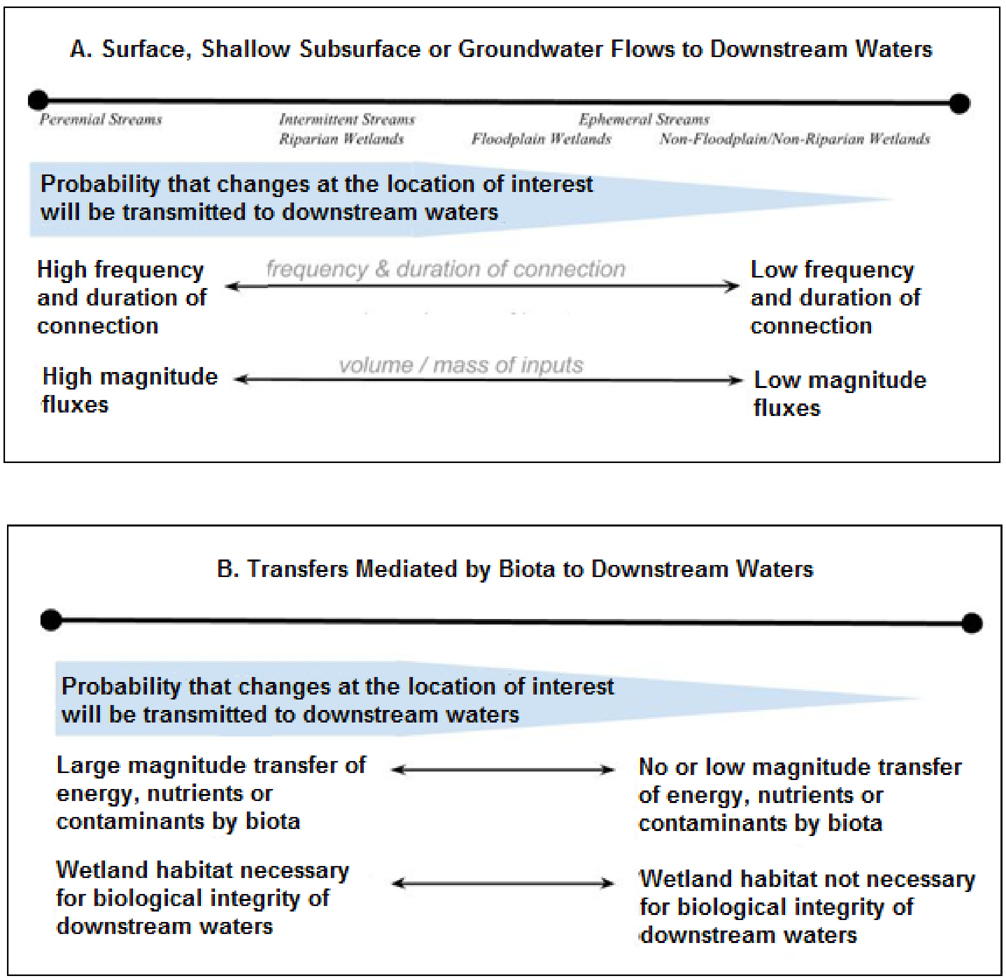

Figure 3: Hypothetical illustration of connectivity gradient and potential consequences to downstream waters. Panel A illustrates changes to downstream waters with increases in the magnitude, duration, and frequency of surface and subsurface connections. Panel B illustrates transfers mediated by biota to downstream waters. All streams (including perennial, intermittent, and ephemeral streams) have a connection to downstream waters. Within non-floodplain wetlands the degree of connectivity and implications for integrity of downstream waters vary considerably.

[3] Note that, in this context, frequency, magnitude, and duration apply to all five functions used to describe connectivity in the Report and not to hydrologic connectivity alone.

Key Recommendations

- When describing connectivity for floodplain and non-floodplain wetlands and certain open waters, the EPA should refer to the conceptual framework the SAB has recommended for the Report (see Section 3.2.3 of this report).

- The EPA should consider using Figure 3 in this SAB report (or a similar figure) to frame the discussion of connectivity gradients and their consequences as a function of the magnitude, duration, and frequency of connectivity pathways among floodplain wetlands and non-floodplain wetlands and downstream waters.

- The EPA should identify endpoints for each connectivity gradient, quantify each connection to the degree possible, and identify research and data gaps.

3.7.4. Temporal and Spatial Scales of Connections among Non-Floodplain Wetlands and Open Waters

Wetlands that are situated alongside rivers and their tributaries are likely to be connected to those waters through the exchange of water, biota and chemicals. As the distance between a wetland and a flowing water system increases, these connections become less obvious. Wetlands that are not contained within river floodplains or stream riparian zones and that lack a permanent surface water connection may still be connected to downstream waters through groundwater flowpaths and through the exchange of organisms. These water bodies can become connected to downstream waters during floods or as a result of rising water tables.

The EPA Report suggests that determining the “connectedness” of each non-floodplain wetland must be done on a case-by-case basis. The SAB suggests that the vast majority of non-floodplain wetlands can be classified with respect to some degree of hydrologic, chemical or biological connections to downstream waters; however, some hydrologically and spatially disconnected wetlands may need to be considered on a case-by case basis. The challenge for the EPA is to describe the hierarchy of decisions and the tools necessary to assess the degree of connection necessary to warrant case-by-case analysis.

The SAB recommends that EPA establish relevant guidelines identifying baseline temporal intervals that are likely to connect a non-floodplain wetland to downstream waters. Current technology exists to map these baselines using empirical observations (e.g., use of LandSat imagery to map extent of high water regimes receiving precipitation greater than the annual mean plus two standard deviations versus low water regimes receiving precipitation less than the annual mean minus two standard deviations, five or ten-year flood return interval, or results of hydrologic models). Such maps would be similar to the Federal Emergency Management Agency (FEMA) floodplain maps, and would need to be recalibrated for changing climate and land cover conditions.

For wetlands outside of these flood boundaries, there may still be quite important subsurface or biological connections. The degree of groundwater connectivity between a wetland and downstream waters varies considerably. For example, ombrotophic bogs, which by definition are rain-fed, have minimal groundwater connections to downstream waters; while groundwater-fed wetlands are clearly exchanging materials with the same groundwater systems that feed downstream waters. EPA scientists should consider where along this gradient, the connections are of sufficient magnitude to impact the integrity of downstream waters. This may represent an important research need for the agency. Past this threshold, groundwater connections will need to be evaluated on a case-by-case basis.

For non-floodplain wetlands where the only significant connection is via the exchange of biota (e.g., the movement of plants and animals between wetlands and rivers), the degree of connection will require an assessment. There is abundant scientific literature documenting that organisms move between these habitats and downstream waters (many relevant references are cited in this SAB report), that these connections are essential for the survival of many species, and that these connections serve to exchange materials across these boundaries; however, there has been insufficient scientific research to date to predict the magnitude of these connections and their effects on downstream ecosystems. A case-by-case evaluation will be required to establish whether these biological connections are of sufficient magnitude to affect the integrity of downstream waters.

Key Recommendation

- The Report should recognize that all aquatic habitats have some degree of connection, though they may vary widely through space and time in terms of the effects on the integrity of downstream waters. As a result, the Report should assess connectivity in terms of those downstream effects with an emphasis on frequency, magnitude, duration, predictability, and consequences of connections.

3.7.5. Assessing Wetland Connectivity Based on Aggregate Analysis of Wetland Complexes

Many watersheds have a large number of non-floodplain wetlands that are collectively responsible for the maintenance of base flows; the attenuation of floods; the production of organic material that fuels downstream food webs; and the trapping or removal of sediments, nutrients and contaminants that would otherwise contribute to the degradation of the physical, chemical, or biological integrity of downgradient waters. Although individually these wetlands may have minimal connections to downstream waters, the cumulative impact of these diffuse connections is tremendously important to the maintenance of downstream biota and ecosystem integrity. Historically, the destruction of wetlands has caused serious declines in the water quality of downstream waters and has had a substantial effect on flood regimes. The EPA report should describe the rich literature on historic wetland loss and the resulting consequences for the water quality, biodiversity, and flood impacts on downstream waters. This literature should be provided as a preface to a discussion of the need to consider the aggregate or cumulative impacts of wetlands that may each individually have minimal hydrologic, chemical or biological connections to downstream waters.

Assessment of the degree of wetland connectivity is best conducted on aggregated wetland complexes rather than on individual wetlands because over a range of precipitation regimes the boundaries of any single wetland may vary through space and time (e.g., Drexler et al. 2013). The regional context (e.g., geology, climate, landforms, and surficial sediments) is a major driver of the temporal and spatial scales of hydrologic linkages. Thus, regional context and spatial landscape position and scale should also be considered when evaluating the degree of connectivity, e.g., distance from and size of wetlands (or similar wetland types). As previously discussed, various frameworks for regionalization exist (e.g., Hydrologic Landscape Regions) and these include characterizations of landscapes at nested scales, such as regional, sub-regional, and local. These nested scales can be used to summarize variability in connectivity identified in the peer-reviewed literature.

Key Recommendations

- The Report should articulate the importance of assessing wetland connectivity in terms of aggregated wetland complexes, rather than individual wetlands.

- The Report should discuss the usefulness of regionalization methods to summarize information about wetland connectivity at nested scales.

- The Report should analyze the scientific literature to determine if there is an appropriate scaling that should be used for determining how non-floodplain wetlands may be aggregated when considering their effects on downstream waters. A discussion on how the scaling may vary geographically, and on the basis of factors affecting connectivity, should be included.

3.7.6. Discussion of Human Alteration of Landscapes in Section 5.4 of the Report

The Report tends to focus on natural wetland systems or those with minimal disturbance. As previously discussed, human modifications alter the type, strength and magnitude of connectivity pathways. The EPA Report should discuss the effects of human alterations on the connectivity of non-floodplain waters and wetlands. Some types of disturbances promote connections where none previously existed; others alter existing types of connections or trigger the transport of novel chemical or biological species. Creating connections where none previously existed, or where they were of low frequency through time, can affect the biological integrity of downstream waters. For example, such connections can be a key problem for amphibians that must breed and rear in wetlands free of fish (i.e., vernal pools). There is a large literature on the importance and conservation of ephemeral habitats for amphibians and other species and functions (e.g., Semlitsch 1998, 2000, 2002; Semlitsch and Bodie 2003; Calhoun and deMaynadier 2008). Most of these references are from the eastern United States. There is also a suite of species, mostly toads that rely on ephemeral aquatic habitats in the Western and Great Plains region, but they are less well known. In addition, there are many instances where man-made isolated wetlands occur within the landscape. These features are often found behind levees or within isolated parcels within urban landscapes and may not provide the same ecosystem functions as natural wetlands. Some features considered as wetlands are man-made and specifically designed to reduce connectivity, such as detention basins, excavated ponds, or ponds related to industrial processes. The SAB recommends that Section 5.4, as well as other sections of the Report, acknowledge these types of alterations or man-made habitats and include a discussion of current and past (legacy) human alterations of watersheds and how they affect the type, strength, and magnitude of connectivity pathways. In particular, human activities such as water diversion or water extraction may influence the water table, thereby reducing the potential for connections within and among wetlands and downstream waters. Extractive activities or those that alter hydrologic flow paths (diking, channelization, damming) may influence the magnitude of natural disturbances such as floods or droughts, and subsequently affect the integrity of downstream waters.

Key Recommendation

- Section 5.4, and other sections of the Report, should be revised to discuss the legacy effects of human activities and their effect on the type, strength, and magnitude of connectivity pathways.

3.8. Non-floodplain Waters and Wetlands: Review of the Findings and Conclusions

Charge Question 5(b). Conclusion (3) in section 1.4.3 of the Report Executive Summary discusses major findings and conclusions from the literature referenced in Charge Question 5(a) above. Please comment on whether the conclusions and findings in section 1.4.3 are supported by the available science. Please suggest alternative wording for any conclusions and findings that are not fully supported.

In commenting on the EPA's findings and conclusions regarding connectivity among open waters and "unidirectional" non-floodplain wetlands and downstream waters (Section 1.4.3 of the Report), the SAB focused on knowledge drawn from the peer-reviewed literature, especially that: (1) connectivity extends beyond hydrologic connectivity, (2) each connectivity flowpath can be described as a gradient that varies over space and time, and (3) multiple low magnitude connections can have large aggregate effects on integrity of downstream waters.

3.8.1. Scientific Support for the Conclusions Concerning Non-floodplain Waters and Wetlands

The SAB disagrees with the overall conclusion in Section 1.4.3 of the Report (Conclusion 3) indicating that, "The literature we reviewed does not provide sufficient information to evaluate or generalize about the degree of connectivity (absolute or relative) or the downstream effects of wetlands in "unidirectional" landscape settings." This statement is inconsistent with the text immediately preceding it, which describes numerous scientifically-established functions of non-floodplain wetlands that can benefit the physical, chemical, and biological integrity of downstream waters. Furthermore, the conclusion largely overlooks the effects of deep aquifer connections and non-hydrologic biological connections on downstream waters. The SAB finds that the scientific literature provides ample information to support a more definitive statement, and strongly recommends that the authors revise this conclusion to focus on what is supported by the scientific literature and then articulate the specific gaps in our knowledge that must be resolved (e.g., degree of connectivity, analyses of temporal or spatial variability).

The SAB recommends that Conclusion 3 in the Report explicitly recognize that the connectivity of non-floodplain waters to downstream ecosystems varies widely. Because of this the connectivity of non-floodplain waters should be evaluated along a gradient rather than as a dichotomous, categorical variable.

The SAB recommends that all of the Report's conclusions recognize connections beyond hydrologic ones, and that the frequency, magnitude, and duration of these connections be considered as well as their predictability and consequences. The SAB recommends that within the text of Conclusion 3 in the Report, the authors explicitly state the four pathways by which non-floodplain wetlands can be connected to downstream waters: via surface water, shallow subsurface or groundwater flowpaths, or through the movement of biota. It is the magnitude and effect of material, water or biotic fluxes rather than the simple presence or absence of a flux that determines the strength of the connection between a wetland and downstream waters.

The SAB disagrees with the notion, implied within the Report, that even minimal hydrologic connections are more important than biological connections, no matter how large the flux. The SAB recommends that this emphasis shift in order to account for strong connections that affect any one of the five functions used to describe connectivity in the EPA Report. If the goal of defining and estimating connectivity is to protect downstream waters, the interpretation must move from a dichotomous, categorical distinction (connected vs. not connected) towards a gradient approach that recognizes variation in the strength, duration and magnitude and effect of those connections. The SAB recommends that an integrated systematic approach be taken to conceptualize the structure and function of non-floodplain wetlands. The systems approach, which evaluates connectivity at the landscape scale, is used by hydrogeologists, and by surface water and groundwater hydrologists, who have the quantitative tools and conceptual models to determine the connectivity of both surface and subsurface hydrological systems to non-floodplain wetlands (ASTM, 1996; Kolm, et. al, 1996). Such an approach could be extended to include biological connections and HGM wetland classifications (Kolm et.al. 1998).

Key Recommendations

- The overall conclusion for non-floodplain wetlands (Conclusion 3 in Section 1.4.3) should be revised to focus on what is supported by the scientific literature and to provide more specifics on data and research gaps (e.g., degree of connectivity, analyses of temporal or spatial variability).

- Conclusion 3 of the Report should explicitly discuss the four pathways by which non-riparian / non-floodplain wetlands can be connected to downstream waters: i.e., via surface water, shallow subsurface flowpaths, shallow or deep groundwater flowpaths, or through the movement of biota.

- The conclusions in the Report should state that the determination of connectivity should be based on the magnitude, duration, frequency, predictability, and consequences of water, material, and biotic fluxes to downstream waters, and their impact on the integrity of downstream waters.

3.8.2. Recommendations Concerning Findings for Waters and Wetlands in Non-floodplain Settings

The SAB provides a number of recommendations to improve the presentation of findings in Section 1.4.3 of the Report.

The SAB recommends that conclusions be stated as concise, declarative statements. To accomplish this, the Report authors should remove references to specific studies within the text of the key findings. The Report’s conclusions are intended to summarize general themes arising from a broad synthesis of diverse literature. The SAB finds that it is not necessary to attribute these overarching findings to one or a few specific studies.

The SAB also recommends that the key findings be more explicitly presented in the text of the Report. Conclusions about non-floodplain wetlands are summarized in Table 5-4, but these same summary points are not clearly explained in the text itself. In addition, Table 5-4 discusses functions of wetlands but does not present conclusions on how those functions translate to an effect on the physical, chemical, or biological integrity of downstream waters based on the magnitude or duration of any of the modes of connection discussed in the literature. For example, the statement that “unidirectional wetlands can remove, retain, and transform many nutrient inputs” refers to such functions, but there is no conclusion about how these would affect downstream waters.

The SAB recommends that the EPA revise several of the key findings in Section 1.4.3 of the Report. These revisions are consistent with the literature synthesis performed and the SAB's knowledge of the subject.

Key Finding (b)

The SAB recommends including the following statement in the Report as an additional key finding on the *biological functions* of "unidirectional" wetlands.

Suggested statement: *Wetlands provide unique and important habitats for many organisms, both common and rare. Some of these organisms require multiple types of waters to complete their full life cycles, including downgradient waters. Other organisms, especially abundant and/or highly mobile species, play important roles in transferring energy and materials between wetlands and downstream waters.*

The SAB also notes that the Report's conclusion on the similarity between wetlands and other water bodies needs further substantiation from the literature as the functions within each are quite different, especially in nutrient and organic matter production. In addition, this conclusion should recognize the differences between natural wetland systems and those that are man-made or are found in urban environments.

Key Finding (c)

The SAB recommends including the following statement in the Report as an additional key finding about non-floodplain wetlands and downgradient waters to parallel the preceding finding on "hydrologic connectivity."

Suggested statement: *Biological connections are likely to occur between all non-floodplain wetlands and downstream waters. Whether those connections are of sufficient magnitude to impact downstream waters will either require estimation of the magnitude of material fluxes or evidence that these movements of organisms are required for the survival and persistence of biota that contribute to the integrity of downstream waters.*

Key Finding (f)

The SAB recommends including the following two additional key findings that summarize important information from the main body of the document that were not emphasized in the original wording of the key finding (f).

Suggested additional key finding on *spatial proximity* of non-floodplain wetlands: *Spatial proximity is one important determinant of the magnitude, frequency and duration of connections between wetlands and streams that will ultimately influence the fluxes of water, materials and biota between wetlands and downstream waters.*

Suggested additional key finding on the *cumulative or aggregate impacts* of non-floodplain wetlands: *The cumulative influence of many individual wetlands within watersheds can strongly affect the spatial scale, magnitude, frequency, and duration of hydrologic, biologic and chemical fluxes or transfers of* *water and materials to downstream waters. Because of their aggregated influence, any evaluation of changes to individual wetlands should be considered in the context of past and predicted changes (e.g., from climate change) to other wetlands within the same watershed.*

The SAB recommends that the Report authors cite the following references in support of this last statement; Lee and Gosselink (1988); Preston and Bedford (1988).

Key Recommendations

- The authors should remove references to specific studies within the text of the key findings in the Report. The Report's conclusions are intended to summarize general themes arising from a broad synthesis of diverse literature.

- The key findings should be more explicitly presented in the text of the Report. Conclusions about "unidirectional" wetlands are summarized in Table 5-4, but these same summary points are not clearly explained in the text itself.

- The SAB recommends revising several of the key findings in Section 1.4.3 of the Report and has provided specific text.

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APPENDIX A: THE EPA'S CHARGE QUESTIONS

Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence

Technical Charge to External Peer Reviewers

Understanding the physical, chemical, and biological connections by which streams, wetlands, and open-waters affect downstream waters such as rivers, lakes, and oceans is central to successful watershed management and to meeting water quality goals. It is also central to informing policy decisions that guide our efforts to meet these goals. The purpose of this Report, titled *Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence* is to summarize the current scientific understanding of broadly applicable ecological relationships that affect the condition or function of downstream aquatic ecosystems. The focus of the Report is on small or temporary non-tidal streams, wetlands, and open-waters. Examples of relevant connections include transport of physical materials such as water or wood, chemical compounds such as nutrients or pesticides, movement of biological organisms such as fish or insects, and processes or interactions that alter material transport, such as nutrient spiraling. Materials reviewed in this Report are limited to peer-reviewed scientific literature. Findings from this Report will help inform EPA and the U.S. Army Corps of Engineers in their continuing policy work and efforts to clarify what waters are covered by the Clean Water Act. As a scientific review, the Report does not consider or make judgments regarding legal standards for Clean Water Act jurisdiction.

The Report is presented in six chapters. Key findings and major conclusions are summarized in Chapters 1 (Executive Summary) and 6 (Conclusions and Discussion). Chapter 2 (Introduction) describes the purpose and scope of the document and the literature review approach. Chapter 3 presents a conceptual framework that describes the hydrologic elements of a watershed, the types of physical, chemical, and biological connections that link them, and watershed climatic factors that influence connectivity at various temporal and spatial scales. Chapter 4 surveys the literature on stream networks with respect to physical, chemical, and biological connections between upstream and downstream habitats. Chapter 5 reviews the literature on connectivity and effects of non-tidal wetlands and certain open waters on downstream waters. All terms are used in accordance with standard scientific meanings, and definitions which are in the Report glossary.

TECHNICAL CHARGE QUESTIONS

Overall Clarity and Technical Accuracy of the Draft Report

1. Please provide your overall impressions of the clarity and technical accuracy of the draft EPA Report, *Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence*.

Conceptual Framework: An Integrated, Systems Perspective of Watershed Structure and Function

2. Chapter 3 of the draft Report presents the conceptual basis for describing the hydrologic elements of a watershed; the types of physical, chemical, and biological connections that link these elements, and watershed climatic factors that influence connectivity at various temporal and spatial scales (e.g., see Figure 3-1 and Table 3-1). Please comment on the clarity and technical accuracy of this chapter and its usefulness in providing context for interpreting the evidence about individual watershed components presented in the Report.

Lotic Systems: Ephemeral, Intermittent, and Perennial Streams

3(a) Chapter 4 of the Report reviews the literature on the *directional* (*downstream) connectivity and effects* of ephemeral, intermittent, and perennial streams (including flow-through wetlands). Please comment on whether the Report includes the most relevant published peer reviewed literature with respect to these types of streams. Please also comment on whether the literature has been correctly summarized. Please identify any published peer reviewed studies that should be added to the Report, any cited literature that is not relevant to the review objectives of the Report, and any corrections that may be needed in the characterization of the literature.

3(b) Conclusion (1) in section 1.4.1 of the Report Executive Summary discusses major findings and conclusions from the literature referenced in Charge Question 3(a) above. Please comment on whether the conclusions and findings in section 1.4.1 are supported by the available science. Please suggest alternative wording for any conclusions and findings that are not fully supported.

Lentic Systems: Wetlands and Open Waters with the Potential for Non-tidal, "Bidirectional" Hydrologic Flows with Rivers and Lakes

4(a) Section 5.3 of the Report reviews the literature on the *directional (downstream) connectivity and effects* of wetlands and certain open waters subject to non-tidal, "bidirectional" hydrologic flows with rivers and lakes. Please comment on whether the Report includes the most relevant published peer reviewed literature with respect to these types of wetlands and open waters. Please also comment on whether the literature has been correctly summarized. Please identify any published peer reviewed studies that should be added to the Report, any cited literature that is not relevant to the review objectives of the Report, and any corrections that may be needed in the characterization of the literature.

4(b) Conclusion (2) in section 1.4.2 of the Report Executive Summary discusses major findings and conclusions from the literature referenced in Charge Question 4(a) above. Please comment on whether the conclusions and findings in section 1.4.2 are supported by the available science. Please suggest alternative wording for any conclusions and findings that are not fully supported.

Lentic systems: Wetlands and Open Waters with Potential for "Unidirectional" Hydrologic Flows to Rivers and Lakes, Including "Geographically Isolated Wetlands"

5(a) Section 5.4 of the draft Report reviews the literature on the *directional (downstream) connectivity and effects* of wetlands and certain open waters, including "geographically isolated wetlands," with potential for "unidirectional" hydrologic flows to rivers and lakes. Please comment on whether the Report includes the most relevant published peer reviewed literature with respect to these types of wetlands and open waters. Please also comment on whether the literature has been correctly summarized. Please identify any published peer reviewed studies that should be added to the Report, any cited literature that is not relevant to the review objectives of the Report, and any corrections that may be needed in the characterization of the literature.

5(b) Conclusion (3) in section 1.4.3 of the Report Executive Summary discusses major findings and conclusions from the literature referenced in Charge Question 5(a) above. Please comment on whether the conclusions and findings in section 1.4.3 are supported by the available science. Please suggest alternative wording for any conclusions and findings that are not fully supported.

APPENDIX B: ADDITIONAL LITERATURE CITATIONS REGARDING BIOLOGICAL CONNECTIVITY

The following additional literature citations addressing biological connectivity are provided for the EPA's consideration in developing the Report**.** These papers represent combinations of floodplain-stream, wetland-stream, and wetland-wetland interactions, but in many cases provide evidence of connectivity among multiple aquatic habitats. The citations are organized by major taxonomic groups and in some cases by topics.

General

Mason, C.F. and S.M. MacDonald. 1982. The input of terrestrial invertebrates from tree canopies to a stream. *Freshwater Biology* 12:305–11.

Winemiller, K.O. 1990. Spatial and temporal variation in tropical fish trophic networks. *Ecological Monographs* 60:331–67.

Birds

Waterbird foraging

Anteau, M.J., M.H. Sherfy, and A.A. Bishop. 2011. Location and agricultural practices influence spring use of harvested cornfields by cranes and geese in Nebraska. *Journal of Wildlife Management* 9999(xx):1-8; DOI: 10.1002/jwmg.135.

Austin, J.E., and A.L. Richert. 2005. *Patterns of habitat use by whooping cranes during migration: summary from 1977-1999 site evaluation data.* Proceedings North American Crane Workshop 9:79-104.

Vrtiska, M.P., and S. Sullivan. 2009. Abundance and distribution of lesser snow and Ross's geese in the Rainwater Basin and Central Platte River Valley of Nebraska. *Great Plains Research* 19:147-155.

Waterfowl freshwater drinking to dilute salt loads

Adair, S.E., J.L. Moore, and W.H. Kiel, Jr. 1996. Wintering diving duck use of coastal ponds: An analysis of alternative hypotheses. *The Journal of Wildlife Management* 60(1): 83-93. [http://www.jstor.org/stable/3802043]

Ballard, B.M.., J.D. James, R.L. Binghan, M.J. Petrie, B.C. Wilson. 2010. Coastal pond use by redheads wintering in the Laguna Madre, TX. *Wetlands* 30:669-674.

Woodin, M.C. 1994. Use of saltwater and freshwater habitats by wintering redheads in southern Texas. *Hydrobiologia* 279/280: 279-287.

Waterbird foraging

Aldrich, T. W., and D. S. Paul. 2002. Avian ecology of Great Salt Lake. Pages 343–374 in *Great Salt Lake: an overview of change.* J.W. Gwynn, (ed.), Utah Department of Natural Resources and Utah Geological Survey Special Publication, Salt Lake City, Utah, USA.

Vest, J. L., and M. R. Conover. 2011. Food habits of wintering waterfowl on the Great Salt Lake, Utah. *Waterbirds* 34:40–50.

Sandhill Cranes

Folk, M.J, and T.C. Tacha. 1990. Sandhill crane roost site characteristics in the North Platte River Valley, Nebraska. *Journal of Wildlife Management* 54:480–486.

Subcommittee on Rocky Mountain Greater Sandhill Cranes. 2007. *Management plan of the Pacific and Central Flyways for the Rocky Mountain population of greater sandhill cranes.* [Joint] Subcommittees, Rocky Mountain Population Greater Sandhill Cranes, Pacific Flyway Study Committee, Central Flyway Webless Migratory Game Bird Tech. Committee [c/o USFWS, MBMO], Portland, OR. 97pp.

Tacha, T.C., S.A. Nesbitt, and P.A. Vohs. 1994. Sandhill cranes. Pages 77-94 In *Migratory Shore and Upland Game Bird Management in North America*. T.C. Tacha and C.E. Braun (eds.) International Association of Fish and Wildlife Agencies, Washington D.C.

Waterbird movements among multiple waters - Prairie Pothole Shorebirds

Farmer, A.H., and A.H. Parent. 1997. Effects of the landscape on shorebird movements at spring migration stopovers. *Condor* 99:698–707.

Waterbird abundance moving among waters

Jorgensen, J.G., J.P. McCarty, and L.L. Wolfenbarger. 2008. Buff-breasted Sandpiper density and numbers during migratory stopover in the Rainwater Basin, Nebraska. *Condor* 110: 63-69.

Pearse, A.T., G.L. Krapu, D.A. Brandt, and P.J. Kinzel. 2010. Changes in Agriculture and Abundance of Snow Geese Affect Carrying Capacity of Sandhill Cranes in Nebraska. *Journal of Wildlife Management* 74(3):479-488.

Waterfowl abundance using multiple wetlands

Fairbairn, S. E. and J. J. Dinsmore. 2001. Local and landscape-level influences on wetland bird communities of the prairie pothole region of Iowa, USA. *Wetlands* 21:41–47.

Haramis G.M. 1990. Breeding ecology of the wood duck: a review. Pages 45–60. In *Proceedings of the 1988 North American wood duck symposium*, L.H. Fredrickson, G.V. Burger, S.P. Havera, D.A. Graber. R.E .Kirby, T.S. Taylor (eds.) St. Louis, MO, p 390.

Krapu, G. L., K. J. Reinecke, D. G. Jorde, and S. G. Simpson. 1995. Spring staging ecology of mid-continent Greater White-fronted Geese. *Journal of Wildlife Management* 59:736–746.

LaGrange, T. G. and J. J. Dinsmore. 1989. Habitat use by mallards during spring migration through central Iowa. *Journal of Wildlife Management* 53:1076–1081.

Skagen, S. K. and S. K. Knopf. 1993. Toward conservation of midcontinental shorebird migrations. *Conservation Biology* 7:533–541.

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Fish

Importance of connectivity between river and floodplain for fish

Babar, M.J., D.L. Childers, K.J. Babbit, and D.L. Anderson. 2002. Controls on the distribution and abundance of fish in temporary wetlands. *Canadian Journal of Fisheries and Aquatic Sciences 5*9:1441-1450.

Boltz, J.M., R.R. Stauffer, Jr. 1989. Fish assemblages of Pennsylvania wetlands. In *Wetland Ecology and Conservation: Emphasis in Pennsylvania*. S.K. Majumdar et al. (eds.) Chapter 14. Pennsylvania Academy of Science, Easton, PA, 395pp.

Langston, M. A., and D. M. Kent. 1997. Fish recruitment to a constructed wetland. *Journal of Freshwater Ecology* 12:123-129.

Vilizzi, L., B.J. McCarthy, O. Scholz, C.P. Sharpe, and D.B. Wood. 2012. Changes in the fish assemblage of a floodplain wetland system of high conservation value in response to pumping and natural flooding. *Aquatic Conservation Marine and Freshwater Ecosystems* 07/2012; DOI:10.1002/aqc.2281

Connectivity of floodplain habitats with rivers

Groom, J.D., and T.C. Grubb Jr. 2002. Bird Species Associated with Riparian Woodland in Fragmented, Temperate-Deciduous Forest. *Conservation Biology* 16(3):832-836.

Keller, C. M. E., C. S. Robbins, and J. S. Hatfield. 1993. Avian communities in riparian forests of different widths in Maryland and Delaware. *Wetlands* 13:137–144.

Steven, D.D., and R. Lowrance. 2011. Agricultural conservation practices and wetland ecosystem services in the wetland-rich Piedmont-Coastal Plain region. *Ecological Applications* 21(3):S3-S-17.

Mammals

Brooks, R.P., and T.L. Serfass. 2013. Wetland-riparian wildlife of the Mid-Atlantic Region: an overview. In *Mid-Atlantic Freshwater Wetlands: Advances in science, management, policy, and practice*. R.P. Brooks and D.H. Wardrop (eds.) Pages 259-268, Chapter 7 Springer Science+Business Media, 491+xiv pp.

Serfass, T.L., M.J. Lovallo, R.P. Brooks, A.H. Hayden, and D.H. Mitcheltree. 1999. Status and distribution of river otters in Pennsylvania following a reintroduction project. *Journal of the Pennsylvania Academy of Science* 73:10–14.

Stevens, S.S., E.H. Just, R.C. Cordes, R.P. Brooks, and T.L. Serfass. 2011. The influence of habitat quality on the detection of River otter (*Lontra canadensis*) latrines near bridges. *American Midland Naturalist* 166:435–445.

Swimley, T.J., R.P. Brooks, and T.L. Serfass. 1999. Otter and beaver interactions in the Delaware Water Gap National Recreation Area. *Journal of the Pennsylvania Academy of Science* 72:97–101

Toweill, D.E., and J.E. Tabor. 1982. The northern river otter Lutra canadensis (Schreber). In *Wild Mammals of North America*. J.A. Chapman and G.A. Feldhamer (eds.) pp. 688–703. Johns Hopkins University Press, Baltimore, MD,

Amphibians and Reptiles

Knutson, M.G., J.R. Sauer, D.A. Olsen, M.J. Mossman, L.M. Hemesath, and M.J. Lannoo. 1999. Effect of landscape composition and wetland fragmentation on frog and toad abundance and species richness in Iowa and Wisconsin, U.S.A. *Conservation Biology* 13:1437–1446.

Connectivity among wetlands increases aquatic snake abundance

Attum, O., Y.M. Lee, J. H. Roe, and B. A. Kingsbury. 2007. Upland–wetland linkages: relationship of upland and wetland characteristics with water snake abundance. *Journal of Zoology* 271(2):134-139.

Movement of materials and how interplay of aquatic species among different habitats changes community composition

Kurzava, L.M., and P.J. Morin. 1998. Tests of functional equivalence: complementary role of salamanders and fish in community organization. *Ecology* 79:477–489.

Movement of stream salamanders upstream, downstream, and into upland areas

Lowe, W.H., G.E. Likens, M.A. McPeek, and D.C. Buso. 2006. Linking direct and indirect data on dispersal: isolation by slope in a headwater stream salamander. *Ecology* 87:334–339.

Macoinvertebrates

Bunn, S.E., and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30(4):492–507.

Smock, L.A. 1994. Movements of invertebrates between stream channels and forested floodplains. *Journal of the North American Benthological Society* 13:524–531.

Stanford, J.A., and J.V. Ward. 1993. An ecosystem perspective of alluvial rivers: connectivity and the hyporheic corridor. Journal of the North American Benthological Society 12:48–60.

Ward J.V., K. Tockner, D.B. Arscott, and C. Claret. 2002. Riverine landscape diversity. *Freshwater Biology* 47:517–539

Yetter, S. 2013. Freshwater macroinvertebrates in the Mid-Atlantic Region. Chapter 10, in *Mid-Atlantic Freshwater Wetlands: Advances in science, management, policy, and practice.* R.P. Brooks and D.H. Wardrop (eds.) Pages 339-379, Springer Science+Business Media, 491+xiv pp.

Example from arid environment

Jackson, J.K., and S.G. Fisher. 1986. Secondary production, emergence and export of aquatic insects of a Sonoran Desert stream. *Ecology* 67:629–38.