Presentations from Panel Subgroups for the Discussion of Key Points in Response to Charge Questions

SAB Panel for the Review of the EPA Water Body Connectivity Report

Wednesday, December 18, 2013

Key Points – Response to Charge Question 1

1. Please provide your overall impressions of the clarity and technical accuracy of the draft EPA report.

- The report represents a well-written and extensive review of the literature, but it needs to be edited for continuity and consistency.
- The usefulness of the report to decision-makers and for informing policy can be improved by quantifying the degree or magnitude of connectivity when possible and by exercising caution when using words that may denote particular legal or regulatory meanings (e.g., significant, adjacent).
- The literature review can be strengthened by clarifying what was considered as peer-reviewed and better describing the kinds of evidence used and types of studies selected for review.
- The conceptual framework should be the integrator of the entire report with clear links to and within each section.
- Spatial and temporal scales of connectivity need to be better articulated.
- Treatment of biological connections and flowpaths need to be strengthened throughout the report.
- The report should cover a greater range of geographic regions (e.g., arctic) and systems, including human modified systems, forested wetlands, and bottomland forests

Overview

- The literature review is thorough, technically accurate, and readable. This generally does not need to be changed. However, the conceptual framework needs to be revised and clearly articulated in the beginning of the chapter to better enable the reader to access and understand the material.

Problem Statement

- The gradient of connectivity needs to be clarified, with connectivity expressed through hydrological, chemical, and biological exchanges.
  - The gradient of connectivity should be discussed in terms of the five functions – source, sink, lag, transformation, and refuge – with reference to how these functions are enhanced by connectivity and isolation.
  - This could include a discussion of human altered systems and how alterations to natural flowpaths change connectivity and therefore affect the integrity of downgradient waters.
  - A discussion of temporal and spatial scale merits its own section, focusing on the degree of connectivity that temporal and spatial variability impart.

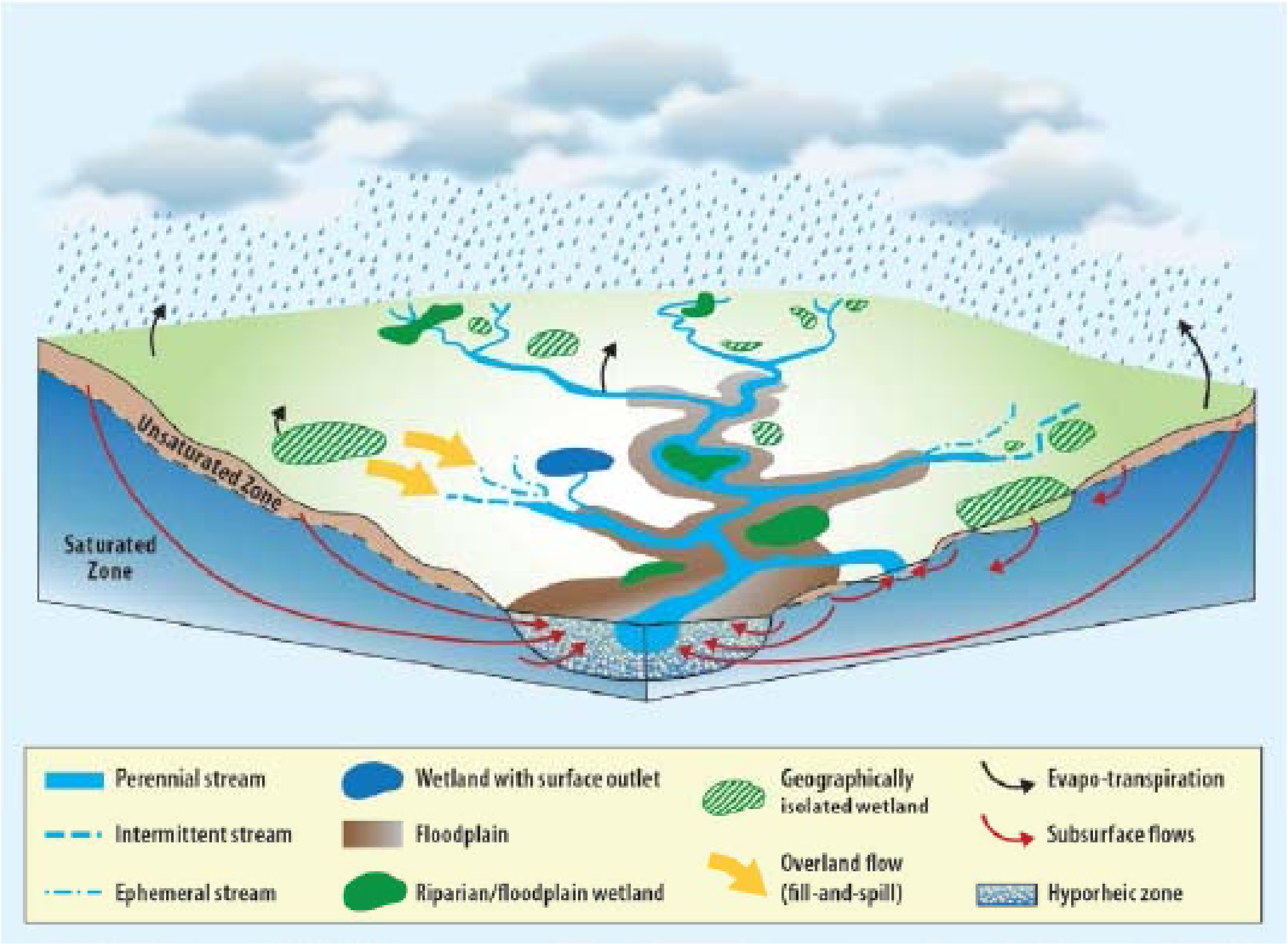
Scope of the Effort

- The definition of wetlands used in this report needs to be clearly addressed, noting that there are scientific and regulatory definitions and that the report uses the former. The key will be to note that the definition used in this report is a broad definition, with "waters of the US" being a subset.

Flowpath Framework

- The conceptual framework needs to be reworked, with a flowpath focus showing that streams and wetlands are connected to downstream waters by hydrological (surface and subsurface) and biological flowpaths. A classification system could then be mapped onto that framework, with an explicit statement that this classification is used as a communication tool.

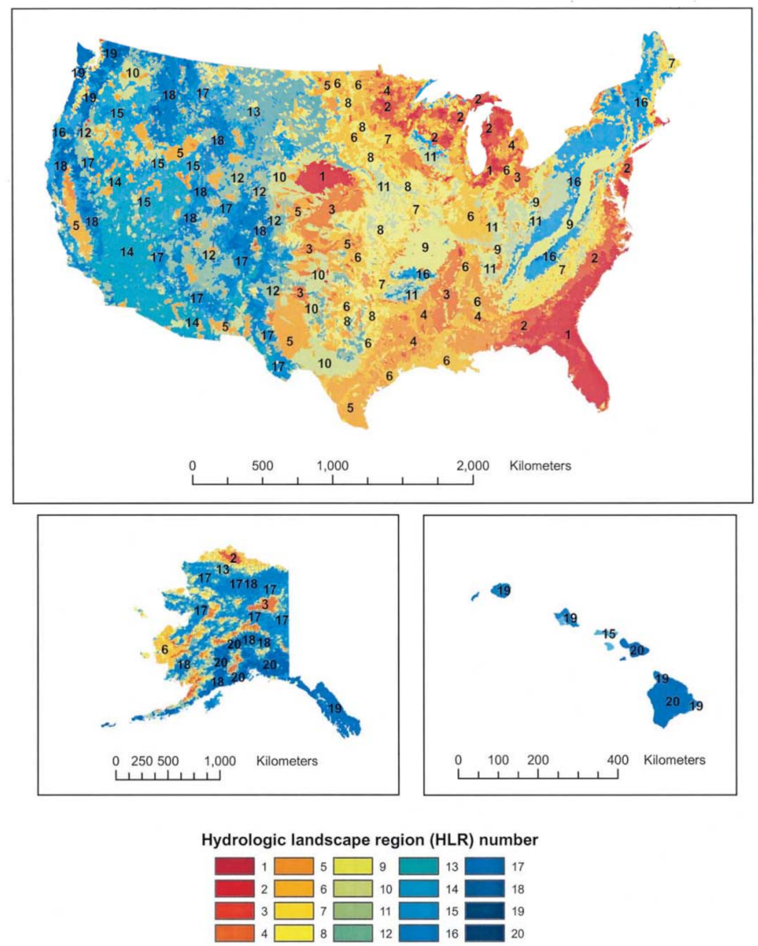
Flowpath Framework



Regionalization

- The conceptual framework could be regionalized by expressing forcings in terms of Hydrologic-Landscape Regions, or HLRs (Wolock et al., 2004). 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., climate, geology).

Regionalization (HLRs)



Key Points – Response to Charge Question 3(a)

Question 3(a)

The panel recommends that the report be expanded to include further discussion of the following:

- **Hydrologic exchange flows between main channels and off channel areas**
- **Naturally occurring chemical constituents other than nutrients (N, P) and contaminants**
- **Multiple factors that influence stream temperature**
- **Biological connectivity**
- **Temporal dynamics of connections**
- **Human-modified headwater streams**
- **Headwater streams in aggregate/cumulative**
- **Nutrient and contaminant transformations**
- **Streamside vegetation (i.e., riparian zones or areas)**
- **Food web dynamics**

The SAB panel members were universally impressed with Chapter 4 and its excellent review of the literature that describes the connectivity of headwater streams to downstream waters. The panel agreed that the report documents the current scientific understanding that there are numerous ways that headwater streams are connected to downstream ecosystems and that these connections are essential in promoting the physical, chemical, and biological integrity of downstream ecosystems. The connections between headwaters and downstream ecosystems are a well established as a foundation concept in stream ecology.

The Panel felt that the review was based on pertinent literature and the text was strongly grounded in current scientific understanding. The general comments that the panel suggests represent ways to improve the document. We have numbered these comments for ease of discussion, but they are not numbered in order of importance. In addition to these general comments, detailed comments and referral to relevant literature are included in the preliminary comments from the panel.

1. Improve the review of hydrologic exchange flows between main channels and off channel areas. Include exchanges between main channels and relatively slowly moving subsurface waters and surface waters located at channel margins, in pools, and in recirculating eddies. Include a more complete discussion of the processes involved and give more attention to spatial and temporal variability.

a. Include a broader discussion of associated biogeochemical transformations that change the form and mobility of dissolved chemicals with effects on downstream water quality. Expand the discussion beyond just nitrate removal by including phosphorus as well as fate and transport of contaminants such as toxic metals and organic contaminants.

   b. Extend the discussion to communicate how surface-subsurface water interactions affect stream temperature, and habitat for fish and other organisms, including when surface water contracts but subsurface flow is present.

2. **Discussion of naturally occurring chemical constituents other than nutrients (N, P) and contaminants, could be expanded.** 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, etc) and the consequences of altering these upslope processes on downstream water chemistry and associated ecological responses.

3. **A more thorough treatment of factors that influence stream temperature is needed.** There is inadequate treatment of the role of upslope factors affecting the relative contributions of surface and shallow and deeper subsurface waters to channel flow. Also, a more explicit treatment of the effects of hyporheic flow and storage and the resulting lag and attenuation effects that buffer temperature extremes is needed. The latter discussion of subsurface effects should include a comparison to direct groundwater discharge in terms of its effects on stream temperature dynamics. In addition, the treatment of the direct and indirect effects of riparian shading, channel morphology, and channel network topology on stream temperature is currently inadequate. Finally, we suggest an expanded discussion of how environmental alterations in channels and upslope areas they influence temperature dynamics.

4. **The temporal dynamics of connections were addressed in the report, but could be expanded.** The panel agreed that a separate section that better addresses temporal dynamics (frequency, duration, timing) would be a welcome addition to this Chapter. For example, the panel agreed that connections that occur only during a short time of year are not necessarily unimportant. The report describes how even though headwater streams are periodically dry, over an annual cycle they can contribute a large fraction of the water in downstream ecosystems; however, the ecological consequences of these connections could be expanded. In the current draft, there is not a short, comprehensive, paragraph that explicitly examines the temporal dynamics of connectivity for headwater streams (connecting perennial, intermittent, and ephemeral channels with variable source areas) and its effects on material and sediment transport and effects on downstream water quality. There is also need for more discussion and literature review on the importance of short duration floods and longer duration droughts and their effects on downstream ecosystems. Finally, we recommend that the report adopt a more encompassing recognition of the important role of variable hydraulic residence times in river networks and their effects on storage and transformation of organic matter and nutrients in downstream waters.

5. **Improve the review of biological connectivity**, to demonstrate that movements of biota in downstream waters to use critical habitats in upstream and lateral habitats have strong effects on biological integrity. A more thorough treatment of biological connectivity would strengthen this chapter of the report. Key points include:
   a. Organisms require habitats that are dispersed throughout watersheds (i.e., their populations cannot persist without them), and move among these habitats during their life cycle.

b. b. 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 water.
c. These mobile species range across many different taxa, even within fish, and include many more than those focused in the report, which are mainly 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.
d. When these upstream, lateral, and disconnected habitats are degraded or destroyed, data from comparative studies and experiments show that these animal populations decline or are extirpated entirely, showing that connectivity to these habitats is a key to the biological integrity of downstream water.
e. Thus, ignoring these connections can create 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.

6. **Human-modified headwater stream literature should be covered more extensively in the report.** A number of panel members raised the issue of the lack of literature on human-modified headwater streams. This inclusion would provide information about how altering these systems have consequences for the water quality and biota of downstream ecosystems. Many headwater stream ecosystems are altered by human activity and the literature on these ecosystems should be reviewed because these modifications often disrupt connectivity and so show its importance in various landscapes. For example, the following alterations should be included in the review: agricultural ditches and tile drains, urban lined channels and buried streams, riparian tree removal, gravel mining, channel diversions, low dams, and grade control structures.

7. Highlight the role of **headwater streams in *aggregate*** *(i.e., cumulative)* effects on downstream ecosystems in this chapter as well. The panel recommends adding a section that explicitly deals with this topic. There is a large literature on cumulative watershed effects of land use based on both modeling and empirical studies. Furthermore, the watershed modeling section could be improved. For example, the work based on SPARROW modeling was covered in the report, but additional modeling of riverine processes and the role of headwaters in downstream ecosystems could be added to the report. We recommend that the authors review the following citations for a more comprehensive review of network scale modeling of headwater and riverine networks.

8. **The role of nutrient and contaminant transformation could be expanded in the report.** The role of nutrient spiraling as a demonstration of connections between headwaters and downstream ecosystems was covered in the report, but more attention 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 would strengthen the report.

9. **The effects of streamside vegetation (i.e., riparian zones or areas) on stream ecosystems that should be expanded in this report**. Many of these effects are not necessarily associated with riparian wetland function (e.g., effects of leaf letter inputs on downstream food resources, effects of woody debris on channel morphology, sediment and organic matter storage, hydrologic retention, stream temperature, etc.). These effects occur along the entire longitudinal profile, but are especially intense in headwater streams.

10. Add a section that treats thoroughly **the food-web connections from riparian zones to streams that support aquatic organisms**. Although the report focuses on strictly aquatic connections, organisms that define the biological integrity of downstream waters are embedded in food webs, and these transcend aquatic-terrestrial boundaries. Key points include:
    a. Streams receive leaves, wood, and other plant litter from riparian vegetation, and these supply carbon and nutrients to biota ranging from microbes to invertebrates, which in turn feed larger invertebrates, fish, amphibians, reptiles, birds, and mammals.
    b. Streams also receive terrestrial invertebrates, which are used directly as prey by fish and amphibians, either in the same reach, or after flowing downstream from headwaters into reaches that support these predators.
    c. As a result, these linkages are critical to maintaining the biological integrity of the nation's waters, and data from comparative studies and experiments support the generalization that cutting off these connections can cause emigration or extirpation of these organisms.

Key Points – Response to Charge Question 3(b)

- *Conceptual Frame & Summary Matrix:* chapter conclusions should be framed within conceptual foundation of 4 dimensional connectivity (3D space + time) and conclusions displayed in a matrix to summarize extent of evidence, and uncertainty across function and system type, including temporal/spatial scale of phenomena, intensity and level of confidence (e.g., as in IPCC reports).

- *Boundaries and Linkages:* include statements on the boundary of upland/headwater transition, providing context of what is considered a stream, as well as increased emphasis on groundwater-surface water interactions, flooding, riparian zones and how these linkages influence biota and food webs.

- *Human Impacts and Case Studies:* conclusions could be improved by mentioning how human activities alter (both increase and decrease) connectivity of streams with downstream waters, ideally through the use of specific examples (e.g., perhaps using existing case studies).

- *Ephemeral Streams:* add text about spatial and temporal variation in the linkage of ephemeral streams and variable source areas (e.g., swale) with downstream waters including frequency of the connection, in addition to when these systems provide critical habitat.

- *Expand chemical connections:* add details in conclusion on how streams influence chemicals beyond nitrate, including sediment-bound nutrients, DOM, and other contaminants and mention nutrient removal processes as well as nutrient spiraling.

Key Points – Response to Charge Question 4(a)

Question 4a Lentic Systems: Wetlands and Open Waters with the Potential for Non-tidal, Bidirectional Hydrologic Flows with Rivers and Lakes

1. We strongly support the conclusion that these areas are connected. Our comments provide the additional emphasis and discussion needed to address the importance of bidirectional connectivity of floodplain/riparian wetlands to downstream waters

2. Move the headwater riparian zone material and associated references to Chapter 4 to best reflect the role of streamside riparian zones on stream structure and function. Section 5.3 will focus on riparian wetlands and floodplains.

3. Stress the effects of riparian wetlands/ floodplains on the flows, chemistry, and biota of downstream waters. Stress lateral dimensions of river systems - higher order structure and function is emphasized over low order riparian interactions. For example, fish nurseries in wetlands or off-channel waters that populate downstream fisheries, or the role of bottomland forests on river biogeochemistry and flood storage. Emphasis is on the spatial connectivity of channels and riparian wetlands/floodplains.

4. Increase emphasis on the temporal aspects of floodplain systems as guided by the 'flood pulse concept'. Address the temporal progression of the flood pulse and its influence on residence time of surface water, seasonal exchanges with groundwater, biological linkages, and ecosystem process. The emphasis here is on temporal connectivity.

5. Make the bidirectional nature of these fluxes/linkages clear by articulating the links back to the river channel. Focus on the fluxes of water, materials and biota emphasizing how exchange flows respond to temporal progression of the flood pulse.

6. Specifically address groundwater and chemical connectivity that recognizes the bidirectional exchange of ground and surface waters and associated chemicals (e.g., upgradient groundwater and hyporheic zone). The emphasis here is on vertical connectivity.

7. Provide a more recent and diverse assessment of biogeochemical implications of exchange flows. Enhance the literature on the role of floodplains as sources, sinks, and transformers of nutrients /material. For example, update and expand the section on N processing (denitrification), expand sections on P and sediments (including legacy sediments). Include our understanding of 'hot-spots and hot-moments' and the bidirectional exchange of particulate organic matter (POM) and dissolved organic matter (DOM). Floodplains can be an important source of POM and DOM to streams and rivers.

8. Address how human impacts to riparian wetlands and floodplains alter connectivity, for example channel incision that breaks the link between riparian wetlands/floodplains with downstream waters.

Key Points – Response to Charge Question 4(b)

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.

General Comments: Overall, 18 SAB Panel members offered written comments relative to 1.4.2 and the associated conclusions in Section 5.3 on riparian wetlands and floodplains. Of these, 11 panel members largely endorsed the conclusions as presented relative to whether the findings are supported by the available science. Additional panel members embedded their comments in broader narratives, while others offered perspectives orally.

SAB Panel members are in general agreement that there is support that riparian wetlands and floodplains are highly connected to receiving waters through multiple pathways, including hydrological and biological connectivity. However, the key findings and conclusions to this chapter need to be directly related to the information presented in the associated section on Riparian Wetlands and Floodplains, and should parallel one another. Currently, many of the conclusions are drawn from literature related to non-floodplain riparian zones, which weakens the potential opportunity to present direct evidence of connectivity (or lack thereof) between riparian wetlands and floodplains with receiving systems. SAB Panel members viewed this discrepancy as highly problematic.

We offer the following additional recommendations:

1. Inconsistent terminology:
We suggest that the language referring to riparian wetlands and floodplains remain consistent both within the key finding and conclusion sections as well as throughout Section 5.3 (e.g., riparian areas, riparian and floodplain areas, riparian/floodplain waters, etc.). The terminology used in the key findings and conclusions must align with the Glossary definitions.

2. Temporal component:
We suggest that the key findings and conclusions recognize the temporal dimension of riparian wetlands and floodplains relative to downstream connectivity; water residence times and the transient nature of floodplains should be key points. This conclusion should reflect the main message of the new temporal section in 5.3.

3. Further quantification:
The key conclusions could be more empirical or more specifically described. Where there is demonstrated connectivity, it should be quantified (e.g., of X studies, X% support conclusion of connectivity).

4. Biological linkages including food webs:
We recommend further highlighting the role of biological connectivity between riparian wetlands and floodplain waters and receiving systems in the key findings and conclusions. Explicitly make linkages to downstream waters. For example: "Riparian 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, etc.*"

5. Export vs. exchange:
We recommend using an “exchange” vs. “export” framework, i.e., reciprocal exchanges between riparian wetlands and floodplain waters and receiving waters.

6. Case studies:
Many panel members found the case studies to be useful. Building on recommendations from 4a, we suggest relating the findings from these studies to the overall conclusions.

7. Human impacts:
The conclusions could be improved by explicitly mentioning how human activities (impairment as well as restoration) alter connectivity of riparian wetlands and floodplain waters with receiving systems.

Note: Table 5-3 should be updated to reflect updates.

Key Points - Response to Charge Question 5(a)

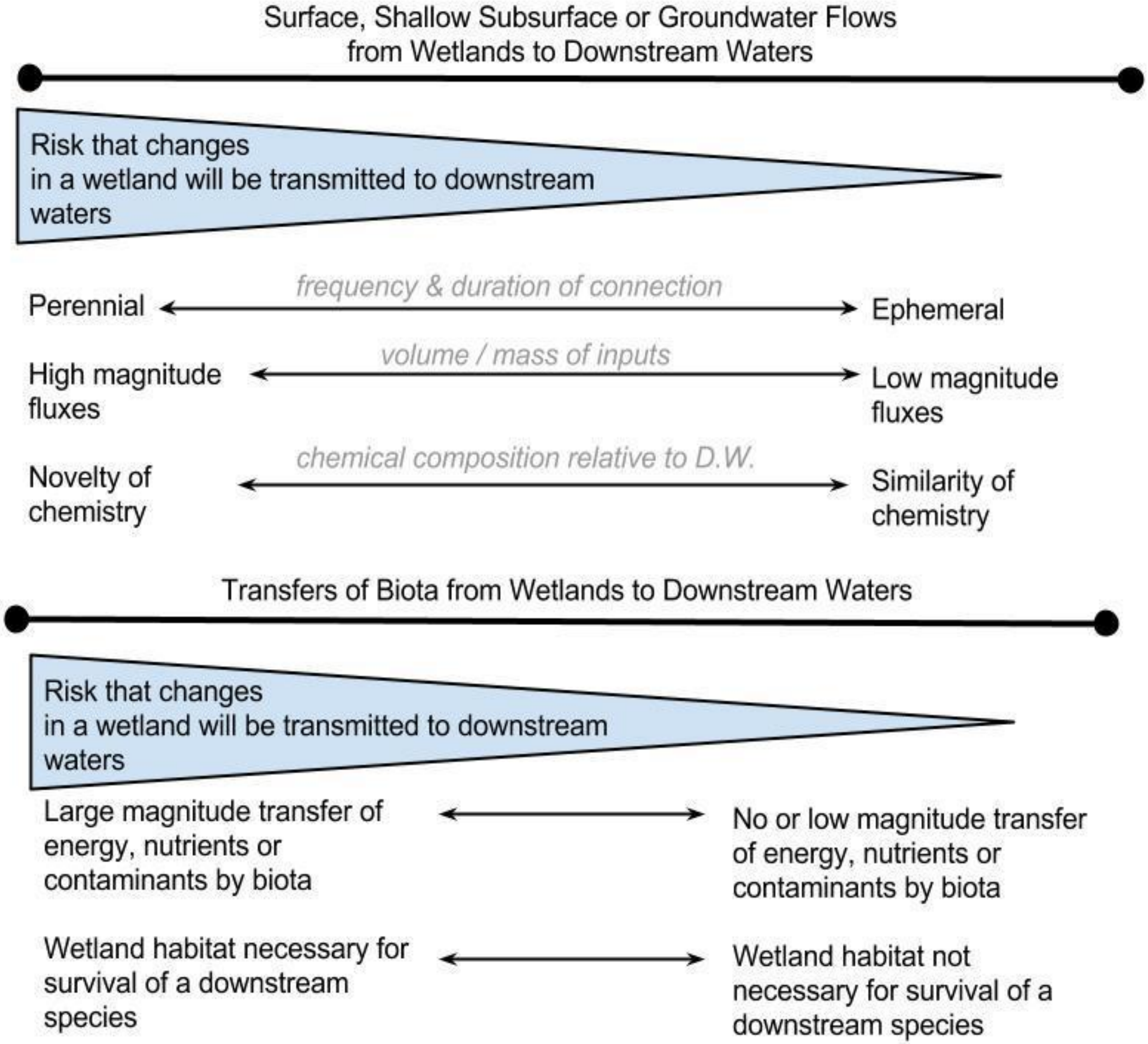
Charge Question 5a

Ali, josselyn, johnson

1. The panel urges the authors to reorganize the discussion of key functions around the **types of connections** between wetlands and downstream waters- including **surface water, ground water and biological**, with specific attention paid to the gradients of these pathways and their role in affecting downstream waters. (see diagram)

Since connectivity is expressed along a gradient, it should be acknowledged that there are bodies of water that are not connected and its important to define this end of the gradient, e.g., terminal salt lakes, playas.

Isolation should be expressed in terms of the framework.


Surface, Shallow Subsurface or Groundwater Flows from Wetlands to Downstream Waters
Risk that changes in a wetland will be transmitted to downstream waters
frequency & duration of connection
Perennial
Ephemeral
volume / mass of inputs
High magnitude fluxes
Low magnitude fluxes
chemical composition relative to D.W.
Novelty of chemistry
Similarity of chemistry
Transfers of Biota from Wetlands to Downstream Waters
Risk that changes in a wetland will be transmitted to downstream waters
Large magnitude transfer of energy, nutrients or contaminants by biota
No or low magnitude transfer of energy, nutrients or contaminants by biota
Wetland habitat necessary for survival of a downstream species
Wetland habitat not necessary for survival of a downstream species

2. **Temporal and spatial scales** of connections should be addressed explicitly with a discussion of the **magnitude, frequency and duration** of connections quantified.

Geology, climate, landforms, and surficial sediments provide the **regional context** regulating transport properties and are major drivers of the temporal and spatial scales of hydrologic linkages.

Regional context is partially addressed by case studies but could further inform the development of the main text.

3. Panel recommends that the report examine connectivity through a **range of time scales** (e.g. days vs thousands of years) to establish the magnitude, duration and frequency of connections.

4. The influence of **landscape position and scale** should be considered, e.g. distance from and size of wetlands (or similar wetland types) in the evaluation of the degree of connectivity. This will likely provide further rationale for treating wetland complexes as aggregates rather than as individual units.

5. Greater attention to **biological connections** including major assemblages, e.g., birds, amphibians, reptiles, invertebrates.

Include issues such as material flows, disease vectors, etc., in addition to contribution to biotic integrity of individual assemblages as they relate to downstream waters.

6. The panel urges the authors to incorporate a discussion about current and past (legacy) human disturbances that alter the type, strength and magnitude of connectivity pathways.

Some types of disturbances promote connections where none existed, others alter existing connection type or the novelty of chemistry / biology.

THE KEY TEXT

The stated objective -->

Q3. What are the physical, chemical, and biological connections to and effects of wetlands and certain open-waters that lack bidirectional hydrologic exchanges with downstream waters (e.g., most prairie potholes, vernal pools), hereafter referred to as unidirectional wetlands, on downstream waters? [p 2-1]

- **Fifteen panel members felt that the conclusions regarding unidirectional wetlands needed to be strengthened. Panelists suggested that the conclusions should encompass connectivity beyond hydrologic ones, and that the frequency, magnitude, and duration of these several connections should be considered.**
- **We have articulated modified versions of the key findings that we feel are consistent with the literature synthesis perfomed and our own expert knowledge of the subject. We offer these revised findings as a straw man to stimulate conversation and revision in response to significant concerns that: a) the original conclusions (5b) did not match the text that preceded it (5a) and b) there was too little attention paid to biological connections.**

Wetlands in landscape settings that lack bidirectional hydrologic exchanges with downstream waters (e.g., many prairie potholes, vernal pools, and playa lakes) provide numerous functions that can benefit downstream water quality and integrity. These functions include storage of floodwater; retention and transformation of nutrients, metals, and pesticides; and recharge of groundwater sources of river baseflow. The functions and effects of this diverse group of wetlands, which we refer to as "unidirectional wetlands," affect the condition of downstream waters if a surface or shallow subsurface water connection to the river network is present. In unidirectional wetlands that are not connected to the river network through surface or shallow subsurface water, the type and degree of connectivity varies geographically within a watershed and over time. Because such wetlands occur on a gradient of connectivity, it is difficult to generalize about their effects on downstream waters from the currently available literature. This evaluation is further complicated by the fact that, for certain functions (e.g., sediment removal and water storage), downstream effects arise from wetland isolation rather than connectivity. 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. However, evaluations of individual wetlands or groups of wetlands could be possible through case-by-case analysis. Further, while our review did not specifically address other unidirectional water bodies, our conclusions apply to these water bodies (e.g., ponds and lakes that lack surface water inlets) as well, since the same principles govern hydrologic connectivity between these water bodies and downstream waters.

1.4.3. Conclusion (3): Unidirectional Wetlands

We suggest opening this with

Over sufficiently long time scales all aquatic habitats are connected to downstream waters through the transfer of water, chemicals or biota, yet the magnitude and effects of these connections vary widely across wetlands.

and stating

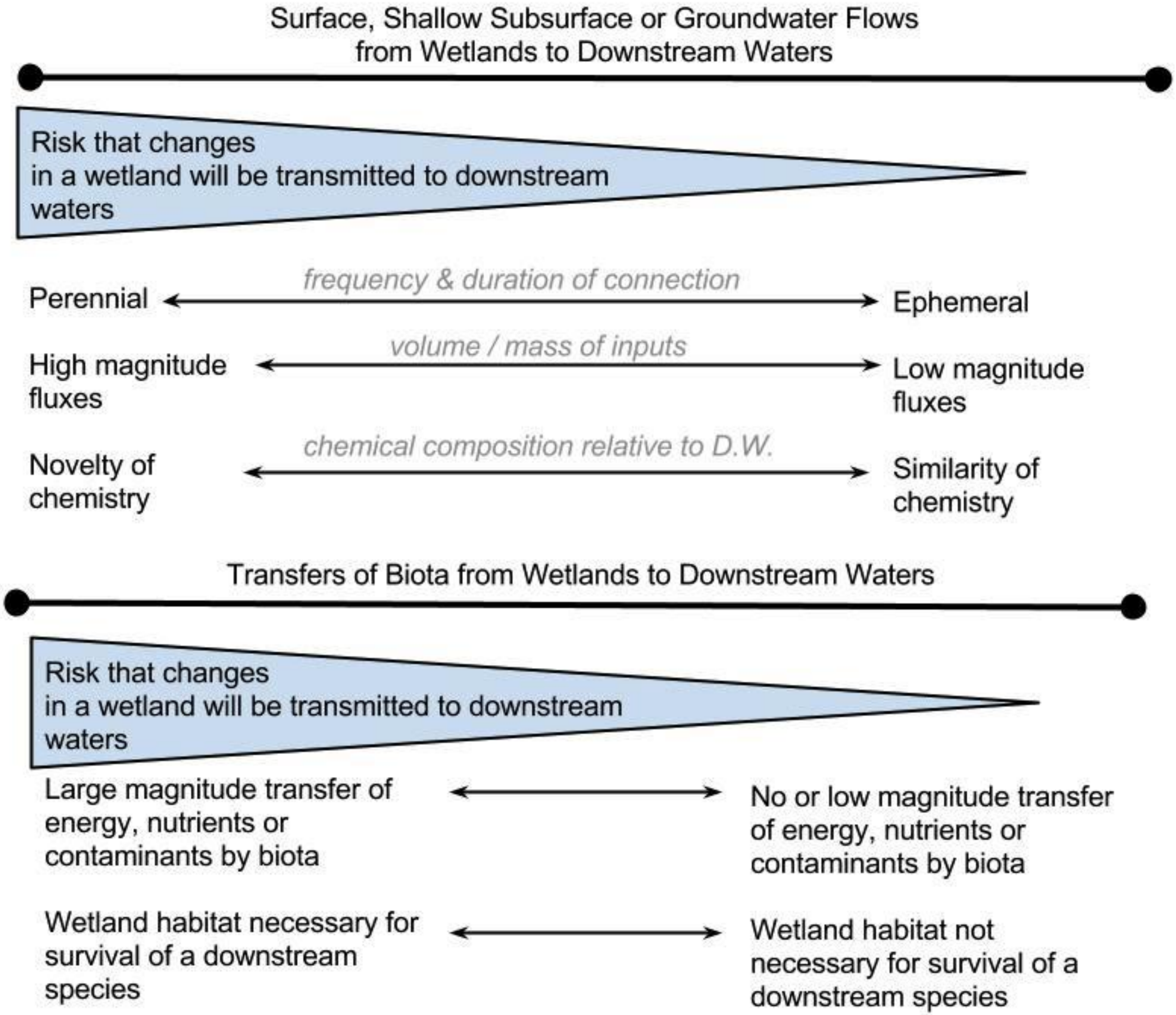
There are four pathways by which unidirectional wetlands can be connected to downstream waters: via surface, shallow subsurface or groundwater flowpaths or through the movement of biota. It is the magnitude of material, water or biotic fluxes between a wetland and downstream waters rather than the simple presence or absence of a connection that determines the strength of the linkage between a wetland and downstream waters.

If we want to protect downstream waters, we must move from a dichotomous, categorical distinction (connected vs not connected) to a gradient approach (strength of connection)

→ the current document suggests that even minimal hydrologic connections are more important than any biological connection (no matter how large the flux) - we suggest that the emphasis must shift in order to account for strong connections along any of these pathways.

Key Findings – Gradient of Hydrologic Connectivity

** [Unidirectional] wetlands occur along a gradient of hydrologic connectivity with respect to river networks, lakes, or marine/estuarine water bodies. This gradient includes, for example, wetlands that serve as origins for stream channels that have permanent surface water connections to the river network; wetlands with outlets to stream channels that discharge to deep groundwater aquifers; geographically isolated wetlands that have local groundwater or occasional surface water connections to downstream waters; and isolated wetlands that have minimal hydrologic connection to other water bodies (but which could include surface and subsurface connections to other wetlands).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Key Findings – Adjacency / Isolation

e. Spatial proximity is an important determinant of the magnitude, frequency and duration of connections between wetlands and rivers that will ultimately influence the fluxes of water, materials and biota between wetlands and downstream waters.

f. Unidirectional wetlands can be hydrologically connected directly to river networks through channels, nonchannelized surface flow, or subsurface flows. A wetland surrounded by uplands is defined as “geographically isolated.” Our review found that in some cases, wetland types such as vernal pools and coastal depressional wetlands are collectively, and incorrectly, referred to as geographically isolated. Technically, the term “geographically isolated” should be applied only to the particular wetlands within a type or class that are completely surrounded by uplands. Furthermore, “geographic isolation” should not be confused with functional isolation, because geographically isolated wetlands can still have hydrological and biological connections to downstream waters.

Wetlands in landscape settings that lack bidirectional hydrologic exchanges with downstream waters (e.g., many prairie potholes, vernal pools, and playa lakes) provide numerous functions that can benefit downstream water quality and integrity. **These functions include storage of floodwater; retention and transformation of nutrients, metals, and pesticides; and recharge of groundwater sources of river baseflow.** The functions and effects of this diverse group of wetlands, which we refer to as "unidirectional wetlands," affect the condition of downstream waters if a surface or shallow subsurface water connection to the river network is present. In unidirectional wetlands that are not connected to the river network through surface or shallow subsurface water, the type and degree of connectivity varies geographically within a watershed and over time. Because such wetlands occur on a gradient of connectivity, it is difficult to generalize about their effects on downstream waters from the currently available literature. This evaluation is further complicated by the fact that, for certain functions (e.g., sediment removal and water storage), downstream effects arise from wetland isolation rather than connectivity. 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. However, evaluations of individual wetlands or groups of wetlands could be possible through case-by-case analysis. Further, while our review did not specifically address other unidirectional water bodies, our conclusions apply to these water bodies (e.g., ponds and lakes that lack surface water inlets) as well, since the same principles govern hydrologic connectivity between these water bodies and downstream waters.

Key Findings
Functions of Unidirectional Wetlands

**** Wetlands well outside of riparian or floodplain areas individually and cumulatively store water can affect streamflow.**

**** Unidirectional wetlands act as sinks and transformers for various pollutants, especially nutrients, which pose a serious pollution problem in the United States. Studies indicate that on-site removal of nutrients by unidirectional wetlands is important and geographically widespread. The effects of this removal on rivers are generally not reported in the literature.**

**** 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 cycle, including downstream waters. Other organisms, especially abundant species, play important roles in transferring energy and materials between wetlands and downstream waters.**

Wetlands in landscape settings that lack bidirectional hydrologic exchanges with downstream waters (e.g., many prairie potholes, vernal pools, and playa lakes) provide numerous functions that can benefit downstream water quality and integrity. These functions include storage of floodwater; retention and transformation of nutrients, metals, and pesticides; and recharge of groundwater sources of river baseflow. **The functions and effects of this diverse group of wetlands, which we refer to as "unidirectional wetlands," affect the condition of downstream waters if a surface or shallow subsurface water connection to the river network is present.** In unidirectional wetlands that are not connected to the river network through surface or shallow subsurface water, the type and degree of connectivity varies geographically within a watershed and over time. Because such wetlands occur on a gradient of connectivity, it is difficult to generalize about their effects on downstream waters from the currently available literature. This evaluation is further complicated by the fact that, for certain functions (e.g., sediment removal and water storage), downstream effects arise from wetland isolation rather than connectivity. 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. However, evaluations of individual wetlands or groups of wetlands could be possible through case-by-case analysis. Further, while our review did not specifically address other unidirectional water bodies, our conclusions apply to these water bodies (e.g., ponds and lakes that lack surface water inlets) as well, since the same principles govern hydrologic connectivity between these water bodies and downstream waters.

Key Findings – Gradient of Biological Connectivity

d. Biological connectivity can occur between [unidirectional] wetlands and downstream waters through two major mechanisms. Activities by biological organisms within wetlands (e.g., foraging, breeding, roosting) can change the amount, concentration, and density of organic and/or inorganic components within the water column or soils, which can be transmitted down-gradient by fluxes of surface water or groundwater. Movements of animals (i.e., macroinvertebrates, fish, amphibians, reptiles, birds, mammals) and plants (i.e., seeds, propagules, including colonization by invasive species) can occur among waters with varying frequency, duration, and distance. Many species in these groups that use both stream and wetland habitats are capable of dispersal distances equal to or greater than distances between many [unidirectional] wetlands and river networks. Migratory waterbirds (e.g., waterfowl, shorebirds, waders, colonial species) can be an important vector of long-distance dispersal of plants, invertebrates, parasites, and disease organisms between these waters and the river network. In addition, the magnitude of translocated biomass and nutrients can be substantial, when large numbers of individuals move temporarily, periodically, or permanently between waters.

Wetlands in landscape settings that lack bidirectional hydrologic exchanges with downstream waters (e.g., many prairie potholes, vernal pools, and playa lakes) provide numerous functions that can benefit downstream water quality and integrity. These functions include storage of floodwater; retention and transformation of nutrients, metals, and pesticides; and recharge of groundwater sources of river baseflow. The functions and effects of this diverse group of wetlands, which we refer to as "unidirectional wetlands," affect the condition of downstream waters if a surface or shallow subsurface water connection to the river network is present. In unidirectional wetlands that are not connected to the river network through surface or shallow subsurface water, the type and degree of connectivity varies geographically within a watershed and over time. Because such wetlands occur on a gradient of connectivity, it is difficult to generalize about their effects on downstream waters from the currently available literature. This evaluation is further complicated by the fact that, for certain functions (e.g., sediment removal and water storage), downstream effects arise from wetland isolation rather than connectivity. 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. However, evaluations of individual wetlands or groups of wetlands could be possible through case-by-case analysis. Further, while our review did not specifically address other unidirectional water bodies, our conclusions apply to these water bodies (e.g., ponds and lakes that lack surface water inlets) as well, since the same principles govern hydrologic connectivity between these water bodies and downstream waters.

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Key Findings – Aggregate Effects

** The cumulative influence of many individual wetlands within watersheds can strongly affect the hydrology, biology and chemistry of downstream waters. Because of their aggregated influence, it is important that any attempt to evaluate changes to individual wetlands is considered in the context of past and planned alternations of other wetlands in the watershed.