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 inform an EPA and U.S. Army Corps of Engineers rulemaking to clarify 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 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. The SAB recommends some revisions to improve the clarity of the Report, better reflect the scientific evidence, 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 conclusion that numerous functions of "unidirectional" non floodplain wetlands sustain the physical, chemical, and/or biological integrity of downstream waters. 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 in certain systems, such as headwater streams and tributaries and floodplain wetlands, relatively low levels of connectivity can be ecologically meaningful in terms of impacts on 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 cumulative and aggregative 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, though additional citations have been suggested to strengthen it further. To make the review process more transparent, the EPA should more clearly describe the approach used to screen, compile, and synthesize the information.

- The SAB finds that the review and synthesis of the literature describing connectivity of streams to downstream waters reflects the pertinent literature and is strongly 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 all tributary streams are connected to downstream waters. 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 temperature on downstream waters, and the movement of biota 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 the review and synthesis of the literature on the connectivity of non-floodplain ("unidirectional") waters and wetlands is generally thorough and technically accurate. However, additional information on biological connections should be included.

- 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 also recommends that the Report clearly indicate that all aquatic habitats have some degree of connection to downstream waters through the transfer of water, chemicals or biota, though the magnitude and effects of these connections vary widely across wetlands.

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 to inform an EPA and U.S. Army Corps of Engineers rulemaking to clarify 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 riparian/floodplain settings; and (4) the downstream connectivity and effects of waters and wetlands in non-riparian/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 generally 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 and voice. 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.

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[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 EPA should also consider including in the Executive Summary a succinct table summarizing all of the key findings of the Report.

The Report is a science, not policy, document that was written to support the EPA's efforts to clarify the jurisdiction of the Clean Water Act. Within this context, the Report could be more useful to decision-makers if it brought more clarity to the interpretation of connectivity, especially with respect to quantification of the frequency, duration, predictability, magnitude, and consequences of 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, in certain systems, such as headwater streams and tributaries and floodplain wetlands, relatively low levels of connectivity can be ecologically meaningful in terms of impacts on 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, but they would be of greater relevance if the reasons why they were selected (i.e., the important points they illustrate) and how they fit into the conceptual framework (i.e., where different systems fall along the connectivity gradient) were more apparent. It would also 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 and 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) might also 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 watersheds. The framework should illustrate the importance of climate, geology, and 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 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 all aquatic habitats have some degree of connection at some point in time. 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 the 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 temperature on downstream connectivity 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 streams exert a strong influence on the character and functioning of downstream waters 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, magnitude, and duration 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 give more attention to biogeochemical transformations and biological connections. In addition, some hydrologic aspects of connectivity that are addressed in the Report require additional detail. These include descriptions of key linkages and exchanges in tributary streams, such as groundwater-surface water interactions, as well as 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 U.S. 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. Articulating the rationale for choosing the specific 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 the 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 does substantiate the 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). 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 create a diversity of habitats supporting 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 also 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 U.S. In particular, studies on peatlands in floodplain settings and forested wetlands, including bottomland hardwoods, should 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 role 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 term "bidirectional wetlands" should 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 the flood pulse. 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 zones (i.e., 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 the conclusions be more empirically and/or specifically described and 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 the 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 thorough and 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. 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 with the term "non-floodplain waters and wetlands." 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 magnitude, duration and frequency of connectivity pathways. The Report should also 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 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 "unidirectional" wetlands have been shown to benefit the physical, chemical, and biological integrity of downgradient waters) and 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 wetlands can be connected to downstream waters and state that the evaluation of connectivity should be based on the magnitude, duration, and frequency 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 revisions to improve the findings concerning "unidirectional" 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 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 to inform an EPA and U.S. Army Corps of Engineers rulemaking on waters that are under 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 riparian/floodplain settings; and (4) the downstream connectivity and effects of waters and wetlands in non-riparian/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. 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 charge questions in 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. Overall Clarity and Technical Accuracy of the Draft Report

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. Caution should be exercised when using words that may denote particular legal or regulatory meanings (e.g., significant, adjacent). The Report is quite long and can be 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.

Recommendations

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

- Terms and definitions should be used consistently throughout the Report and 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 is aware that it was written to support 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 magnitude, frequency, or 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 an 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. As noted in the many public comments to the SAB, the binary perspective in the Report implies that any connectivity must significantly affect the biological, physical, or chemical integrity of downstream[1] waters. Although certain systems, such as headwater streams and tributaries and floodplain wetlands are known to exhibit a level of connectivity that is ecologically meaningful 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) an 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") and discuss the spatial and temporal scales at which the functional aggregation should be evaluated.

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.

[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.

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 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 and other references have been suggested in written comments from the public.

The SAB also finds that the EPA could better highlight gaps in our 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.

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; (2) the kinds of evidence used to support the findings and conclusions; and (3) 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:

- *The importance and relevance of different spatial and temporal scales.* For example, what is the relevant spatial and temporal scale for assessing connectivity in different water systems? At which scales are wetlands 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 time and spatial scales. Ultimately, these scales determine how policy makers will deal with connectivity within the context of the Clean Water Act.

- *The extent to which biological connections among water systems affect the integrity of downstream waters.* Birds, mammals, and other fauna (e.g., salamanders), can be important sources of material transfers to, and also critical sources of, organisms necessary to support viable populations in 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.

- *The necessity of adopting watershed, riverscape, 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.

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

- *The role of ground water, sediments, and chemical and biological parameters in establishing connectivity of water bodies.*

- *Human modifications and the ways that they affect connectivity.* Modifications that could affect connectivity in ways that impact downstream waters can include directly eliminating, restoring, or altering connectivity via roads, agricultural tiles, dams, pumping ground water, irrigation, channelization, and other manmade infrastructure (piped streams, stormwater pipes). Certain systems, such as effluent-dependent waters, are more closely tied to human modifications than others. Functions associated with these man-altered systems and their natural counterparts should be evaluated using the scientific literature.

- *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 most needed scientific, methodological, and technical advances in order 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 of different types of water bodies, including at least one where intermittent connectivity is important. The case studies also could be used to compare geographic regions, such as Southwest arid, Midwest mesic, and arctic permafrost systems. 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 which form the basis of the concept of Hydrologic-Landscape Regions (i.e., HLRs), as a framework for the case studies.

An alternative structure would be to present the case studies as brief textboxes that clearly and simply articulate key points. Within these textboxes the expanded versions could be referenced and included 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. 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 (e.g., arctic) and systems, including human-modified systems, forested wetlands, and bottomland forests.

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 constrained to text boxes that: (1) provide shorter, clear illustrations of where different systems sit along the gradients of connectivity, and (2) highlight differences in the ecologically relevant temporal and spatial scales. The reader should be able to see how the case studies fit within the conceptual framework. If expanded case studies are desired, these should be presented in the appendices.

- The EPA should consider including in the Report case studies of a greater range of geographic regions (e.g., arctic) and systems, including human modified systems, forested wetlands, and bottomland forests.

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. The literature review generally does not need to be changed, 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 that is grounded in 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 in the Report; and (6) a summary and synthesis of the conceptual model should be added at the end of Chapter 3.

3.2.1. Defining Connectivity and Isolation

Because connectivity and isolation can be defined in many ways, the Report needs to define and concisely discuss what is meant by both "connectivity" and "isolation" at the beginning of Chapter 3. Currently, only connectivity is defined, and it is not defined until page 3-28, long after much of the conceptual framework has been presented and discussed. 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 could be brief, with the many details and nuances to be addressed later.

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 Report should state that connectivity is a scalable quantity ranging continuously from fully connected to completely isolated, rather than a binary condition of either connected or isolated. This could be expressed in a simple conceptual figure here, 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 for an example developed for waters and wetlands in non-riparian/non-floodplain settings.)

Defining connectivity as discussed above creates a problem with the related definition of isolation. If connectivity really is the transfer of matter, energy, and/or organisms within or between elements of the landscape, and connectivity really is a scalable quantity ranging from fully connected to fully isolated, then one might infer that true isolation doesn't occur until there is 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 improved by drawing upon the literature on disturbance ecology (see Stanley et al. 2010 and references therein). In that literature, a disturbance is seen as a discrete event that disrupts ecosystem structure and function, substantively changing the physical, chemical, and/or biological environment. Such disturbances are commonly viewed through a filter of the biological consequences, i.e., does the disturbance event matter to biota? However, to facilitate objective comparisons among events, such disturbances are nevertheless commonly quantified in terms of physical measures of the disturbance itself (e.g., frequency, magnitude, duration) rather than in terms of the biological response to the disturbance. Predictability is often part of this definition, with the stipulation that disturbances must be outside of some normal range to which biota are typically adapted (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.

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 improved by connecting to literature on disturbance ecology.

3.2.2. 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 the consequences from impacts on one water body will affect chemical, physical, and/or biological integrity of downstream waters. In addition, multiple dimensions of connectivity should be described, notably, 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) which are made manifest along multiple flowpaths (e.g., via surface water, the hyporheic zone, and ground water). Such approaches also should note that these dimensions should be assessed 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 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 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, and 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 (ASTM 1996; Kolm et al. 1996; Heath 1983; Winter et al. 1998). This approach has been extended to biological connectivity and 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) and metrics (Ali and Roy 2010).

Other examples can be found in the literature related to water quantity and quality modeling (Appel and Reilly, 1994; Sun et al. 1997; Cunningham and Schalk 2011; Parkhurst et al. 2010; Harbaugh 2005), and integrated surface water ground water modeling (Markstrom et al. 2008; Ely and Kahle 2012; Huntington and Niswonger 2012; Woolfenden and Nishikawa 2014), sediment transport modeling (McDonald et al. 2005; Nelson et al. 2003), and watershed and biological/habitat/landscape modeling (Kinzel et al. 2005; Hunt et al. 2013). Approaches have also been developed to quantify linkages due to ground water movement and storage (Heath 1983) and the effects of "flood pulses" (Kolm et al. 1998). Likewise, the role of chemical movement and storage to ground water 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; Harbaugh 2005; Conaway and Moran 2004; McDonald et al. 2005; Nelson et al. 2003; 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. For example, the Integral Index of Connectivity was successfully used by Van Looy et al. (2013) 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. Recent advances have allowed better integration of 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.

Insights from Disturbance Ecology

In many respects connectivity can be described using concepts borrowed from disturbance ecology – frequency, magnitude, timing, duration, rate of change, and predictability (e.g., Resh et al. 1988; Poff 1992; Poff et al 1997). Frequency is inversely related to magnitude, and describes how often a flow exceeding a particular magnitude recurs over a specified time period. Magnitude is the rate of flow moving past a fixed location. Duration is the time period associated with a specific condition, either in terms of a specific flow event (e.g., number of days inundated by a specific flood event) or over a time period (e.g., number of days inundated in a year).

The temporal and spatial predictability of connectivity should be an especially important attribute 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 U.S. (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)

Recommendations

- The Report should discuss approaches to measuring or otherwise quantifying connectivity. The Report could do so 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 should be drawn from both the hydrological and disturbance ecology literature.

3.2.3. 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 hydrologic, climatic, and other processes that occur across landscapes to connect various waters and wetlands. The breadth of the literature discussed in the Report need not be constrained by regulatory definitions of waters and wetlands. However, the SAB notes that a primary use of the Report is to assess connectivity among waters and wetlands and downgradient waters. As currently written, the Report is not clear 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). The Report uses the water and wetland definition of Cowardin et al. (1979), and many public commenters have expressed concern about the potential expansion of the scope of jurisdiction of the underlying Clean Water Act – from "three-parameter[2]" to "one-parameter" waters and wetlands. These confusions and concerns could be explicitly 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 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.

Recommendations

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

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

3.2.4. 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 riparian/floodplain settings, and waters and wetlands in non-riparian non-floodplain settings), the SAB finds 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. As previously noted, 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 describe 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 these terms

[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.

be changed to terms from 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 "bidirectional" wetlands could be called *waters and wetlands in floodplain settings* and "unidirectional" wetlands could be called *waters and wetlands in non-floodplain settings*. These terms will be used throughout this report**.**

Use of the term "geographically isolated wetlands" by itself in the Report is problematic in that "geographically isolated wetlands" technically mean "wetlands isolated in space." However, "geographically isolated wetlands" are 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 2003b; 2003c). However, in the flowpath framework recommended by the SAB, there are no truly isolated waters or wetlands. As discussed in other sections of this SAB report, all waters and wetlands are connected, differing only in the degree of connection (e.g., frequency, magnitude, timing, duration) and the degree to which those connections affect the chemical, physical, and biological integrity of downstream waters. Therefore, the term "geographically isolated wetlands" runs counter to the continuous flowpath conceptual framework recommended by the SAB. A final point is that the term "geographically isolated wetlands" does not even fit into the current conceptual framework in the Report because the Report explicitly states that geographically isolated wetlands can occur in both riparian/floodplain settings and non-riparian/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" was never meant to 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.

EPA should consider defining and adding the term "interrupted stream" to its discussion of stream categories (e.g., Meinzer 1923; Hall and Steidl 2007). Interrupted streams are those that change from ephemeral, intermittent or perennial streams for ecologically distinct reaches. Such streams are common when geological conditions (i.e., change in substrate, faulting) create rapid changes in aquifer-to-stream recharge/discharge (e.g., the San Pedro River or many streams in volcanic terrains such as the Snake River Plain, Columbia Basin, or Hawaiian Islands). Human interaction (ground water pumping, wastewater discharge) also can create interrupted streams (Rio Grande, Santa Ana River, South Platte River). Connectivity across such interrupted reaches can radically shift, with concomitant alteration in habitat or impact when connection is reestablished. Although EPA may consider such streams "connected," there may be no clear stream bank and bed preserved across the reach and it may be difficult to quantify the ecological importance of the connection.

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 recommends 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 then further explain that "geographically isolated wetlands" will not be used as an organizational term in Report.

- The term 'interrupted stream' should be defined and used in the discussion of streams where flow is impeded or reduced on the reach scale.

3.2.5. 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 Chapter lacks an explicit conceptual framework, 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," 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, relief, and biology and are expressed in terms of surface water and ground water 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 ground water flowpaths, with the latter including the potential for ground water 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). However, chemical flowpaths could also 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.

Ground water connectivity, in particular, could be better represented in the Report. The U.S. Geological Survey (USGS) has published numerous reports and learning tools on ground water 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, given that ground water 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 riparian/floodplain settings,” and “waters and wetlands in non-riparian/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 Ground water Flow: This is the normal saturated ground water 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; Rains et al. 2006; 2008; Vanderkwaak and Loague 2001). This type of variability suggests that connectivity should be discussed within a continuum of runoff producing mechanisms. As previously noted, the EPA has chosen 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 there is no scientific consensus on separating the categories.

The Report tends to focus on the site and subregional scales, perhaps due to cost, 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 ground water. This is a problem because regional ground water 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 ground water connectivity, and the way that ground water 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 ground water 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 ground water flow systems is critical to the understanding of four-dimensional hydrologic connectivity on both the local and regional scales. Understanding ground water 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 also recommends that the EPA include in the Report additional evidence of biological connectivity. Organismal movement is important for ecosystem function as well as for population dynamics. Organisms use habitats that are critical to their life-history requirements (i.e., their life cycles cannot be completed without these habitats). These habitats are often dispersed throughout watersheds and organisms move in all directions among these habitats throughout their life cycles (e.g., Schlosser and Angermeier 1995; Falke and Fausch 2010). Some species maintain populations in downgradient waters but move upstream or laterally to use habitats that are dry seasonally and in some cases are dry several years in a row (Falke et al. 2010). Thus, these sometimes-dry habitats can be critical to the biological integrity of downgradient waters. Species using these habitats range across many different taxa, even within fish. There are also significant connections from terrestrial to aquatic ecosystems, particularly among macroinvertebrates. The examples used in the Report tend to focus on only a few taxa, primarily salmon and other anadromous fish species. Many fish restricted to freshwater and many other taxa including invertebrates, amphibians, reptiles, birds, and mammals require these critical habitats and move to access them. When these upstream, lateral, and disconnected habitats are degraded or destroyed, populations decline and species can become threatened or endangered (or otherwise imperiled), or are extirpated entirely (Fausch and Bestgen 1997). Therefore, connectivity is a key to the biological integrity of downgradient waters. Moreover, 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.

Recommendations

- The conceptual framework in the Report 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 hydrological (surface and subsurface), chemical, and biological flowpaths.

- The conceptual framework in the Report should generally express the importance of climate, geology (surface and subsurface), relief, and biology on flow and transport (e.g., hydrological, chemical, and biological connectivity). 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.

- Ground water connectivity, including regional ground water connectivity across watershed divides, should be better defined in the Report and described in the context of connectivity between waters and wetlands and downgradient waters.

- Biological connectivity should be better defined in the Report, described in the context of connectivity between waters and wetlands and downstream waters and shown to be critical to the biological integrity of these connected waters.

3.2.6. 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 implicitly made throughout the Report and explicitly made 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 the role it plays in 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 ground water connectivity as it relates to the chemical, physical, and biological integrity of downgradient waters.

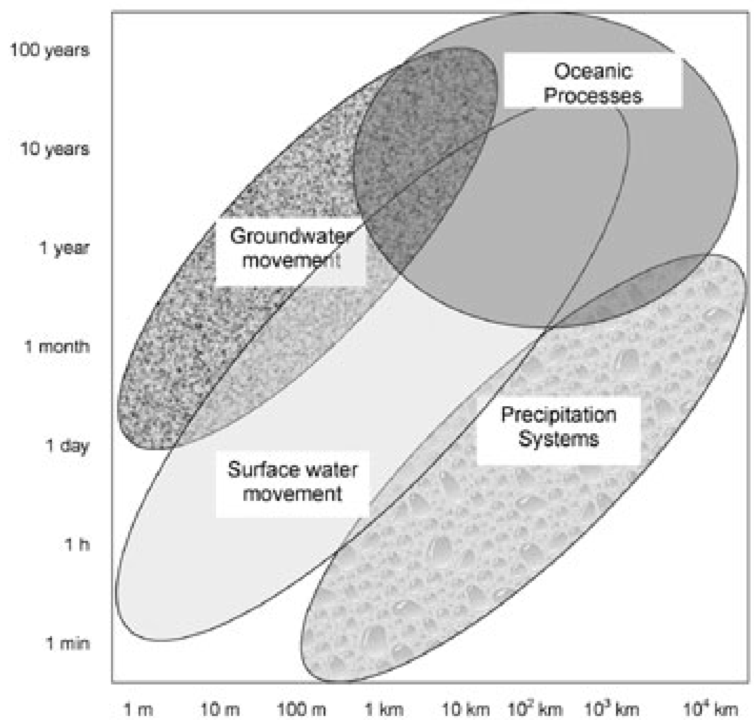

Figure 1: Relative spatial and temporal scale of hydrologic connectivity and interaction. (Source: U.S. Global Change Research Program 2001)

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. 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 1957). 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 scale 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. 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. One way to conceptualize this in the Report is by developing a matrix of relative likelihood × relative consequence, which would facilitate a discussion of spaces occupied by given waters and wetlands (Figure 2). Such a figure would go a long way toward helping readers understand the regional context of the spatial and temporal scale of connectivity.

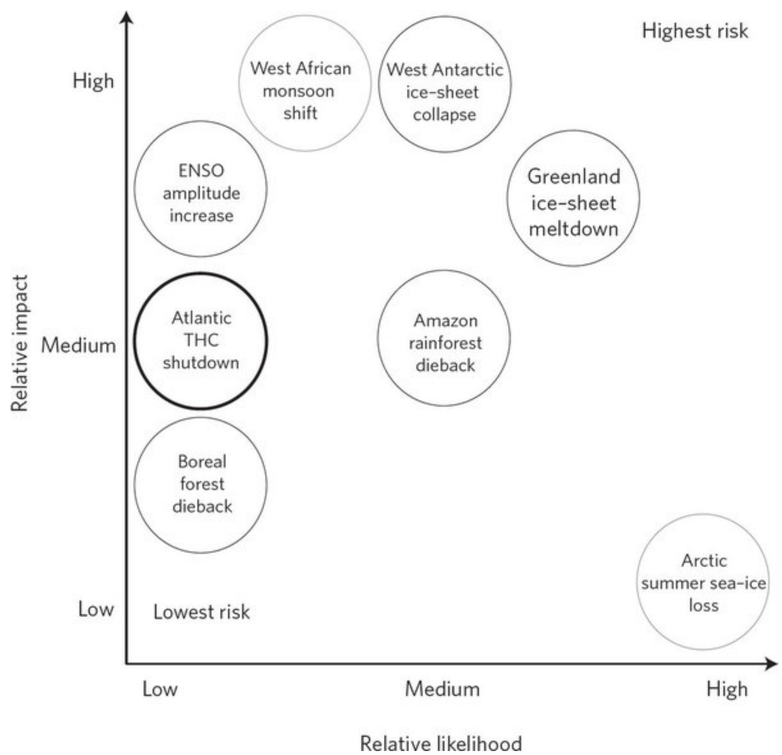

Figure 2: Relative likelihood × relative impact of global-scale phenomena. (Source: Lenton 2011. Reprinted by permission from Macmillan Publishers Ltd: Nature Climate Change 1(4):201-209, copyright 2011.)

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 ground water 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 three types of alterations constitute alterations to connectivity and therefore to 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 problem has been 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. This would not represent a large departure from the approach used in the Report because HLRs are fundamentally a function of climate, geology, and 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. The 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 on this matter. This could then serve as a means to discuss regionalization, because generalizations are context dependent, i.e., the expressions of chemical, physical, and biological phenomena depend on environmental setting (e.g., climatic, geologic, topographic). 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 readers use the HLRs 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 ground water 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 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 could 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. However, at the watershed scale, there are hundreds of headwater streams, which means that the annual probability of a debris flow in the "population" 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 the context of 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 consider reviewing 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 is mentioned in several parts of the Report but it 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 (DEMs) 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.

It is critical that readers of the Report understand 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-riparian 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 degree of connectivity will be determined in some part by in the database and/or data collection technology used for the analysis.

Recommendations

- Once the EPA has described the flowpath framework and explained how the framework is used in the Report, additional layers of complexity should be represented in the conceptual model. In developing additional layers of complexity, the EPA should focus on the following issues.

- A water and wetland function framework should be layered 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 the role it plays in 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, or HLRs to help readers to 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.

3.2.7. Summary and Synthesis of the Conceptual Framework

Chapter 3 of the Report ends abruptly, with no 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 in Chapter 3.

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

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 and give more attention to spatial and temporal variability that could affect connectivity of streams. The revised text should also 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 is also 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.

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.

- The following references (and others that are similar) should be considered for inclusion in a broader discussion of hyporheic processes: Stromberg 2001, Buffington and Tonina (2009); Karwan and Saiers (2012); Poole et al. (2006); Sawyer, et al. (2011); and Stonedahl et al. (2010).

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

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. The SAB finds that the Report needs a more thorough characterization of upslope (surface and subsurface) effects of geology, soils, and hydrology 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, but 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 should also further discuss both sediments and sediment-bound contaminants and their downstream movement and effects on downstream waters.

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).

Recommendations

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

- The additional references identified above, and others that are similar, should be considered for inclusion in the discussion.

3.3.3. Factors that Influence Stream Temperature

Stream temperature is an important component of ecosystem integrity because it controls many fundamental ecosystem properties and processes. Upslope factors affect the relative contributions of surface and 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 the influence of stream temperature on downstream connectivity and vice versa, 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 ground water discharge in terms of their comparative effects on stream temperature dynamics (Callahan et al. in press).

Recommendations

- The discussion of upslope factors that influence stream temperature should be expanded to include: hyporheic flow and storage, a comparison to ground water 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 the influence of stream temperature on downstream connectivity and vice versa.

- 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).

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 sediment 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 human alterations affect the natural temporal dimensions of connectivity (e.g., water withdrawal or augmentation can alter the timing and duration of flow). Overall, the SAB recommends that report include a clear discussion 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 in space and time to downstream ecosystems and the effects of time-varying flow connections: McDonough et al., 2011; Levick et al., 2008; Boano et al. (2013); Brooks et al. (2006); Constantz (2008); Harvey et al. (2012); and O'Connor et al. (2012); RWRD (2002); and Walker et al. (2005).

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, and 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 dominated stream flow.

- The additional references identified above (and others that are similar) should be considered for inclusion in the Report.

3.3.5. Strengthening the Review of Biological Connectivity

As previously mentioned, 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:

- 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).

- Some species maintain populations in downstream receiving 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 et al. 2010).

- Mobile species that use ephemeral or intermittent waters include many different taxa, even within fish, and encompass many more than those identified in the Report, which focuses largely on salmon and other anadromous fish. Many fish living solely in freshwater, and many other taxa including amphibians, reptiles, birds, mammals, and important invertebrates, require these habitats and move to access them.

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

- 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).

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

As previously mentioned, the SAB finds that the Report lacks references to the literature on human-modified headwater streams. 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; the current version of the report generally excluded the many studies that have been conducted in human-modified stream ecosystems. The SAB finds that there are many insights to be gained about the importance of connectivity to downstream waters, either when connections are 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 should be included in the report.

The SAB recommends that writers of the report consider including examples from at least *some* of the following human alterations: 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, 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); Doyle et al. (2000); Graf (2006); Gregory (2006); Faulkner (2004); Horner et al (2001); Lautz et al. (2008); and O'Connor et al. (2010); Paul and Meyer (2001); Schumm et al (1984); Williams and Wolman (1984); and Wohl (2005).

Recommendations

- The draft 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. These revisions could, for example, include discussion of some of these topics listed above.

- The additional references identified above, and others that are similar, should be considered for inclusion in the Report.

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

The SAB recommends that a new section on the role of headwater streams in aggregate and cumulative effects 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 the just the SPARROW model (SPAtially Referenced Regressions On Watershed attributes) 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 watershed for examining aggregate and cumulative effects on downstream waters.

Recommendations

- A new section on aggregate and cumulative effects of headwater streams on downstream ecosystems should be added to Chapter 4 of the Report.

- 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 other models in addition to the SPARROW model (SPAtially Referenced Regressions On Watershed attributes).

- The following references (and others that are similar) should be considered for inclusion in the Report to document the role of headwater streams in aggregate and cumulative effects on downstream ecosystems: Alexander et al. (2009); Böhlke et al. (2009); and Helton et al. (2011).

3.3.8 Connections to the Broader Riverine 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 broader riverine 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 beneficial ecological effects of streamside vegetation are not exclusively associated with 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 beneficial effects occur along the entire longitudinal stream profile, but are especially important to headwater streams. The

SAB recommends that the draft Report be revised to expand the discussion of the effects of streamside vegetation on stream ecosystems.

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:

1) 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).

2) 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).

3) 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.

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 that text be added to the Report to clarify how the 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; Long Term Ecological Research Network 2014). The SAB notes that the San Pedro River example in the Report is never mentioned or interpreted in other parts of the Report.

Recommendations

- The Report text should explain the rationale for selecting 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 SAB finds that 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, and magnitude 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.

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.

- 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).

3.4. <u>Ephemeral, Intermittent, and Perennial Streams: Review of the Findings and Conclusions</u>

> *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, EPA should recognize that there is a gradient of connectivity that is a function of the frequency, magnitude, and duration of physical, chemical, and biological processes. The SAB strongly supports the current emphasis in this Section 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 that would highlight the main findings. This would underscore the key functions summarized in Table 4.1 which outline the five key stream functions and their effect on downstream waters: sources, sinks, refuges, transformations, and lags. 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[3] 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 and, most importantly, these inconsistencies obscure the Report’s conclusions.

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] The summary should not include reference to literature already cited in the Report.

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., ground water-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 (i.e., 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 U.S. 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 (ground water recharge and water table rise) versus fall baseflow (ground water 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 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 ground water-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 the 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 authors consider summarizing and displaying the Report's conclusions in matrix form. A well designed matrix could have several advantages as it 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 Intergovernmental Program on Climate Change report (IPCC 2007) would also help to better communicate findings. For example, conclusions drawn at broad regional scales could have a high level of certainty and conclusions drawn for an individual site at a local scale could have lower certainty.

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. Highlighting the key point of each of the longer case studies would make them more impactful. In addition, the SAB also finds that some case study conclusions appear to be overreaching, such as for arid streams. In this case, real-world management scenarios can contrast greatly with the situations described in this particular case study.

For the summary conclusions in case studies, the SAB recommends that the authors 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.

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) of the Report "Streams: Synthesis and Implications" and Section 1.4.

- The SAB suggests that the EPA could 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 ground water-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 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 U.S. 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. Waters and Wetlands in Floodplain Settings: Review of the Literature

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 be expanded to adequately address this important type of connectivity. That said, the literature reviewed does substantiate 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 wetlands 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, 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 review). 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 also 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).

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 receiving waters (i.e., lateral exchange between floodplains and rivers followed by downstream transport) within riverscape (*sensu* Wiens 2002) and riverine landscape (*sensu* 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.

- The EPA should also consider reviewing the following additional selected on references on fauna in waters and wetlands in riparian/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); Gresswell (2011); Koel et al. (2005); McIntyre et al. (2007); Mion et al. (1998); Modde et al. (2001); Modde et al. (2005); Schick and Lindley (2007); Spinola et al. (2008); and Zelasko et al. (2010).

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.

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.

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 recommended 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 here. 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 character 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). The concept of riverine landscapes is not discussed, but could be a strong organizational framework.

Short duration high intensity flood events for surface waters and long duration low intensity lateral discharge for ground water need additional emphasis, including descriptions of the influence of the flooding on residence time of surface water, seasonal exchanges with ground water, chemical and biological linkages, and ecosystem processes. For example, 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 ground water 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 ground water 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 ground water movement and storage, including the effects of flood pulses on the hydrologic differences between, for example, “slope” (primarily ground water 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 ground water 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. In this way, 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 of the linkage and expansion of these environments associated with lateral flows caused by flood events. The authors of the Report need to clearly articulate the “bidirectional” nature of fluxes and connections back to the river channel, focusing on the fluxes of water, materials, and biota and emphasizing how exchange flows respond to the temporal progression of the flood pulse and move back to the channel. This will reflect flowpaths described in the conceptual model shown described in Section 3.2 of this SAB report. As such, Section 5.3 of the EPA Report should stress 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 in this regard. Flood-forecasting methods could be used as a means to quantify the strength of connectivity (spatial and temporal) between floodplains and rivers. Hydrological methods in flood frequency – floodplain inundation provide estimates of water residence time (or hydroperiod) on floodplains, with implications for fluxes of biota and biogeochemical processing, for example, of nitrogen (N) and phosphorus (P). The results are measures of vertical and lateral connectivity. Analyses of this kind 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 would address floodplain geomorphological and functional diversity and place emphasis on the continuum of floodplains along stream networks. This would lead to a better understanding of factors that shape the degree of connectivity between floodplains and receiving waters by describing floodplain/channel geomorphology and the duration of flooding or saturation. 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) 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 as fish nurseries that act to populate downstream fisheries. These references include studies describing fish species that spawn and rear in backwaters and floodplain wetlands that flood during high-water seasons, then dry down as flows decrease. As previously noted, these habitats are particularly important for fish larvae. Similarly, some endangered fishes have been shown to use backwaters extensively for spawning and rearing (e.g., Modde et al. 2001; 2005; Bestgen et al. 2007). The Report would be strengthened by discussing the importance of these floodplain habitats and their multi-dimensional connectivity.

The SAB also finds that it would be instructive to broaden the range of examples used in the Report and make it more representative of the U.S. 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.

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); Hudson et al. (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).

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 ground water) and downstream waters, recognizing the full range of temporal and spatial variability (i.e., short duration high intensity floods for surface waters, long duration low intensity lateral discharge for ground water, 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, which describe the movement of channels within floodplains over time as a result of large floods, 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 the Report to demonstrate that 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 used in the Report could be broadened to make it more representative of the U.S. 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.

- The EPA should consider reviewing the additional references identified above.

3.5.4. Chemical Linkages

Wetlands and floodplains serve as sinks, sources 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, which 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 fully 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 are not 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 (McClain et al. 2003; see also extensive work by 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 indicating, for example, that nitrogen levels increased or decreased. In this specific example the Report should indicate the percent concentration change. The SAB notes that, depending on hydrologic connectivity and water residence time, riparian/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, leading 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 POM and DOM 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 reviewing the following selected references on biogeochemistry as support to the Report: 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); Freeman et al. (2004b); Hefting et al.(2004); Osborne (2005); Qualls and Richardson. (2003); Reddy et al. (1999); Reddy et al. (2005); Reddy et al. (2011); Strack et al. (2008); Wetzel (1990); and Wetzel (2002).

Recommendations:

- The Report should provide a more recent and diverse assessment of the chemical implications of exchange flows. This can be accomplished by enhancing the review of the 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 section 3.5.8 of this SAB report). The Report could also 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 3.5.8 of this SAB report).

- The EPA should consider reviewing the selected references on biogeochemistry identified above (and others that are similar) as support to the 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 (Groffman et al. 2003; McClain et al. 2003). In particular, the EPA should consider including in the Report further discussion of the residence time of water. Water residence time is a critical concept that can have significant biological impacts, which can be particularly relevant to downstream waters (additional references are provided in section 3.5.8 of this SAB report).

- The EPA should consider strengthening the Report by reporting the literature findings more quantitatively and not by simple qualitative statements, for example, that nitrogen levels increased or decreased.

3.5.5. Export versus Exchange

Floodplains and 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., receiving waters), moving onto the floodplain in periods of high flows and back to the channel as floods recede. As mentioned above, the Report text as written 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.

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 U.S. wetlands. A box case study could address this gap, and include the role of bottomland forests on river biogeochemistry and flood storage.

Recommendation

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

3.5.7. Human Impacts to Floodplains and Aggregate Effects

The effect of human impacts to waters and wetlands in floodplain settings on connectivity 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 decrease 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 (Barkesdale 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.

Recommendations (arranged in order of priority, from higher to lower):

- The Report should address the effects of human impacts to waters and wetlands in floodplain settings on connectivity.

- The water quality benefits of riparian areas and floodplains should 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 as support to the Report: Dudley and Platania (2007); and Verhoeven et al. (2006).

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 highly 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 ground water connectivity. 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 the information presented in Section 5.3 on Floodplain Wetlands. The discussion of findings and conclusions in these two sections should be parallel. 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 zones), which potentially undermines the ability to speak to connectivity between waters and wetlands in floodplain settings and receiving 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.

Recommendations (arranged in order of priority, from higher to lower):

- There is strong scientific support for the conclusion that waters and wetlands in floodplain settings are highly connected to receiving 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 ground water 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 waters and wetlands in floodplain settings.

Inconsistent Terminology

As previously mentioned, the Report language 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, as previously discussed, the SAB recommends 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 at 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 ground water 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 ground water 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 the SAB response to Charge Question 4(a).

Further Quantification of Key Conclusions

The key conclusions in the Report 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 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) in order to refer to literature on floodplain wetlands and water bodies rather than rely 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 receiving 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 receiving 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 as well as those species that are state and/or federally 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 receiving 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. Additionally, 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 the function of waters and wetlands in floodplain settings is 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.

Recommendations (arranged in order of priority, from higher to lower):

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

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 generally thorough, technically accurate, and readable. As previously mentioned, the SAB recommends the authors reconsider use of the terms "unidirectional" and "geographically isolated wetlands" and replace them with 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 ground water and non-hydrologic biological exchanges that can strongly influence the integrity of downstream waters. 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 ground water flowpaths, or through the movement of biota, with specific attention paid to the magnitude, duration, and frequency of these connections. The SAB recommends that spatial landscape position and scale 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 the temporal and spatial scales of hydrologic 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. As previously discussed, the SAB also finds that human alterations of watersheds may change the type of connections as well as the magnitude, frequency, and duration of the connections between non-floodplain waters and downstream ecosystems. The SAB recommends that the draft Report be revised to acknowledge the role of humans in these changes. In addition the draft 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." While the Report already includes several major review papers, the SAB recommends adding a review paper by Bracken, et al. (2013). The SAB also recommends adding additional citations on biological connections (e.g., Naiman et al 1994; Polis et al. 1997). Other publications on the subject of biological connections are referenced throughout this SAB report. Evidence from the large and growing literature on biological exchanges between non-floodplain wetlands should be included in the Report. In particular, the SAB recommends including literature addressing: the bulk exchange of materials via biota, e.g., energy (Norlin 1967, Mason and MacDonald 1982, Polis et al. 1997, Sabo and Power 2002, Baxter et al. 2005, Spinola et al. 2008, Lowe et al. 2005, 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); 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); Croke et al. (2005); Conly et al. (2001); Fang and Pomeroy (2008); Gray et al. (1984); Hayashi and Van der Kamp (2000); Hayashi et al. (2003); Montgomery (1994); Shaw et al. (2012); Spence (2007); Spence and Woo (2003); Stichling and Blackwell (1957); Thompson et al. (2008); Van der Kamp et al. (2003); Van der Kamp et al. (2008); Wemple et al. (1996); Wemple et al. (2001); Wigmosta and Perkins (2001); Winter and LaBaugh (2003); Woo and Rowsell (1993); and Yang, et al. (2010).

Recommendations

- The literature review in Section 5.4 of the Report is generally thorough, technically accurate and readable; however, the SAB recommends that the review article by Bracken et al. (2013) be added to the Report.

- The SAB recommends including additional literature references (identified above) in the Report to address: bulk exchange of materials via biota, e.g., energy, 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. Other selected references (identified above) should be reviewed and, if needed, included in the Report.

- The literature review should address the relative degree of connectivity for various non-floodplain wetlands and describe the relative strengths of those connections for those 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 on 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. The SAB suggests that the draft Report's "uni- and bi-directional" terminology be replaced by terms that better describe landscape position. In this case, "bidirectional wetlands" would be redefined as those within floodplain settings, and “unidirectional wetlands” as those not within 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.

Recommendation

- The terms “unidirectional” and “geographically isolated” wetlands should be replaced in the Report with the term “wetlands in non-floodplain settings.”

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

As discussed in the response to charge question 2, the SAB recommends the Report be revised to use a conceptual framework with multiple flowpaths that correspond to 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 (“unidirectional”) wetlands to downstream waters.

Similarly the SAB recommends that a 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 ground water, 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[4]) 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.

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

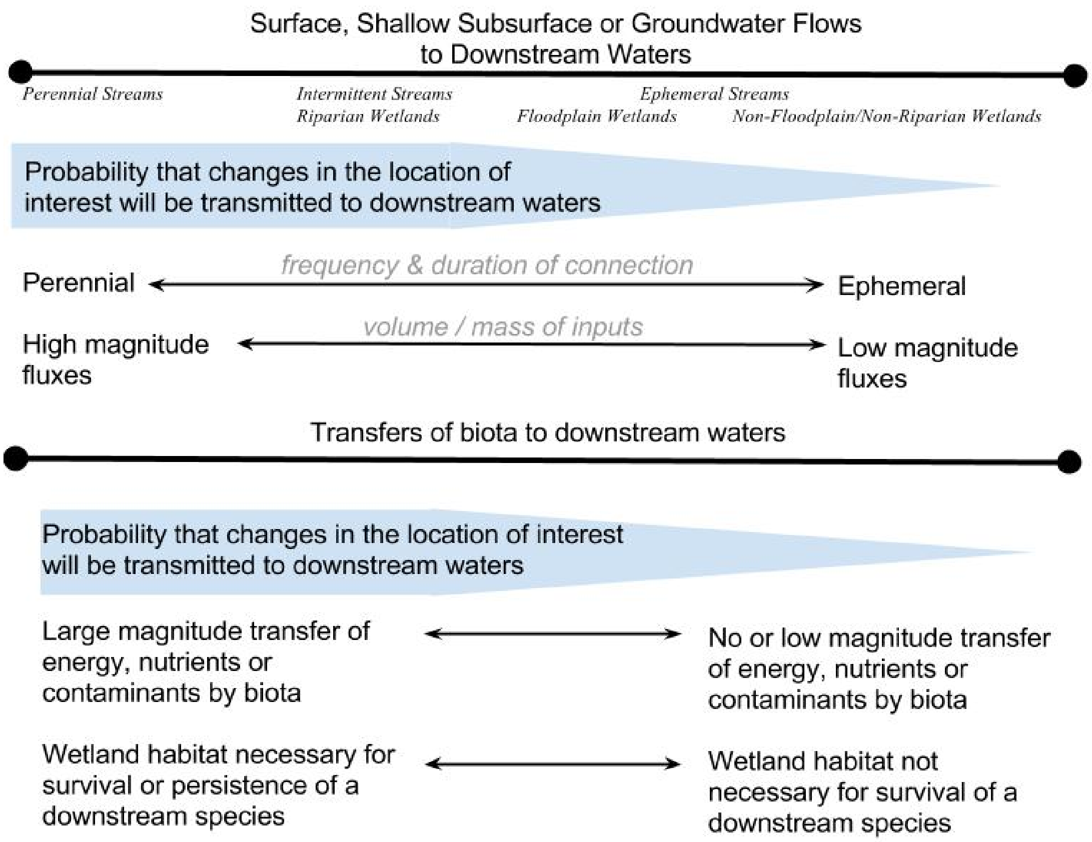

Figure 3: Hypothetical illustration of potential consequences of changes to downstream waters with increases in the magnitude, duration, and frequency of surface and subsurface connections. Connections to all streams including perennial, ephemeral have a connection to downstream waters. Within non-floodplain wetlands the degree of connectivity and its implications for integrity of downstream waters varies considerably.

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 use Figure 3 in this SAB report 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, and 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 ground water 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. Whether those connections are sufficient to warrant protections under the Clean Water Act requires that the exchange of water, materials or biota is of sufficient magnitude to impact the physical, chemical, or biological integrity of downstream waters. It is not sufficient to establish the mere existence of a connection, but rather, the magnitude and the impact of those connections should be considered.

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 that action.

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 LandSat imagery to map extent of high water regimes (>2x s.d., annual precipitation) versus low water regimes (<2x s.d. annual precipitation), 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 ground water connectivity between a wetland and downstream waters varies considerably. For example, ombrotophic bogs, which by definition are rain-fed, have minimal ground water connections to downstream waters; while ground water-fed wetlands are clearly exchanging materials with the same ground water 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 represents an important research need for the agency. Past this threshold, ground water 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, 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.

Recommendations

- The Report should recognize that all aquatic habitats have some degree of connection, though they may vary widely 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, and duration 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 flood; 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). The SAB notes that various frameworks for regionalization exist (e.g., Hydrologic Landscape Regions) and 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.

Recommendations

- The Report should be articulate and justify 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 the how the scaling may vary geographically and based on 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 disturbances (and related legacy effects) alter the type, strength and magnitude of connectivity pathways. 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 (Calhoun and deMaynadier 2008; Semlitsch 1998, 2000, 2002; Semlitsch and Bodie 2003). Most of these references are from the eastern U.S. There is a suite of species, mostly toads that rely on ephemeral aquatic habitats in the west 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 do not provide the same ecosystem functions as natural wetlands. 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.

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. <u>Non-floodplain Waters and Wetlands: Review of the Findings and Conclusions</u>

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 responding to 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 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 encompass connections beyond hydrologic ones, and that the frequency, magnitude, and duration of these connections be considered as well as their predictability. 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 ground water 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 ground water 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).

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 ground water 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 and frequency 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 which 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: Preston and Bedford (1988); Lee and Gosselink (1988).

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 (see suggested text above).

REFERENCES

Ahmed, F. 2014. Cumulative hydrologic impact of wetland loss: numeric modeling study of the Rideau River Watershed, Canada. *Journal of Hydrologic Engineering*. 19:593-606.

Aitkenhead-Peterson, J.A., W.H. McDowell, and J.C. Neff. 2003. Sources, Production, and Regulation of Allochthonous Dissolved Organic Matter. In *Aquatic ecosystems: interactivity of dissolved organic matter inputs to surface waters.* S. Findlay and R. L. Sinsabaugh. Academic Press, San Diego, CA. pp.25-61.

Alexander, R.B, E.W. Boyer, R.A. Smith, G.E. Schwarz, and R.B. Moore. 2007. The role of headwater streams in downstream water quality. *Journal of the American Water Resources Association* 43:41-59.

Alexander, R.B., J.K. Böhlke, E.W. Boyer, M B. David, J.W. Harvey, P.J. Mulholland, S P. Seitzinger, C.R. Tobias, C. Tonitto, and W.M. Wollheim. 2009. Dynamic modeling of nitrogen losses in river networks unravels the coupled effects of hydrological and biogeochemical processes. *Biogeochemistry* 93: 91-116.

Alford, J.B., and M.R. Walker. 2013. Managing the flood pulse for optimal fisheries production in the Atchafalaya River Basin, Louisiana (USA). *River Research and Applications* 29:279-296.

Ali, G.A., and A.G. Roy. 2010. Shopping for hydrologically representative connectivity metrics in a human temperate forested catchment. *Water Resources Research* 46:W12544.

Amoros, C and G Bornette. 2002. Connectivity and biocomplexity in waterbodies of riverine floodplains. *Freshwater Biology* 47: 761-776.

Anderson, C.J., and B.G. Lockaby. 2012. Seasonal patterns of river connectivity and saltwater intrusion in tidal freshwater forested wetlands. *River Research and Applications* 28:814-826.

Appel, CA, and T.E. Reilly. 1994. *Summary of selected computer programs produced by the U.S. Geological Survey for simulation of ground-water flow and quality*. U.S. Geological Survey Circular 1104.

Arrigoni, A.S., G.C. Poole, L A. K. Mertes, S J. O'Daniel, W.W. Woessner, and S.A. Thomas. 2008. Buffered, lagged, or cooled? Disentangling hyporheic influences on temperature cycles in stream channels. *Water Resources Research*. 44:W09418, doi:10.1029/2007WR006480.

ASTM (American Society for Testing and Materials). 1996. Standard Guide for Conceptualization and Characterization of Ground-Water Systems. Designation: D 5979-96 (Reapproved 2002). ASTM International, West Conshohocken, PA. Available at: http://www.astm.org/Standards/D5979.htm [accessed February 12, 2014]

Baker, M.A., H.M. Valett, and C.N. Dahm. 2000. Organic carbon supply and metabolism in a near-stream groundwater ecosystem. *Ecology* 81:3133-3148.

Barkesdale, F., C. Anderson, and L. Kalin. 2013. The influence of watershed runoff on the Hydrology, Forest Floor Litter and soil carbon of headwater wetlands. *Ecohydrology* 7(2):803-804.

Baxter, C.V., K.D. Fausch, and W.C. Saunders. 2005. Tangled webs: reciprocal flows of invertebrate prey link streams and riparian zones. *Freshwater Biology* 50:201-220.

Bedford, B. and E. Preston. 1988. Developing the scientific basis for assessing the cumulative effects of wetland loss and degradation on landscape functions: status, perspectives. *Environmental Management* 12:751-771.

Benda, L., M.A. Hassan, M. Church, and C.L. May. 2005. Geomorphology of steepland headwaters: the transition from hillslopes to channels. *Journal of the American Water Resources Association* 41:835-851.

Benda, L.E., and T. Dunne. 1997a. Stochastic forcing of sediment supply to channel networks from landsliding and debris flow. *Water Resources Research* 33(12): 2849-2863.

Benda, L.E., and T. Dunne. 1997b. Stochastic forcing of sediment routing and storage in channel networks. *Water Resources Research* 33(12):2865-2880.

Benda, L., D. Miller, J. Sias, D. Martin, R. Bilby, C. Veldhuisen, and T. Dunne. 2003. Wood Recruitment Processes and Wood Budgeting. In *The Ecology and Management of Wood in World Rivers*. S.V. Gregory, K.L. Boyer, and A.M. Gurnell (eds.) American Fisheries Society. Symposium 37:49-74. Bethesda, Maryland.

Benke, A.C., I. Chaubey, G.M. Ward, and L. Dunn. 2000. Flood pulse dynamics of an unregulated river floodplain in the southeastern U.S. coastal plain. *Ecology* 81:2730-2741.

Bestgen, K.R., D.W. Beyers, J.A Rice, and G.B. Haines. 2006. Factors affecting recruitment of young Colorado pike minnow: synthesis of predation experiments, field studies, and individual-based modeling. *Transactions of the American Fisheries Society* 135:1722-1742

Bestgen, K.R., J.A. Hawkins, G.C. White, K.D. Christopherson, J. M. Hudson, M.H. Fuller, D.C. Kitcheyan, R. Brunson, P. Badame, G. B. Haines, J.A. Jackson, C.D. Walford, and T.A. Sorensen. 2007. Population status of Colorado pike minnow in the Green River Basin, Utah and Colorado. *Transactions of the American Fisheries Society* 136(5):1356-1380.

Beven, K., and P. Germann. 1982. Macropores and water flow in soils. *Water Resources Research* 18:1311–1325.

Blanchong, J.A., M.D. Samuel, and G. Mack. 2006. Multi-species patterns of avian cholera mortality in Nebraska's Rainwater Basin. *Journal of Wildlife Diseases* 42:81-91.

Blann, K.L., J. Anderson, G. Sands, and B. Vondracek. 2009. Effects of agricultural drainage on aquatic ecosystems: a review. *Critical Reviews in Environmental Science and Technology* 39(11):909-1001.

Boano, F., R. Revelli, *and* L. Ridolfi. 2013. Modeling hyporheic exchange with unsteady stream discharge and bedform dynamics. *Water Resources Research* 49:4089–4099, *doi:*10.1002/wrcr.20322.

Böhlke, J. K., R.C. Antweiler, J.W. Harvey, A.E. Laursen, L.K. Smith, R.L. Smith, and M.A.Voytek. 2009. Multi-scale measurements and modeling of denitrification in streams with varying flow and nitrate concentration in the upper Mississippi River basin, USA. *Biogeochemistry* 93:117-141, doi:10.1007/s10533-008-9282-8.

Booth, D.B. 1990. Stream-channel incision following drainage-basin urbanization. *Journal of the American Water Resources Association* 26: 407–417.

Bottom, D.L., K.K. Jones, R.J. Cornwell, A. Gray, and C.A. Simenstad. 2005. Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). *Estuarine, Coastal, and Shelf Science* 64:79-93.

Bourg, A.C.M., and C. Bertin. 1993. Biogeochemical processes during the infiltration of river water into an alluvial aquifer. *Environmental Science and Technology* 27(4): 661-666.

Bracken, L.J., J. Wainwright, G.A. Ali, D. Tetzlaff, M.W. Smith, S.M. Reaney, and A.G. Roy. 2013. Concepts of hydrological connectivity: Research approaches, pathways and future agendas. Earth-Science Reviews 119:17-34.

Bridgham, S.D., K. Updegraff and J. Pastor. 2001. A comparison of nutrient availability indices along an ombrotrophic-minerotrophic gradient in Minnesota wetlands. *Soil Science Society of America Journal* 65:259-269.

Bridgham, S.D., J.P. Megonigal, J.K. Keller, N.B. Bliss and C. Trettin. 2006. The carbon balance of North American wetlands. *Wetlands* 26:889-916.

Brinson, M. 1988. Strategies for assessing the cumulative effects of wetlands on water quality. *Environmental Management* 12:655-662.

Brinson, M.M. 1993. *A hydrogeomorphic classification for wetlands*. WRP-DE-4 Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Brooks, B.W., T.M. Riley, and R.D. Taylor. 2006. Water quality of effluent-dominated ecosystems: ecotoxicological, hydrological, and management considerations. *Hydrobiologia* 556(1):365-379.

Brooks, R.P., T.J. O'Connell, D.H. Wardrop, and L.E. Jackson 1998. Towards a regional index of biological integrity: the examples of forested riparian ecosystems. *Environmental Monitoring and Assessment* 51:131–143.

Brooks, R.P., C. Snyder, and M.M. Brinson. 2013. Aquatic Landscapes: the importance of integrating waters. In *Mid-Atlantic Freshwater Wetlands: Advances in Science, Management, Policy, and Practice.* R.P. Brooks and D.H. Wardrop (eds.), 1-37. Springer Science Business Media.

Brummer, C.J., T.B. Abbe, J.R. Sampson and D.R. Montgomery. 2006. Influence of vertical channel change associated with wood accumulations on delineating channel migration zones, Washington, USA. *Geomorphology* 80:295-309.

Brunet, N.N. and C.J. Westbrook. 2012. Wetland drainage in the Canadian prairies: Nutrient, salt and bacteria characteristics. Agriculture. *Ecosystems and Environment* 146(1):1-12.

Buffington, J. M., and D. Tonina.2009. Hyporheic exchange in mountain rivers II: Effects of channel morphology on mechanics, scales, and rates of exchange, *Geography Compass* 3: doi:10.1111/j.1749-8198.2009.00225.x.

Bull, W.B., and K.M. Scott. 1974. Impact of mining gravel from urban stream beds in the Southwestern United States. *Geology* 2: 171–174.

Bunn, S.E., M.C. Thoms, S.K. Hamilton, and S.J. Capon. 2006. Flow variability in dryland rivers: Boom, bust and the bits in between. *River Research and Applications* 22:179-186.

Buresh, R.J, K.R. Reddy and C. van Kessel. 2008. Nitrogen transformations in submerged soils. In *Nitrogen in Agricultural Systems*. J.C. Schepers and W. R. Raun (eds.) Agronomy Monograph 49, 401-436. American Society of Agronomy, Madison, WI

Callahan, M.K., M.C. Rains, J.C. Bellino, C.M. Walker, S.J. Baird, D.F. Whigham, and R.S. King. Controls on temperature in salmonid-bearing headwater streams in two common hydrogeologic settings, Kenai Peninsula, Alaska. *Journal of the American Water Resources Association* (in press).

Calhoun, A.J.L., and P.G. deMaynadier. 2008. *Science and Conservation of Vernal Pools in Northeastern North America.* CRC Press. Boca Raton, FL

Cary Institute of Ecosystem Studies. 2014. *Baltimore Ecosystem Study*. http://www.caryinstitute.org/science-program/research-projects/baltimore-ecosystem-study. [accessed April 21, 2014]

Chin, A., and K.J. Gregory. 2001. Urbanization and adjustment of ephemeral stream channels. *Annals of the Association of American Geographers* 91: 595–608.

Conant, B. Jr., J.A. Cherry, and R.W. Gillham. 2004. A PCE groundwater plume discharging to a river: influence of the streambed and near-river zone on contaminant distributions. *Journal of Contaminant Hydrology* 73(1-4): 249-279, doi:10.1016/j.jconhyd.2004.04.001.

Conaway, J.S., and E.H. Moran. 2004. *Development and calibration of two-dimensional hydrodynamic model of the Tanana River near Tok, Alaska.* U.S. Geological Survey Open-File Report 2004-1225.

Conly, F.M., and G. Van der Kamp. 2001. Monitoring the hydrology of Canadian prairie wetlands to detect the effects of climate change and land use changes. *Environmental Monitoring and Assessment* 67:195–215.

Constantz, J. 2008. Heat as a tracer to determine streambed water exchanges. *Water Resources Research* 44:W00D10, doi:10.1029/2008WR006996.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. *Classification of Wetlands and Deepwater Habitats of the United States*. U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services, Washington, DC.

Croke, J., I.Takken, and S. Mockler. 2005. Sediment concentration changes in runoff pathways from a forest road network and the resultant spatial pattern of catchment connectivity. *Geomorphology* 68:257-268.

Cunningham, W.L. and C.W. Schalk 2011. Groundwater technical procedures of the U.S. Geological Survey. *U.S. Geological Survey Techniques and Methods 1–A1*. U.S. Geological Survey, Washington, DC

Darst, M.R., and H.M. Light. 2008. *Drier forest composition associated with hydrologic change in the Apalachicola River floodplain, Florida*. U.S. Geological Survey Scientific Investigations Report 2008-5062, U.S. Geological Survey, Washington, DC.

Davis, C.A. 2003. Habitat use and migration patterns of sandhill cranes along the Platte River, 1998-2001. *Great Plains Research* 13:199-216.

Dietch, M.J., A.M. Merenlender, and S. Feirer. 2013. Cumulative effects of small reservoirs on streamflow in northern California catchments. *Water Resources Management* 27:5101-5118.

Doyle, M.W., J.M. Harbor, C.F. Rich, and A. Spacie. 2000. Examining the effects of urbanization on streams using indicators of geomorphic stability. *Physical Geography* 21: 155–181.

Doyle, M.W., E.H. Stanley, and J.M. Harbor. 2003. Hydrogeomorphic controls on phosphorus retention in streams, *Water Resources Research* 39(6):1147.

Drexler, J.Z., D. Knifong, J. Tuil, L.E. Flint, and A.L. Flint. 2013. Fens as whole-ecosystem gauges of groundwater recharge under climate change. *Journal of Hydrology* 481(2013):22-24

Dudley, R.K., and S.P. Platania. 2007. Flow regulation and fragmentation imperil pelagic-spawning riverine fishes. *Ecological Applications* 17:2074-2086.

Dunne, T. 1978. Field studies of hillslope flow processes and their significance, in *Hillslope Hydrology*. M.J. Kirby (ed.) Pp. 227-293, Wiley-Interscience, NY.

Dunne, T., and R.D. Black. 1970. Partial area contributions to storm runoff in a small New England watershed. *Water Resources Research* 6:1296—1311.

Dunne, T., J. Agee, S. Beissinger, W. Dietrich, D. Gray, M. Power, V. Resh, and K. Rodrigues. 2001. *A Scientific Basis for the Prediction of Cumulative Watershed Effects*. University of California Wildland Resource Center Report No. 46. 103 pp. University of California, Berkeley, CA

Ellis, L.M., C.S. Crawford, and M.C. Molles. 2001. Influence of annual flooding on terrestrial arthropod assemblages of a Rio Grande riparian forest. *Regulated Rivers-Research and Management* 17:1-20.

Ely, D.M., and S.C. Kahle. 2012. *Simulation of groundwater and surface-water resources and evaluation of water-management alternatives for the Chamokane Creek basin, Stevens County, Washington*. U.S. Geological Survey Scientific Investigations Report 2012-5224. U.S. Geological Survey, Washington, DC.

Ensign, S.H., M.F. Piehler, and M.W. Doyle. 2008. Riparian zone denitrification affects nitrogen flux through a tidal freshwater river. *Biogeochemistry*, 91:133-150.

Falke, J.A., and K.D. Fausch. 2010. From metapopulations to metacommunities: linking theory with empirical observations of the spatial population dynamics of stream fishes. *American Fisheries Society Symposium*73:207-233.

Fang, X., and J.W. Pomeroy. 2008. Drought impacts on Canadian prairie wetland snow hydrology. *Hydrological Processes* 22: 2858-2873.

Faulkner, S. 2004. Urbanization impacts on the structure and function of forested wetlands. *Urban Ecosystems* 7:89-106.

Fausch, K.D. 2010. A renaissance in stream fish ecology. *American Fisheries Society Symposium* 73:199-206.

Fausch, K.D., and K.R. Bestgen. 1997. Ecology of fishes indigenous to the central and southwestern Great Plains. In *Ecology and Conservation of Great Plains Vertebrates.* F.L Knopf and F.B. Sampson (eds.) Pages 131–166, Ecological Studies 125. New York: Springer-Verlag.

Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. *BioScience* 52:483–498.

Fennessy, M.S., and J.K. Cronk. 1997. The effectiveness and restoration potential of riparian ecotones for the management of nonpoint source pollution, particularly nitrate. *Critical Reviews in Environmental Science and Technology* 27:285-317.

Figuerola J, A.J. Green, and L. Santamaria. 2003. Passive internal transport of aquatic organisms by waterfowl in Doñana, south-west Spain. *Global Ecology and Biogeography* 12:427-436.

Findlay, S.E.G. 1995. Importance of surface-subsurface exchange in stream ecosystems: the hyporheic zone. *Limnology and Oceanography* 40:159-164.

Flecker, A.S., P.B. McIntyre, J.W. Moore, J.T. Anderson, B.W. Taylor, and R.O. Hall. 2010. Migratory fishes as material and process subsidies in riverine ecosystems. *American Fisheries Society Symposium* 73:559-592.

Fowler, D. 2004. Link land-atmosphere- stream carbon fluxes in a lowland peatland system. *Global Biogeochemical Cycles* 18:GB1024. DOI: 10Ð1029/2003GB002058

Freeman, C., N. Fenner, N. J. Ostle, H. Kang, D.J. Dowrick, B. Reynolds, M.A. Lock, D. Sleep, S. Hughes and J. Hudson. 2004a. Dissolved organic carbon export from peatlands under elevated carbon dioxide levels. *Nature* 430:195-198.

Freeman, C., N.J. Ostle, N. Fenner and H. Kang. 2004b. A regulatory role for phenol oxidase during decomposition in peatlands. *Soil Biology and Biochemistry* 36:1663-1667.

Frohn, R.C., M. Reif, C. Lane, and B. Autrey. 2009. Satellite remote sensing of isolated wetlands using object-oriented classification of Landsat-7 data. *Wetlands* 29:931-941.

Frohn, R.C., E. D'Amico, C. Lane, B. Autrey, J. Rhodes, and H. Liu. 2012. Multi-temporal sub-pixel Landsat ETM+ classification of isolated wetlands in Cuyahoga County, Ohio, USA. *Wetlands* 32:289-299.

Fuller, C.C., and J.W. Harvey. 2000. Reactive uptake of trace metals in the hyporheic zone of a mining-contaminated stream, Pinal Creek, Arizona. *Environmental Science and Technology* 34(6): 1150-1155.

Gabet, E.J. and T. Dunne. 2003. A stochastic sediment delivery model for a steep, Mediterranean landscape. *Water Resources Research* 39:1237-1245.

Galat, David L., L.H. Fredrickson, D.D. Humburg, K.J. Bataille, J.R. Bodie, J. Dohrenwend, G.T. Gelwicks, J.E. Havel, D.L. Helmers, J.B. Hooker, J.R. Jones, M.F. Knowlton, J. Kubisiak, J. Mazourek, A.C. McColpin, R.B. Renken, and R.D. Semlitsch. 1998. Flooding to Restore Connectivity of Regulated, Large-River Wetlands. *BioScience* 48(9):721-733.

Gasith, A., and V.H. Resh. 1999. Streams in Mediterranean climate regions: abiotic influence snd biotic responses to predictable seasonal events. *Annual Review of Ecology and Systematics* 30:51-81.

Goodrich, D.C., D.G. Williams, C.L. Unkrich, J.F. Hogan, R.L. Scott, R. L., K.R. Hultine, and S. Miller. 2004. Comparison of methods to estimate ephemeral channel recharge, Walnut Gulch, San Pedro River Basin, Arizona. *Water Science and Application* 9:77-99.

Graf, W. L. 1988. *Fluvial Processes in Dryland Rivers (Vol. 3).* Springer, New York.

Graf, W.L. 2006. Downstream hydrologic and geomorphic effects of large dams on American rivers. *Geomorphology* 79: 336–360.

Granado, D.C., and R. Henry. 2014. Phytoplankton community response to hydrological variations in oxbow lakes with different levels of connection to a tropical river. *Hydrobiologia* 721:223-238.

Gray, D.M., P.G. Landine, and R.J. Granger. 1984. Simulating infiltration into frozen Prairie soils in streamflow models. *Canadian Journal of Earth Sciences* 22:464-472.

Green, A.J, K.M. Jenkins, D. Bell, P.J. Morris, and R.T. Kingsford. 2008. The potential role of waterbirds in dispersing invertebrates and plants in arid Australia. *Freshwater Biology* 53:380-392.

Gregory, K.J. 2006. The human role in changing river channels. *Geomorphology* 79: 172–191.

Gresswell, R.E. 2011. Biology, status, and management of the Yellowstone cutthroat trout. *North American Journal of Fisheries Management* 31:782-812.

Groffman, S.C., J.W. Hart, C.A. Harvey, E. Johnston, E. Mayorga, W.H, McDowell, and G. Pinay. 2003. Biogeochemical Hot Spots and Hot Moments at the Interface of Terrestrial and Aquatic Ecosystems. *Ecosystems* 6:301-312. DOI: 10.1007/s10021-003-0161-9.

Haag, K.H., and W. Pfeiffer. 2012. *Flooded area and plant zonation in isolated wetlands in well fields in the Northern Tampa Bay Region, Florida, following reductions in groundwater-withdrawal rates.* U.S. Geological Survey Scientific Investigations Report 2012-5039. U.S. Geological Survey, Washington, DC.

Hall, D.H., and R.J. Steidl, 2007. Movements, activity, and spacing of Sonoran mud turtles (*Kinosternon sonoriense*) in interrupted mountain streams. *Copeia* 2007:403-412.

Harbaugh, A.W. 2005. *MODFLOW-2005, the U.S. Geological Survey Modular Ground-Water Model – the Ground-Water Flow Process*. U.S. Geological Survey Techniques and Methods 6-A16. U.S. Geological Survey, Washington, DC.

Harvey, J.W., and C.C. Fuller. 1998. Effect of enhanced manganese oxidation in the hyporheic zone on basin-scale geochemical mass balance. *Water Resources Research* 34(4):623-636.

Harvey, J.W., J.D. Drummond, R.L. Martin, L.E. McPhillips, A.I. Packman, D.J. Jerolmack, S.H. Stonedahl, A. Aubeneau, A.H. Sawyer, L.G. Larsen, and C. Tobias. 2012. Hydrogeomorphology of the hyporheic zone: Stream solute and fine particle interactions with a dynamic streambed. *Journal of Geophysical Research – Biogeosciences* 117, G00N11, doi:10.1029/2012JG002043.

Harvey, J.W., J.K. Böhlke, M.A. Voytek, D. Scott, and C.R. Tobias. 2013. Hyporheic zone denitrification: Controls on effective reaction depth and contribution to whole-stream mass balance. *Water Resources Research* 49:6298-6316, doi:10.1002/wrcr.20492.

Hayashi, M., and G. Van der Kamp. 2000. Simple equations to represent the volume-area-depth relations of shallow wetlands in small topographic depressions. *Journal of Hydrology* 237:74-85.

Hayashi, M., G. Van der Kamp, and R. Schmidt. 2003. Focused infiltration of snowmelt water in partially frozen soil under small depressions. *Journal of Hydrology* 270: 214-229.

Healy, R.W., T.C. Winter, J.W. LaBaugh, and O.L. Franke. 2007. *Water budgets: foundations for effective water-resources and environmental management.* U.S. Geological Survey Circular 1308. U.S. Geological Survey, Washington, DC.

Heath, R.C. 1983. *Basic Ground Water Hydrology.* U.S. Geological Survey Water Supply Paper 2220. U.S. Geological Survey, Washington, DC.

Heath, R.C. 1984. *Ground-Water Regions of the United States*. U.S. Geological Survey Water Supply Paper 2242, U.S. Government Printing Office, Washington, DC.

Hedin, L.O., J.C. von Fischer, N.E. Ostrom, B.P. Kennedy, M.G. Brown, Robertson, G.P. 1998. Thermodynamic constraints on nitrogen transformations and other biogeochemical processes at soil-stream interfaces. *Ecology* 79(2): 684-703.

Hefting, M., J.C. Clement, D. Dowrick, A.C. Cosandey, S. Bernal, C. Cimpian, A. Tatur, T.P. Burt and G. Pinay. 2004. Water table elevation controls on soil nitrogen cycling in riparian wetlands along a European climatic gradient. *Biogeochemistry* 67:113-134.

Heiler, G., T. Hein, F. Schiemer, and G. Bornette. 1995. Hydrological connectivity and flood pulses as the central aspects for the integrity of a river-floodplain system. *Regulated Rivers-Research and Management* 11:351-361.

Helfield, J.M., and R.J. Naiman. 2001. Effects of salmon-derived nitrogen on riparian forest growth and implications for stream productivity. *Ecology* 82:2403-2409.

Helton, A.M., G.C. Poole, J.L. Meyer, W.M. Wollheim, B.J. Peterson, P.J. Mulholland, E.S. Bernhardt, J.A. Stanford, C. Arango, L.R. Ashkenas, L.W. Cooper, W.K. Dodds, S.V. Gregory, R.O. Hall, S.K. Hamilton, S.L. Johnson, W.H. McDowell, J.D. Potter, J.L. Tank, S.M. Thomas, H.M. Valett, J.R. Webster, and L. Zeglin. 2011. Thinking outside the channel: modeling nitrogen cycling in networked river ecosystems. *Frontiers in Ecology and the Environment* 9(4):229-238, doi:10.1890/080211.

Henson, S.S., D.S. Ahearn, R.A. Dahlgren, E. Van Nieuwenhuyse, K.W. Tate, and W.E. Fleenor. 2007. Water quality response to a pulsed-flow event on the Mokelumne River, California. *River Research and Applications* 23:185-200.

Hernandez, M., S.N. Miller, D.C. Goodrich, B.F. Goff, W.G. Kepner, C.M. Edmonds, and K.B. Jones. 2000. Modeling runoff response to land cover and rainfall spatial variability in semi-arid watersheds. In *Monitoring Ecological Condition in the Western United States.* S.S. Sandju, B.D. Melzian, E.R. Long, W.G. Whitford, and B.T. Walton (eds.) 285-298. Springer, Netherlands.

Hester, E.T., M.W. Doyle, and G.C. Poole. 2009. The influence of in-stream structures on summer water temperatures via induced hyporheic exchange. *Limnology and Oceanography* 54(1):355-4 367.

Horner, R., S. Cooke, L. Reinelt, K. Ludwa, N. Chin and M. Valentine. 2001. Effects of watershed development on water quality and soils. In: *Wetlands and Urbanization: Implications for the Future*, A. Azous and R. Horner (eds.) New York: Lewis Publishers.

Horton, R.E. 1945. Erosional development of streams and their drainage basins; Hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin* 56:275–370. http://www.astm.org/Standards/D5979.htm [accessed February 12, 2014]

Hudson, P.F., F.T. Heitmuller, and M.B. Leitch. 2012. Hydrologic connectivity of oxbow lakes along the lower Guadalupe River, Texas: The influence of geomorphic and climatic controls on the "flood pulse concept." *Journal of Hydrology* 414:174-183.

Hudson, P.F., M.A. Sounny-Slittine, and M. LaFevor. 2013. A new longitudinal approach to assess hydrologic connectivity: Embanked floodplain inundation along the lower Mississippi River. *Hydrological Processes* 27:2187-2196.

Hunt, R.J., J.F. Walker, W.R. Selbig, S.M. Westenbroek, and R.S. Regan. 2013. *Simulation of climate-change effects on streamflow, lake water budgets, and stream temperature using GSFLOW and SNTEMP, Trout Lake Watershed, Wisconsin.* U.S. Geological Survey Scientific Investigations Report 2013-5159.

Huntington, J.L., and R.G. Niswonger. 2012. Role of surface-water and groundwater interactions on projected summertime streamflow in snow dominated regions: An integrated modeling approach. *Water Resources Research* 48:W11524.

IPCC. 2007. *Intergovernmental Panel on Climate Change. Fourth Assessment Report: Climate Change 2007 (AR4).* Intergovernmental Panel on Climate Change, Geneva, Switzerland. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm [accessed February 7, 2014]

Izbicki, J.A. 2007. Physical and temporal isolation of mountain headwater streams in the western Mojave Desert, southern California. *Journal of the American Water Resources Association* 43:26-40.

Johnston, C. 1994. Cumulative impacts to wetlands. *Wetlands* 14:49-55.

Johnston, C.A., and R.J. Naiman. 1987. Boundary dynamics at the aquatic-terrestrial interface: the influence of beaver and geomorphology. *Landscape Ecology* 1:47–57.

Johnston, C.A., N.E. Detenbeck, and G.J. Neimi. 1990. The cumulative effect of wetlands on stream water quality and quantity. A landscape approach. *Biogeochemistry* 10:105-141.

Julian, J.T., G.L. Rocco, M.M. Turner, and R.P. Brooks. 2013. Assessing wetland-riparian amphibian and reptile communities. In R.P. Brooks and D.H. Wardrop (eds.) *Mid-Atlantic Freshwater Wetlands: Advances in science, management, policy, and practice*. Chapter 9, p. 313-337, Springer Science+Business Media, 491+xiv pp.

Kanno, Y., B.H. Letcher, J.A. Coombs, K.H. Nislow, and A.R. Whiteley. 2014. Linking movement and reproductive history of brook trout to assess habitat connectivity in a heterogeneous stream network. *Freshwater Biology* 59(1):142-154.

Karwan, D.L. and J.E. Saiers. 2012. Hyporheic exchange and streambed filtration of suspended particles. *Water Resources Research* 48, W01519, doi: 10.1029/2011WR011173.

Kim, B.K., A.A.P. Jackman, and F.J. Triska. 1992. Modeling biotic uptake by periphyton and transient hyporrheic storage of nitrate in a natural stream. *Water Resources Research* 28(10): 2743–11 2752, 36.

Kim, H., Hemond, H.F., Krumholz, L.R., and Cohen, B.A. 1995. In-situ biodegradation of toluene in a contaminated stream. Part 1. Field studies. *Environmental Science and Technology* 29(1): 108-116, doi:10.1021/es00001a014.

Kimball, B.A., R.E. Broshears, K.E. Bencala, and D.M. McKnight. 1994. Coupling of hydrologic transport and chemical-reactions in a stream affected by acid-mine drainage. *Environmental Science and Technology* 28(12):2065-2073.

Kinzel, P.J., J.M. Nelson, and R.S. Parker. 2005. *Assessing sandhill crane roosting habitat along the Platte River, Nebraska*. U.S. Geological Survey Fact Sheet 2005-3029. U.S. Geological Survey, Washington, DC.

Koel, T.M., P.E. Bigelow, P.D. Doepke, B.D. Ertel, and D.L. Mahony. 2005. Nonnative lake trout result in Yellowstone cutthroat trout decline and impacts to bears and anglers. *Fisheries* 30(11):10-19.

Kolm, K.E., P.K.M. van der Heijde, J.S. Downey, J.S, and E.D. Gutentag. 1996. Conceptualization and characterization of ground-water systems. In *Subsurface Fluid-Flow (Ground-Water and Vadose Zone) Modeling*. J.D. Ritchey, and J.O. Rumbaugh (eds.) ASTM STP 1288, American Society for Testing and Materials, West Conshohocken, PA.

Kolm, K. E., R.M.Harper-Arabie, J.C. and Emerick. 1998. *A Stepwise, Integrated Hydrogeomorphic Approach for the Classification of Wetlands and Assessment of Wetland Hydrological and Geochemical function in the Southern Rocky Mountains of Colorado*. Colorado Geologic Survey, Colorado Department of Natural Resources Technical Report, Denver, CO. 241p.

Lake, P. 2003. Ecological Effects of perturbation by drought in flowing waters. *Freshwater Biology* 48: 1161-1172.

Lancaster, S.T., and N.E. Casebeer. 2007. Sediment storage and evacuation in headwater valleys at the transition between debris-flow and fluvial processes. *Geology* 35:1027-1030. Reprint. Supplementary material

Lane, C.R., E. D'Amico, and B. Autrey. 2012. Isolated wetlands of the southeastern United States: abundance and expected condition. *Wetlands* 32:753-767.

Larsen, L.G., J. Choi, M.K. Nungesser, and J.W. Harvey. 2012. Directional Connectivity in Hydrology and Ecology. *Ecological Applications* doi: 10.1890/11-1948.1.

Lautz, L., and R. Fanelli.2008. Seasonal biogeochemical hotspots in the streambed around restoration structures. *Biogeochemistry* 91(1):85–104.

Lee, L.C., and J.G. Gosselink. 1988. Cumulative Impacts on Wetlands: Linking Scientific Assessments and Regulatory Alternatives. *Environmental Management* 12(5): 591-602.

Leibowitz, S.G., P.J. Wigington Jr., M.C. Rains, and D.M. Downing. 2008. Non-navigable streams and adjacent wetlands: addressing science needs following the Supreme Court's Rapanos decision. *Frontiers in Ecology and the Environment* 6:364-371.

Lenton, T.M. 2011. Early warning of climate tipping points. *Nature Climate Ch*ange 1(4):201-109.

Levick, L.R., J. Fonseca, D.J. Semmens, J. Stromberg, M. Tluczek, R. A. Leidy, M. Scianni, D. P. Guertin, and W.G. Kepner. 2008. *The Ecological and Hydrological Significance of Ephemeral and Intermittent Streams in the Arid and Semi-arid American Southwest*. EPA/600/R-08/134 ARS/233046, U.S. Environmental Protection Agency, Washington, DC

Light, H.M., M.R. Darst, and J.W. Grubbs. 1998. *Aquatic Habitats in Relation to River Flow in the Apalachicola River Floodplain, Florida*. U.S. Geological Survey Professional Paper 1594. U.S. Geological Survey, Washington, DC.

Long Term Ecological Research Network. 2014. *Central Arizona Phoenix LTER* http://www.lternet.edu/sites/cap. [accessed April 21, 2014]

Lowe, W.H., K.H. Nislow, and G.E. Likens. 2005. Forest structure and stream salamander diets: implications for terrestrial-aquatic connectivity. *Verhandlungen des Internationalen Verein Limnologie* 29(1):279-286.

Lytle, D.A., and N.L. Poff. 2004. Adaptation to natural flow regimes. *Trends in Ecology and Evolution* 19:94-100.

Magana, H.A. 2013. Flood pulse trophic dynamics of larval fishes in a restored arid-land, river-floodplain, Middle Rio Grande, Los Lunas, New Mexico. *Reviews in Fish Biology and Fisheries* 23:507-521.

Malcolm, A., C. Soulsby, A.F. Youngson, and D.M. Hannah. 2005. Catchment-scale controls on groundwater-surface water interactions in the hyporheic zone: Implications for salmon embryo survival. *River Research and Applications* 21:977–989.

Malvadkar U, F. Scatena, and M. Leon. 2014. A comparison of connectivity metrics on watersheds and implications for water management. *River Research and Applicat*ions DOI: 10.1002/rra.2730.

Markstrom, S.L., R.G. Niswonger, R.S. Regan, D.E. Prudic, and P.M. Barlow. 2008. *GSFLOW-Coupled Ground-water and Surface-water FLOW model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005).* U.S. Geological Survey Techniques and Methods 6-D1. U.S. Geological Survey, Washington, DC.

Martin, GI, L.K. Kirkman, and J. Hepinstall-Cymerman. 2012. Mapping geographically isolated wetlands in the Dougherty Plain, Georgia, USA. *Wetlands* 32:149-160.

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

McClain, M.E, E.W. Boyer, C.L. Dent, S.E. Gergel, N.B. Grimm, P.M. Groffman, S.C. Hart, J.W. Harvey, C.A. Johnston, E. Mayorga, W.H. McDowell, and G. Pinay. 2003. Biogeochemical Hot Spots and Hot Moments at the Interface of Terrestrial and Aquatic Ecosystems. *Ecosystems* 6: 301-312. DOI: 10.1007/s10021-003-0161-9.

McColl, J.G., and J. Burger. 1976. Chemical input by a colony of Franklin Gulls nesting in cattails. *American Midland Naturalist* 96:270–80.

McDonald, R.R., J.M. Nelson, and J.P. Bennett. 2005. *Multi-dimensional surface-water modeling system user's guide.* U.S. Geological Survey Techniques and Methods, 6-B2. U.S. Geological Survey, Washington, DC.

McDonnell, J.J. 2013. Are all runoff processes the same? *Hydrological Processes* 27:4103-4111.

McDonough, O.T., J.D. Hosen, and M.A. Palmer. 2011. The hydrology, geography, and ecology of non-perennially flowing waters, in River *Ecosystems: Dynamics, Management and Conservation.* H.S. Elliot and L.E. Martin (Eds.), NOVA Science Publishers, ISBN: 978-1-61209-145-7, 2011.

McIntyre, P.B., L E. Jones, A S. Flecker, and M.J. Vanni. 2007. Fish extinctions alter nutrient recycling in tropical freshwaters. *Proceedings of the National Academy of Sciences* (USA) 104:4461–4466.

Meinzer, O.E. 1923. *Outline of ground-water hydrology*. U.S. Geology Survey Water Supply Paper 8. U.S. Geological Survey, Washington, DC.

Meyer, J.L., and J.B. Wallace. 2001. Lost linkages and lotic ecology: Rediscovering small streams. In: *Ecology: Achievement and Challenge*, eds. M.C. Press, N.J. Huntly, and S. Levin, 295-317. Blackwell Science, Oxford, UK.

Miyazono, S, J.N. Aycock, L.E. Miranda, and T.E. Tietjen. 2010. Assemblage patterns of fish functional groups relative to habitat connectivity and conditions in floodplain lakes. *Ecology of Freshwater Fish* 19:578–585

Min, J-H, D. Perkins, and J. Jawitz. 2010. Wetland-groundwater interactions in subtropical depressional wetlands. *Wetlands* 30:997-1006.

Mion, J.B., R.A. Stein, and E.A. Marschall. 1998. River discharge drives survival of larval walleye. *Ecological Applications* 8:88-103.

Modde, T., R.T. Muth, and G.B. Haines. 2001. Floodplain wetland suitability, access, and potential use by juvenile razorback suckers in the Middle Green River, Utah. *Transactions of the American Fisheries Society* 130:1095-1105.

Modde, T., Z.H. Bowen, and D.C. Kitcheyan. 2005. Spatial and temporal use of a spawning site in the middle Green River by wild and hatchery-reared razorback suckers. *Transactions of the American Fisheries Society* 134:937-944.

Montgomery, D.R. 1994. Road surface drainage, channel initiation, and slope instability. *Water Resources Research* 30(6): 1925-1932.

Naiman, R.J., G. Pinay, C.A. Johnson, and J. Pastor. 1994. Beaver influences on long term biogeochemical characteristics of boreal forest drainage networks. *Ecology* 75:905-921.

Nakano, S, and M. Murakami. 2001. Reciprocal subsidies: dynamic interdependence between terrestrial and aquatic food webs. *Proceedings of the National Academy of Sciences* 98:166–170.

Nanson, G.C., and J.C. Croke. 1992. A generic classification of floodplains. *Geomorphology* 4:459-486.

Nelson, J.M., J.P. Bennett, and S.M. Wiele. 2003. Flow and sediment transport modeling In *Tools in Fluvial Geomorphology*. M. Kondolph and H. Piegay (eds.) Chichester, England, Wiley and Sons, pp. 539-576.

Newbold, J.D., J.W. Elwood, R.V. O'Neill, and W.V. Winkle. 1981. Measuring nutrient spiralling in streams. *Canadian Journal of Fisheries and Aquatic Sciences* 38:860-863.

Norlin, A. 1967. Terrestrial insects on lake surfaces, their availability and importance as fish food. *Report/Institute of Fresh-water Research, Drottningholm* 47:39–55.

O’Connor, B.L., and J.W. Harvey. 2008. Scaling hyporheic exchange and its influence on biogeochemical reactions in aquatic ecosystems. *Water Resources Research* 44, W12423, doi:10.1029/2008WR007160.

O’Connor, B.L., M. Hondzo, and J.W. Harvey. 2010. Predictive modeling of transient storage and nutrient uptake. *Journal of Hydraulic Engineering* 136(12)2010. ISSN 0733-9429/2010/12-1018–1032.

O'Connor, B.L., J.W. Harvey, and L.E. McPhillips. 2012. Thresholds of flow-induced bed disturbances and their effects on stream metabolism in an agricultural river, *Water Resources Research* 48, W08504, doi:10.1029/2011WR011488.

Opperman, J. J., R. Luster, B.A. McKenney, M. Roberts, and A.W. Meadows. 2010. Ecologically Functional Floodplains: Connectivity, Flow Regime, and Scale. *Journal of the American Water Resources Association* 46:211-226.

Osborne, T.Z. 2005. *Characterization, Mobility, and Fate of Dissolved Organic Carbon in a Wetland Ecosystem*. Ph.D. Dissertation, University of Florida.

Osterkamp, W.R., L.J. Lane, and C.S. Savard. Recharge Estimates Using a Geomorphic/Distributed Parameter Simulation Approach, Amaragosa Rwer Basani. *Journal of the American Water Resources Association* 30(3):493-507.

Parkhurst, D.L., K.L. Kipp, and S.R. Charlton. 2010. *PHAST Version 2—A program for simulating groundwater flow, solute transport, and multicomponent geochemical react*ions. U.S. Geological Survey Techniques and Methods 6–A35. U.S. Geological Survey, Washington, DC.

Paul, M. and J. Meyer. 2001. Streams in the urban landscape. *Annual Review of Ecology and Systematics* 32: 333-365.

Pearse, A.T., G.L. Krapu, R.R. Cox, and B.E. Davis. 2011. Spring-migration ecology of Northern Pintails in South-central Nebraska. *Waterbirds* 34(1):10-18.

Poff, N.L.1992. Why disturbances can be predictable: a perspective on the definition of disturbance in streams. *Journal of the North American Benthological Society* 11:86-92.

Poff, N.L, and J.V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. *Canadian Journal of Fisheries and Aquatic Sciences* 46:1805-1818.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, Sparks and, J.C. Stromberg. 1997. The natural flow regime. *BioScience* 47:769-784.

Poff, N.L., B.P. Bledsoe, and C.O. Cuhaciyan. 2006. Hydrologic variation with land use across the contiguous United States: geomorphic and ecological consequences for stream ecosystems. *Geomorphology* 79:264-285.

Polis, G.A., W.B. Anderson, and R.D. Holt. 1997. Toward an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs. Annual Review of Ecology, Evolution, and Systematics 28:289–316.

Poole, G.C., J.A. Stanford, S.W. Running, and C.A. Frissell. 2006. Multiscale geomorphic drivers of groundwater flow paths: subsurface hydrologic dynamics and hyporheic habitat diversity. *Journal of the North American Benthological Society* 25(2):288-303.

Power, M.E., A. Sun, G. Parker, W.E. Dietrich, and J.T. Wootton. 1995a. Hydraulic food-chain models. *BioScience* 45:159-167.

Power, M.E., G. Paker, W.E. Dietrich, and A. Sun. 1995b. How does floodplain width affect floodplain river ecology? A preliminary exploration using simulations. *Geomorphology* 13: 301-317.

Powers, S.M., R. A. Johnson, and E.H. Stanley. 2012. Nutrient Retention and the Problem of Hydrologic Disconnection in Streams and Wetlands. *Ecosystems* 15:435-449.

Preston, E. and B. Bedford. 1988. Developing the scientific basis for assessing the cumulative effects of wetland loss and degradation on landscape functions: status, perspectives. *Environmental Management* 12: 751-771.

Pringle, C.M. 2001. Hydrologic connectivity and the management of biological reserves: a global perspective. *Ecological Applications* 11:981-998.

Pringle, C.M. 2003. What is hydrologic connectivity and why is it ecologically important? *Hydrological Processes* 17:2685-2689.

Qualls, R.G. and C.J. Richardson. 2003. Factors controlling concentration, export, and decomposition of dissolved organic nutrients in the Everglades of Florida. *Biogeochemistry* 62:197-229.

Rains, M.C., G.E. Fogg, T. Harter, R.A. Dahlgren, and R.J. Williamson. 2006. The role of perched aquifers in hydrological connectivity and biogeochemical processes in vernal pool landscapes, Central valley, California. *Hydrological Processes* 20: 1157–1175.

Rains, M.C, R.A. Dahlgren, G.E. Foff, T. Harter, and R.J. Williamson. 2008. Geological control of physical and chemical hydrology in California vernal pools. *Wetlands* 28:347-362.

Randall, G.W., D.R. Huggins, M.P. Russelle, D.J. Fuchs, W.W. Nelson, and J.L. Anderson. 1997. Nitrate losses through subsurface tile drainage in conservation reserve program, alfalfa, and row crop systems. *Journal of Environmental Quality* 26:1240-1247.

Rapp C.F., and T.B. Abbe. 2003. A framework for delineating channel migration zones. *Ecology* Final Draft Publication #03-06-027. 66 pp.

Reddy, K.R., R.H. Kadlec, E. Flaig and P.M. Gale. 1999. Phosphorus retention in streams and wetlands: a review. *Critical Reviews in Environmental Science and Technology* 29:83-146.

Reddy, K.R., R.G. Wetzel, and R. Kadlec. 2005. Biogeochemistry of Phosphorus in Wetlands. In *Phosphorus: Agriculture and the Environment* J.T. Sims and A.N. Sharpley (eds.) 263-316. Soil Science Society of America.

Reddy, K.R., S. Newman, T.Z. Osborne, J.R. White, and H.C. Fitz. 2011. Phosphorus cycling in the Everglades ecosystem: Legacy phosphorus implications for management and restoration. *Critical Reviews in Environmental Science and Technology* 41:149-186.

Reid, L. 1998. Cumulative watershed effects and watershed analysis. In *River Ecology and Management: Lessons from the Pacific Coastal Ecoregion*. R.J. Naiman and R. Bilby (eds.) Pages 476-501. Springer.

Resh, V.H., A.V., Brown, A.P. Covich, M.E. Gurtz, H.W. Li, G.W. Minshall, S.R. Reice, A.L. Sheldon, J.B. Wallace, and R.C. Wissmar. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society* 7:433-455.

Rodriguez-Iturbe, I., and J. Valdes. 1979. The geomorphologic structure of hydrologic response. *Water Resources Research* 15(6):1409–1420.

Rooney, R.C., C. Carli, and S. Bayley. 2013. River connectivity affects submerged and floating aquatic vegetation in floodplain wetlands. *Wetlands* 33:1165-1177.

Roses, T.P., M.L. Davisson, and R.E. Criss, 1996. Isotope hydrology of voluminous cold springs in fractured rock from an active volcanic region, northeastern California. *Journal of Hydrology* 179:207–236.

RWRD (Pima County Regional Wastewater Reclamation Project) 2002, *Arid West Water Quality Research Project-Habitat Characterization Project Final Report*, Prepared for the Arid West Water Quality Research Project by CDM, in association with URS Corporation, CEC, Inc., Environmental Planning Group (EPG), and Risk Sciences. Pima County Regional Wastewater Reclamation Department, Tucson, AZ.

Sabo, J.L., and M.E. Power. 2002. River-watershed exchange: effects of riverine subsidies on riparian lizards and their terrestrial prey. *Ecology* 83:1860–1869.

Sawyer, A.H., M.B. Cardenas, and J. Buttles. 2011. Hyporheic exchange due to channel-spanning logs. *Water Resources Research* 47, W08502

Sawyer, A.H., M.B Cardenas, and J. Buttles. 2012. Hyporheic temperature dynamics and heat exchange near channel-spanning logs. *Water Resources Research* 48, W01529, doi:10.1029/2011WR011200.

Schick, R.S., and S.T. Lindley. 2007. Directed connectivity among fish populations in a riverine network. *Journal of Applied Ecology* 44:1116-1126.

Schindler, D. 2001. The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. *Canadian Journal of Fisheries and Aquatic Sciences* 58:18-29.

Schlosser, I.J, and P.L. Angermeier. 1995. *Spatial variation in demographic processes of lotic fishes: conceptual models, empirical evidence, and implications for conservation*. American Fisheries Society Symposium 17:392—401.

Schramm, H.L., and M.A. Eggleton. 2006. Applicability of the flood-pulse concept in a temperate floodplain river ecosystem: Thermal and temporal components. *River Research and Applications* 22:543-553.

Schumm, S.A., M.D. Harvey, and C.C. Watson. 1984. *Incised Channels: Morphology, Dynamics, and Control.* Littleton, CO: Water Resources Publications.

Schwalb, A.N., T.J. Morris, N.E. Mandrak, and K. Cottenie. 2013. Distribution of unionid freshwater mussels depends on the distribution of host fishes on a regional scale. *Diversity and Distributions* 19:446–454.

Semlitsch, R.D. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. *Conservation Biology* 12:1113-1119.

Semlitsch, R.D. 2000. Principles of management of aquatic-breeding amphibians. *Journal of Wildlife Management* 64:615-631.

Semlitsch, R.D. 2002. Critical elements for biologically based recovery plans of aquatic-breeding amphibians. *Conservation Biology*16:619-629.

Semlitsch, R.D. and J.R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. *Conservation Biology* 17:1219-1228.

Shaw, D. A., G. Van der Kamp, M. Conly, A. Pietroniro, and M. Lawrence. 2012. The fill-spill hydrology of prairie wetland complexes during drought and deluge. *Hydrological Processes* 26:3147-3156.

Skagen, S.K, D.A. Granfors, and C.P. Melcher. 2008. On determining the significance of ephemeral continental wetlands to North American migratory shorebirds. *The Auk* 125:20-29.

Spence, C. 2007. On the relation between dynamic storage and runoff: A discussion on the thresholds, efficiency and function. *Water Resources Research* 43:1-11.

Spence, C., and M.K. Woo. 2003. Hydrology of subarctic Canadian Shield: soil-filled valleys. *Journal of Hydrology* 279:151-166.

Spinola, R.M, T.L. Serfass, and R.P. Brooks. 2008. Survival and post-release movements of river otters translocated to western New York. *Northeastern Naturalist* 15(1):13-24.

Squires, A.J. and M.G. Dube. 2013. Development of an effects-based approach for watershed scale aquatic cumulative effects assessment. *Integrated Environmental Assessment and Management* 9:380-391.

Stanley, E.H., S.M. Powers, and N.R. Lottig. 2010. The evolving legacy of disturbance in stream ecology: concepts, contributions, and coming challenges. *Journal of the North American Benthological Society* 29:67-83.

Stichling, W., and S.R. Blackwell. 1957. *Drainage area as a hydrologic factor on the Canadian prairies*. International Union of Geodesy and Geophysics (IUGG) Proceedings, Toronto, Ontario.

Stonedahl, S.H., J.W. Harvey, A. Wörman, M. Salehin, and A.I. Packman. 2010. A multiscale model for integrating hyporheic exchange from ripples to meanders. *Water Resources Research* 46, W12539, doi:10 1029/2009WR008865

Strack. M, J., M. Waddington, R.A. Bourbonniere, E.L. Buckton, K. Shaw, P. Whittington, and J. S. Price. 2008. Effect of water table drawdown on peatland dissolved organic carbon export and dynamics. Hydrological Processes 22:3373-3385.

Stratton, B.T., V. Sridhar, M.M. Gribb, J.P. McNamara, and B. Narasimhan. 2009. Modeling the Spatially Varying Water Balance Processes in a Semiarid Mountainous Watershed of Idaho. *Journal of the American Water Resources Association* 45(6):1390-1408.

Stromberg, J. C. 2001. Restoration of riparian vegetation in the south-western United States: importance of flow regimes and fluvial dynamism. *Journal of Arid Environments* 49.1:17-34.

Sullivan, S.M.P., and A.D. Rodewald. 2012. In a state of flux: The energetic pathways that move contaminants from aquatic to terrestrial environments. *Environmental Toxicology and Chemistry* 31:1175-1183.

Sullivan, S.M.P., and M. C. Watzin. 2009. Stream-floodplain connectivity and fish assemblage diversity in the Champlain Valley, Vermont, U.S.A. *Journal of Fish Biology* 74:25.

Sun, R.J., J.B. Weeks, and H.F. Grubb. 1997. *Bibliography of Regional Aquifer-System Analysis Program of the U.S Geological Survey, 1978-96. Regional Aquifer-System Analysis.* U.S. Geological Survey Water-Resources Investigations Report 97-4074, U.S. Government Printing Office, Washington, DC

Sun, R.J., J.B. Weeks, and H.F. Grubb. 1991. *Bibliography of Regional Aquifer-System Analysis Program of the U.S. Geological Survey, 1978-91*. U.S. Department of the Interior, Washington, DC

Thompson, C.J., I. Takken, P.B. Hairsine, and J. Croke. 2008. Hydrological and sedimentological connectivity of forest roads. In *Sediment Dynamics in Changing Environments.* J. Schmiddt, T. Cochrane, C. Philips, S. Elliot, T. Davies, and L. Basher, L. (eds) 325:524-531. International Association of Hydrological Sciences (IAHS) Publication.

Thorp, J.H., M.C. Thoms, and M.D. Delong. 2006. The riverine ecosystem synthesis: Biocomplexity in river networks across space and time. *River Research and Applications* 22:123-147.

Tiner, R.W. 2003a. Estimated extent of geographically isolated wetlands in selected areas of the United States. *Wetlands* 23:636-652.

Tiner, R.W. 2003b. Geographically isolated wetlands of the United States. *Wetlands* 23:494-516.

Tockner, K., F. Malard, and J.V. Ward. 2000. An extension of the flood pulse concept. *Hydrological Processes* 14:2861-2883.

Toth, L.A., and A. van der Valk. 2012. Predictability of flood pulse driven assembly rules for restoration of a floodplain plant community. *Wetlands Ecology and Management* 20:59-75.

USACE. 1987. *Corps of Engineers Wetlands Delineation Manual*. Technical Report Y-87-1. U.S. Army Corps of Engineers, Washington, DC.

USGS. 2014. *U.S. Geological Survey National Elevation Dataset*. http://ned.usgs.gov/ [accessed April 21, 2014]

U.S. Global Change Research Program. *A Plan for a New Science initiative on the Global water Cycle. Chapter 3, Predictability of Variations in Global and Regional Water Cycle.* U.S. Climate Change Science Program / U.S. global Change Research Program, Washington. DC

Valett, H.M., M.A. Baker, J.A. Morricew, C.S. Crawford, M.C. Molles, Jr., C.N. Dahm, D.L. Moyer, J.R. Thibault, and L.M. Ellis. 2005. Biogeochemical and metabolic responses to the flood pulse in a semiarid floodplain. *Ecology* 86:220-234.

Van der Kamp, G., M. Hayashi, and D. Gallen. 2003. Comparing the hydrology of grassed and cultivated catchments in the semi-arid Canadian prairies. *Hydrological Processes* 17:559-575.

Van der Kamp, G., D. Keir, and M.S. Evans. 2008. Long-term water level changes in closed-basin lakes of the Canadian prairies. *Canadian Water Resources Journal* 33(1):23-38.

Van der Kwaak, J.E., and K. Loague. 2001. Hydrologic-response simulations for the R-5 catchment with a comprehensive physics-based model. *Water Resources Research* 37(4):999-1013.

Van Looy, K, C. Cavillon, T. Tormos, J. Piffady, P. Landry, and Y. Souchon. 2013. A scale-sensitive connectivity analysis to identify ecological networks and conservation value in river networks. *Landscape Ecology* 28:1239-1249.

Van Vilet, M and J. Zwolsman. 2008. Impacts of summer droughts on the water quality of the Meuse River. *Journal of Hydrology* 353: 1-17.

Vaughn, C.C. 2012. Life history traits and abundance can predict local colonization and extinction rates of freshwater mussels. *Freshwater Biology* 57:982-992.

Verhoeven, J.T.A., B. Arheimer, C.Q. Yin, and M.M. Hefting. 2006. Regional and global concerns over wetlands and water quality. *Trends in Ecology and Evolution* 21:96-103.

Vidon, P.C., C. Allan, D. Burns, T.P. Duval, N. Gurwick, S. Inamdar, R. Lowrance, J. Okay, D. Scott, and S. Sebestyen. 2010. Hot spots and hot moments in riparian zones: Potential for improved water quality management. *Journal of the American Water Resources Association* 46:278-298.

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.

Wainwright, J., L. Turnbull, T. G. Ibrahim, I. Lexartza-Artza, S.F. Thornton, and R.E. Brazier. 2011. Linking environmental regimes, space and time: Interpretations of structural and functional connectivity. *Geomorphology* 126:387-404.

Walker, D.B., C. Goforth, and S. Rector. 2005. *An Exploration of Nutrient and Community Variables in Effluent Dependent Streams in Arizona* (pp. 05-09). EPA Grant Number X-828014-01-01, Publication Number OFR 05-09 Arizona Department of Environmental Quality. Available at http://www.azdeq.gov/environ/water/assessment/download/edw.pdf [Accessed April 17, 2014]

Wallace, J.B., S.L. Eggert, J.L. Meyer, and J.R. Webster. 1997. Multiple Trophic Levels of a Forest Stream Linked to Terrestrial Litter Inputs. *Science* 277(5322):102-104. DOI: 10.1126/science.277.5322.102

Walsh, C.J., T.D. Fletcher, and M.J. Burns. 2012. Urban stormwater runoff: a new class of environmental flow problem. *PLoS ONE* 7:e45814.

Ward, J.V. 1989. The four-dimensional nature of lotic ecosystems. *Journal of the North American Benthological Society* 8:2-8.

Ward, J.V. and J.A. Stanford. 1983. The serial discontinuity concept of lotic ecosystems. In *Dynamics of Lotic Ecosystems*. T.D. Fontaine and S.M. Bartell (eds.) Pages 29-42 Ann Arbor Science, Ann Arbor, MI.

Ward, J.V., C.T. Robinson, and K. Tockner. 2002. Applicability of ecology theory to riverine ecosystems. *Verhandlungen des Internationalen Verein Limnologie* 28: 443-450.

Washington State Department of Ecology. 2011. *Shoreline Master Program Guidelines*. Chapter 173-26 WAC, Part III.

Wemple, B.C., J.A. Jones, and G.E. Grant 1996. Channel network extension by logging roads in two basins, Western Cascades, Oregon. *Water Resources Bulletin* 32(6):1195-1207.

Wemple, B.C., F.J. Swanson, and J.A. Jones. 2001. Forest roads and geomorphic process interactions, Cascade Range, Oregon. *Earth Surface Processes and Landforms* 26:191-204.

Wetzel, R.G. 1990. Land-water interfaces: metabolic and limnological regulators. *Verhandlungen des Internationalen Verein Limnologie* 24:6-24.

Wetzel, R.G. 2002. Dissolved organic carbon: detrital energetics, metabolic regulators, and drivers of ecosystem stability of aquatic ecosystems. In *Aquatic Ecosystems: Interactivity of Dissolved organic Matter*. S. Findlay and R. Sinsabaugh (eds.) 455-474. Academic Press, San Diego, CA

Wiens, J.A. 2002. Riverine landscapes: taking landscape ecology into the water. *Freshwater Biology* 47:501–515.

Wigmosta, M. S., and W.A. Perkins 2001. Simulating the effects of forest roads on watershed hydrology. In *land use and watersheds: human influence on hydrology and geomorphology in urban and forest areas*. M.S. Wigmosta and S.J. Burges (eds.), p. 127-144 Water Science and Application 2. American Geophysical Union, Washington, DC

Williams, G.P., and M.G. Wolman. 1984. *Downstream effects of dams on alluvial rivers*. Professional Paper 1286. Reston, VA: U.S. Geological Survey

Winter, T.C., J.W. Harvey, O.L. Franke, and W.M. Alley. 1998. *Ground Water and Surface Water: A Single Resource*. U.S. Geological Survey Circular 1139, U.S. Government Printing Office, Washington, DC

Winter, T.C., and J.W. LaBaugh. 2003. Hydrologic considerations in defining isolated wetlands. *Wetlands* 23:532-540.

Wipfli, M.S., and C.V. Baxter. 2010. Linking ecosystems, food webs, and fish production: Subsidies in salmonid watersheds. *Fisheries*35:373-387.

Wohl, E. 2005. *Disconnected Rivers: Linking Rivers to Landscapes*: Yale University Press, New Haven, CT

Wolman, M.G., and J.P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. *The Journal of Geology* 68:54-74.

Wolock, D.M., T.C. Winter, and G. McMahon. 2004. Delineation and evaluation of Hydrologic-Landscape Regions in the United States using Geographic Information System tools and multivariate statistical analyses. *Environmental Management* 34:S71-S8.

Woo, M.-K., and R.D. Rowsell. 1993. Hydrology of a prairie slough. *Journal of Hydrology* 146:175-207.

Woolfenden, L.R., and T, Nishikawa. 2014. *Simulation of groundwater and surface-water resources of the Santa Rosa Plain watershed, Sonoma County, California*. U.S. Geological Survey Scientific Investigations Report 2014-5052. U.S. Geological Survey, Washington, DC.

Yang, W., X. Wang, Y. Liu, S. Gabor, L. Boychuk and P. Badiou. 2010. Simulated environmental effects of wetland restoration scenarios in a typical Canadian prairie watershed. *Wetlands Ecology and Management* 18(3):269-279.

Zelasko, K.A., K.R. Bestgen, and G.C. White. 2010. Survival rates and movement of hatchery-reared razorback suckers in the upper Colorado River Basin, Utah and Colorado. *Transactions of the American Fisheries Society* 139:1478-1499.

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 GM (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.

Webb, Elisabeth K., L.M. Smith, M.P. Vrtiska, and T.G. LaGrange. 2010. Effects of local and landscape variables on wetland bird habitat use during migration through the Rainwater Basin. *Journal of Wildlife Management* 74(1):109-119.

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.