# The effects of non-navigable streams and adjacent wetlands on navigable waters: An approach for addressing information needs following the US Supreme Court's *Rapanos* and *Carabell* decisions

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**Abstract:** In June 2006, the US Supreme Court ruled in two cases concerning jurisdiction under the Clean Water Act (CWA). The decisions suggest that hydrological permanence of non-navigable streams and adjacent wetlands (NNSAWs), and whether they have significant nexus with navigable waters, are relevant in determining CWA jurisdiction. This has increased the need for scientific information to support regulatory determinations and to inform future policies, rulemaking, and legislation. Here we propose an approach for addressing these science needs. We define two metrics to assess hydrological permanence: maximum duration of continuous stream or hyporheic flow, and maximum duration of continuous surface or hyporheic connection. We also define two metrics to evaluate significant nexus: proportion of total benefit to the navigable water contributed by an NNSAW class, and proportion of time that a navigable water receives benefit from an NNSAW. These metrics could be useful in implementing the Court's new legal standards.

**In a nutshell:**

- Recent Supreme Court cases have created new legal standards for determining jurisdictional waters under the Clean Water Act

- Addressing the science needs prompted by these cases requires that the various waters be regarded as components of integrated hydrological and ecological systems

- Based on this view, we define metrics of hydrological permanence and significant nexus

- Applying these metrics could help implement the new legal standards during jurisdictional determinations

## Introduction

The Clean Water Act (CWA) protects "navigable waters," defined as "waters of the United States" (see 33 USC §502(7)). Regulations by the Environmental Protection Agency (EPA) and Army Corps of Engineers (Corps) further define "waters of the US" (33 CFR §328.3(a) and 40 CFR §230.3(s)). Prior to 2001, any tributary to a navigable-in-fact water was regarded as jurisdictional under the CWA, and virtually all delineated wetlands were considered jurisdictional because of their potential to serve as migratory bird habitat. Two Supreme Court cases altered this perspective. In *Solid Waste Agency of Northern Cook County (SWANCC)*, the Court held that the presence of migratory birds was an insufficient sole basis for asserting CWA jurisdiction over isolated, intrastate, non-navigable waters (*Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers,* 531 US 159 (2001)). However, the Court did not invalidate the regulations defining "waters of the US." The reasoning in *SWANCC* could suggest that waters need some relationship with a navigable-in-fact water to be afforded protection under the CWA. By introducing the term "isolated" into the issue of CWA jurisdiction, *SWANCC* has encouraged research on the relative connectivity among wetlands and other waters (Leibowitz and Nadeau 2003).

Five years after *SWANCC,* the Supreme Court explored CWA protections for tributaries and adjacent wetlands in *Rapanos v. United States* and *Carabell v. United States* (these were consolidated into one decision, *Rapanos v. United States*, 547 US ___ (2006)). In June 2006, the Justices issued five opinions in *Rapanos*, with no single opinion commanding a majority. As a result, the scope of "waters of the US" will be determined by how the EPA, Corps, and courts interpret these decisions.

In the plurality opinion, Justice Scalia (joined by three other Justices) opined that "waters of the US" extend beyond navigable-in-fact waters to include "relatively permanent, standing or flowing bodies of water" (Figure 1). Scalia indicated that the phrase includes "seasonal rivers" having continuous flow during some months of the year, and some waters that dry during drought. However, it would not include "ordinarily dry channels through which water occasionally or intermittently flows" or "streams whose flow is '[c]oming and going at intervals … [b]roken, fitful' … or 'existing only, or no longer than, a day…'" The opinion also asserts that only wetlands with a continuous surface connection to other jurisdictional waters are considered "adjacent" and protected by the CWA.

Justice Kennedy's concurring opinion takes a different approach. Kennedy concludes that "waters of the US" include wetlands that "possess a 'significant nexus' to waters that are or were navigable in fact or that could reasonably be so made." He suggests that wetlands and other waters have significant nexus if the waters "either alone or in combination with similarly situated lands in the region, significantly affect the chemical, physical, and biological integrity of other covered waters more readily understood as 'navigable'" (Figure 1). Such a nexus must be more than "speculative or insubstantial." Kennedy also observes that in some circumstances the absence of a hydrological connection may create a significant nexus.

The four dissenting Justices, in an opinion by Justice Stevens, as well as the Department of Justice, EPA and Corps, have all taken the position that a water may be found jurisdictional if it meets <u>either</u> the Scalia or Kennedy standard. The agencies are working to develop field guidance as to the legal standards required for CWA jurisdiction, but as of April, 2007 that guidance was unavailable. For the time being, the EPA and Corps are encouraging field staff to include in their jurisdictional files information relevant to both the Scalia and Kennedy standards. This is not because both standards must be met, but because the legal landscape is potentially evolving.

*Rapanos* poses challenges to EPA and Corps field staff, and to the regulated community, as they seek to determine whether a particular water is jurisdictional under the CWA. The research community is in a position to help ensure those determinations are well-grounded in science, both by clarifying relationships among waters, and by developing protocols that readily identify and document such relationships. Before these protocols can be developed, basic research needs to address the fundamental hydrological and ecological relationships underlying

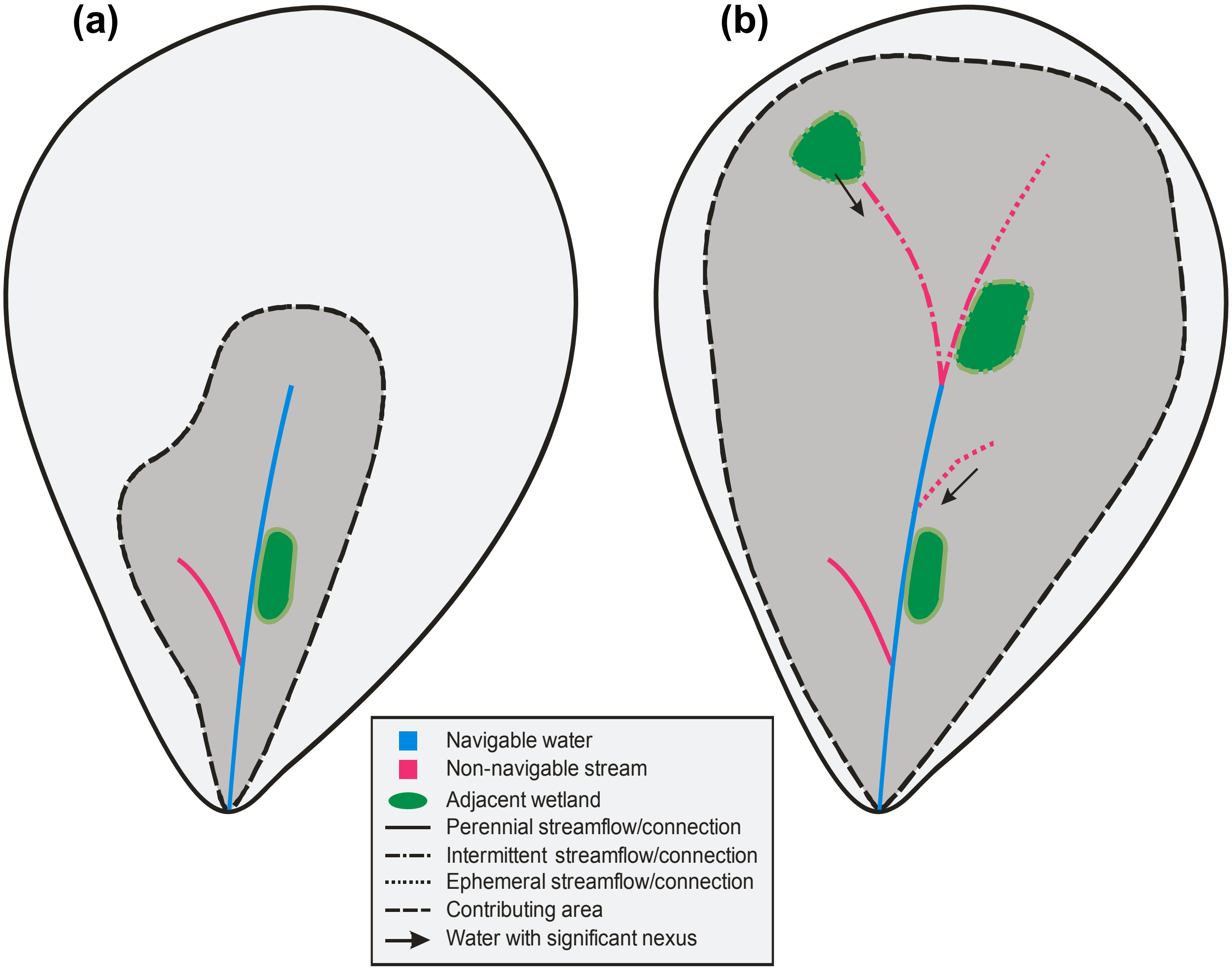

***Figure 1.*** *Hypothetical watershed illustrating concepts relevant to* Rapanos. *Integrated hydrological-ecological systems contain perennial, intermittent, and ephemeral streams, adjacent wetlands, and upslope contributing areas. The contributing area is the portion of the watershed that actually supplies water – through surface- or groundwater flows – to the stream system for a given discharge. This area fluctuates in response to inputs of rain or snow, as illustrated for baseflow (a) and flood (b) conditions. Navigable waters are jurisdictional under the Clean Water Act. The Scalia standard also considers "relatively permanent" non-navigable streams and adjacent wetlands (NNSAWs) jurisdictional. This includes NNSAWs with perennial flow or connections and some with intermittent flow or connections (based on hydrological definitions). According to the Kennedy standard, an NNSAW is jurisdictional if it either individually or as a class has "significant nexus" with navigable waters, i.e., significantly affects the chemical, physical, and biological integrity of navigable waters. Examples are for purposes of illustration only. Significant nexus has to be determined based on actual relationships with downstream, navigable waters.*

the Scalia and Kennedy standards. This research can also help inform future policies, rulemaking, or legislation that might result from the Court's decision.

This paper deals with the characteristics of non-navigable streams and adjacent wetlands (NNSAWs, pronounced "en-saws") and their relationship to the physical, chemical, and biological integrity of navigable-in-fact waters (referred to here as "navigable waters"). Non-navigable streams occur upstream from and may ultimately discharge into navigable waters. Adjacent wetlands border, are contiguous to, or neighbor a jurisdictional water. To address the issues raised by *Rapanos*, we provide background for understanding NNSAWs and their relationships with navigable waters. We then present several metrics that could be useful in implementing the new legal standards. This is followed by recommendations for future research and conclusions.

## Integrated hydrological-ecological systems

The physical, chemical, and biological integrity of any ecosystem is the synergistic product of processes operating at many spatial and temporal scales. Stream networks are special cases, because hydrological and ecological connectivity allows for the exchange of materials (e.g., mass, energy, and organisms) longitudinally, laterally, vertically, and temporally throughout the basins and underlying aquifers (Ward 1989; Pringle 2001). Therefore, NNSAWs and navigable waters are best considered as elements of integrated hydrological-ecological systems (Nadeau and Rains 2007; Figure 1). Within these systems, materials are passively transported as water flows downgradient from NNSAWs to navigable waters, and actively transported as organisms move downgradient, upgradient, or over land between NNSAWs and navigable waters (Alexander *et al.* 2007; Meyer *et al.* 2007). Consequently, NNSAWs cumulatively contribute to the integrity of the navigable waters by performing a variety of functions.

Non-navigable streams can be perennial, intermittent, or ephemeral. During a typical year, perennial streams flow year-round, intermittent streams cease to flow during dry periods, and ephemeral streams flow for short durations in direct response to precipitation (Mosley and McKerchar 1993). This widely-accepted hydrological definition of "intermittent" differs from Justice Scalia's usage, which inferred that intermittent includes flow that is "broken and fitful" and does not occur continuously for months. From a scientific perspective, intermittent streams have widely-varying hydrographic characteristics (Poff *et al.* 2006), and can include both the "seasonal rivers" that may pass the Scalia standard and the "ordinarily dry channels" that might not.

Adjacent wetlands are proximal to jurisdictional streams and may include slope wetlands on hillslopes and depressional, slope, fringe, or riverine wetlands on valley bottoms (Brinson 1993). Adjacent wetlands can have continuous surface water connections to nearby streams, or they can be geographically isolated (Leibowitz and Nadeau 2003). However, the latter can have intermittent surface water connections to streams through overbank flooding or spillage. They also can have perennial, intermittent, or ephemeral connections to streams through groundwater flow.

Both surface water and groundwater flowpaths connect individual elements between separate NNSAWs and between NNSAWs and navigable waters. Groundwater connections, though more difficult to observe and quantify than surface water connections, can be equally or more influential in maintaining the integrity of stream networks. An important type of groundwater/surface water interaction occurs in the hyporheic zone, where water from the stream channel flows into subsurface materials of the streambed and bank and then returns to the stream (Bencala 2005). The dimensions of the hyporheic zone are controlled by the distribution and characteristics of alluvial deposits and by hydraulic gradients between streams and local groundwater (Morrice *et al.* 1997). If wetlands are located in settings with active hyporheic exchange, materials may be transferred between streams and wetlands (Figure 2). Streams and wetlands within hyporheic zones are integrally connected; neither can properly function if the other is impaired. For example, much of the nutrient cycling in streams occurs during flow excursions through hyporheic zones (Hill and Lymburner 1998; Hill *et al.* 1998).

Groundwater connections between more isolated wetlands and streams may also occur through local or regional groundwater flow systems outside hyporheic zones but within larger hydrological landscapes (Winter 2001). In these groundwater flows, materials may be transported from wetlands to streams but not from streams to wetlands (Figure 2). These groundwater flows can also play important roles in material fluxes between wetlands and streams (e.g., Triska *et al.* 2007).

Organisms can move between NNSAWs and navigable waters by hydrological, terrestrial, and aerial pathways. This biological connectivity allows NNSAWs to function as refugia from predators, competitors, invasive species, and adverse conditions such as extreme temperature and flow (Meyer *et al.* 2007). Exchanges between NNSAWs and navigable waters also help maintain populations, e.g., through gene flow and recolonization following local extinctions. In addition, biological connectivity can represent an important pathway by which nutrients are transported back upgradient (Gresh *et al.* 2000; Naiman *et al.* 2002).

The importance of connections between NNSAWs and navigable waters to the integrity of navigable waters typically varies with landscape setting, watershed characteristics, and stream network characteristics. Quantifying the importance of these connections is challenging, in part, because of temporal variability from natural variations in flow regimes (Poff *et al.* 1997; Izbicki 2007). Temporal variability can result in intra- and inter-annual expansion and contraction (Figure 1) and subsequent changes in surface and subsurface connectivity (Junk *et al.* 1989; Stanley *et al.* 1997; Rains and Mount 2002; Wigington *et al.* 2005; Izbicki 2007). Because this affects processing and delivery of materials and movement of organisms, the benefits that NNSAWs provide navigable waters may also vary with time.

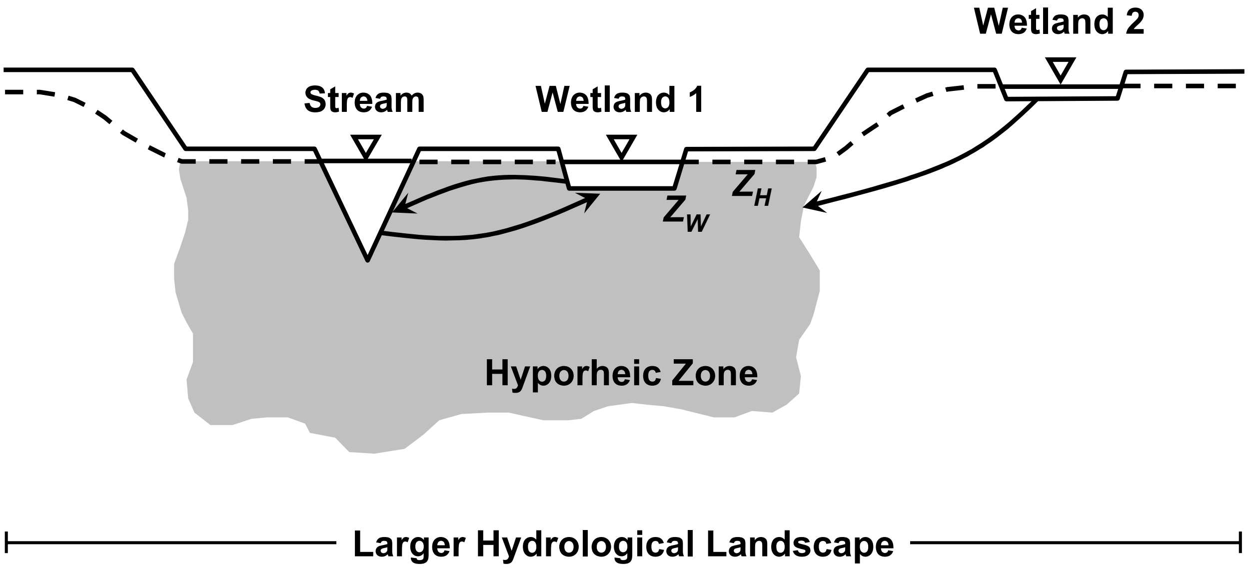

***Figure 2.*** *Hydrological connectivity between wetlands and streams. Wetland 1 is located within the hyporheic zone (shaded area), so water from the stream can move into the wetland and return to the channel.* $Z_H$ *is the elevation of the water table (dashed line) within the hyporheic zone, and* $Z_W$ *is the elevation of the bottom of Wetland 1. Wetland 2 is outside the hyporheic zone, and so connections between it and the stream occur through unidirectional groundwater flow. Both wetlands can also be connected to the stream during overbank flooding.*

## Approach

In this section, we develop metrics for hydrological permanence and significant nexus that reflect the hydrological and ecological characteristics implied by the Scalia and Kennedy opinions. Our focus is not the individual NNSAW, but classes of NNSAWs. A full treatment of classification is beyond the scope of this paper. However, classification approaches need to be developed that are dualistic and hierarchical, because characteristics of both NNSAWs and downstream navigable waters must be included at various spatial scales.

### *Hydrological permanence*

According to Justice Scalia, a stream or wetland NNSAW would be considered jurisdictional if it was relatively permanent or had a continuous surface connection, respectively. Duration of continuous flow appears to be one of the main jurisdictional considerations advanced by Scalia. To evaluate whether a stream meets this standard, we define $D_{max,q}$ as the maximum duration (in days) of continuous flow. This metric can be evaluated from a stream's hydrograph (Figure 3). Biological indicators might also be useful in evaluating duration of flow (Fritz *et al.* 2006). For

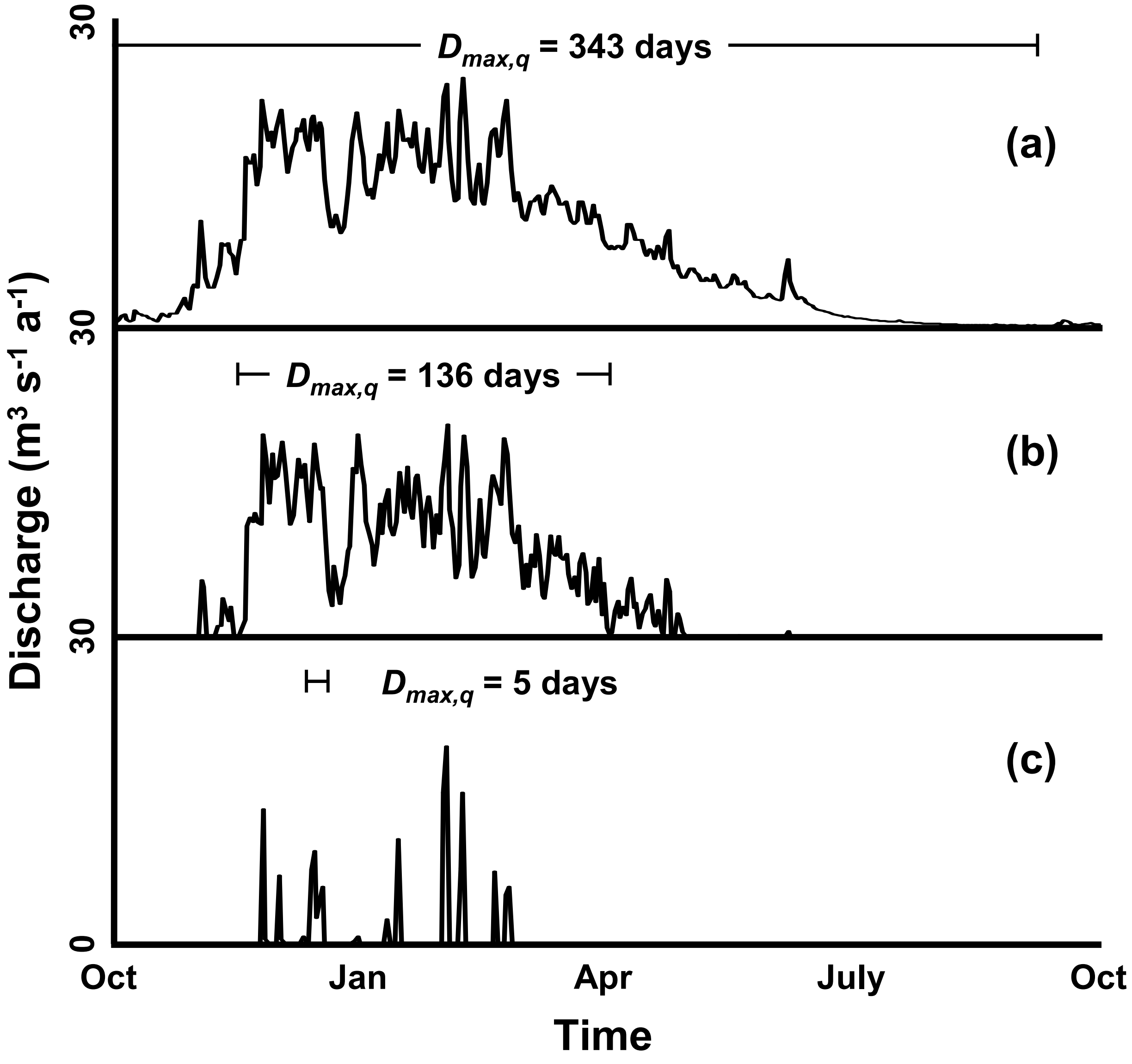

***Figure 3.*** *Hypothetical hydrographs illustrating* $D_{max,q}$ *values for perennial (a), intermittent (b), and ephemeral (c) streams.* $D_{max,q}$ *is the maximum duration (in days) of continuous stream or hyporheic flow. Note that the hydrographs do not consider hyporheic flow; including days when the channels were empty but hyporheic flow occurred would increase* $D_{max,q}$ *values. Examples are for purposes of illustration only, and* $D_{max,q}$ *values do not necessarily represent the actual values for those classes of streams.*

adjacent wetlands, we define $D_{max,c}$ as the maximum duration of continuous connection between the wetland and jurisdictional stream.

Because stream and hyporheic waters are so integrally linked, both surface and shallow subsurface hyporheic water could be included when evaluating $D_{max,q}$ and $D_{max,c}$. This means that a dry stream channel might still be considered relatively permanent if it has hyporheic flow. For an adjacent wetland, a continuous connection could occur whenever the elevation of the water table within the hyporheic zone, $Z_H$, is greater than or equal to the elevation of the bottom of the wetland, $Z_W$ (Figure 2). The inclusion of hyporheic water could still be consistent with Justice Scalia's approach.

### ***Significant nexus***

Significant nexus is more complex than hydrological permanence. It involves not only the hydrological characteristics of the NNSAW, but also its physical, chemical, and biological attributes. Furthermore, significant nexus is not a property of the NNSAW alone, but reflects characteristics of the combined stream network. Our approach to significant nexus is to consider the ways that NNSAWs alter material fluxes so as to contribute to the integrity of the navigable water. These include:

(1) *Supplying beneficial materials* (source function) – NNSAWs can be sources of energy, inorganic nutrients, organic matter, and organisms. Source functions include net growth that occurs when NNSAWs serve as spawning and rearing habitat for migratory fish. NNSAWs are also sources of water, maintaining flow regimes by delivering water from the watershed and by storing and releasing storm water.

(2) *Removing harmful materials* (sink function) – NNSAWs can serve as sinks of harmful materials such as sediments and pollutants, and they can attenuate high flows through temporary storage of water.

(3) *Preventing removal of beneficial materials* (refuge function) – NNSAWs can reduce mortality of migratory organisms, particularly fish, by providing refugia from harmful conditions, such as presence of predators or extreme temperatures (refugia effects on resident organisms are implicitly incorporated into the source function). NNSAWs can also help form refugia in other waters, e.g., by providing cold or warm water to downstream reaches.

To evaluate these functions, we define a metric that assesses the relative benefit provided by an NNSAW of class $i$:

$$B_i = b^*_i / \Sigma b^*_j$$

where $B_i$ is the proportion of total benefit to the navigable water contributed by NNSAW$_i$ for a given material; $b^*_i$ is the amount of the material in the navigable water that NNSAW$_i$ does or can beneficially alter (i.e., supply, remove, or prevent removal of); and $\Sigma b^*_j$ is the total amount of the material that is or can be beneficially altered by all NNSAW classes and the navigable water itself. By including benefits from the navigable water in the denominator, we give greater weight to benefits that are mostly provided by NNSAWs than those mainly derived from the navigable water.

The variable $b^*$ is dependent on $b$, the net change in material that is or can be caused by the class, and $k$, the proportion of the altered amount that is or would be transferred downstream to the navigable water:

$$b^* = b\,k$$

Below, we separately interpret $b$ for source, sink, and refuge functions, and illustrate how the metric could be applied.

For source functions, $b$ represents the net amount of material (i.e., output minus input) supplied by an NNSAW. We provide an example of how $b^*$ can be directly estimated from a study in the West Fork Smith River (WFSR) basin in coastal Oregon (Figure 4). For the purposes of this illustration, we assume that the mainstem WFSR meets the legal definition of a navigable water. Wigington *et al.* (2006) reported that 123, 640, and 197 juvenile coho salmon (*Oncorhynchus kisutch*) recaptured during 2004 outmigration were tagged in intermittent and perennial NNSAWs and the mainstem, respectively. Total outmigration for 2004 was 23,054 (Jepsen *et al.* 2006). Assuming that tagging was representative of juveniles in each class, and that the location of tagging was the primary habitat, then $b^*$ values for intermittent, perennial, and mainstem classes are 2954, 15,369, and 4731, respectively. This gives $B$ values of 13, 67, and 21% for the intermittent, perennial, and mainstem classes, respectively. For 2005, respective $B$ values were 31, 56, and 13%.

For sink functions, $b$ could represent the net amount of material removed by an NNSAW. As an example, Alexander *et al.* (2007) calculated N removal in the northeastern US. They estimated that headwater stream denitrification removed 3-4% of the nitrogen in fourth- and higher-order streams. There are two problems with using this approach for determining CWA jurisdiction. First, because total nitrogen is the denominator, rather than total N removal, the percentage varies with N concentrations in the navigable water. Determining significant nexus with such a metric would result in degraded navigable waters having fewer jurisdictional waters than less impacted waters. Second, using actual removal for $b$ means that NNSAWs with relatively pristine catchments would remove less N, and provide less benefit, than NNSAWs with degraded catchments having high loads. Yet, the former can still have capacity to remove harmful materials, should they be present in the future. Such a capacity helps maintain the integrity of the navigable water.

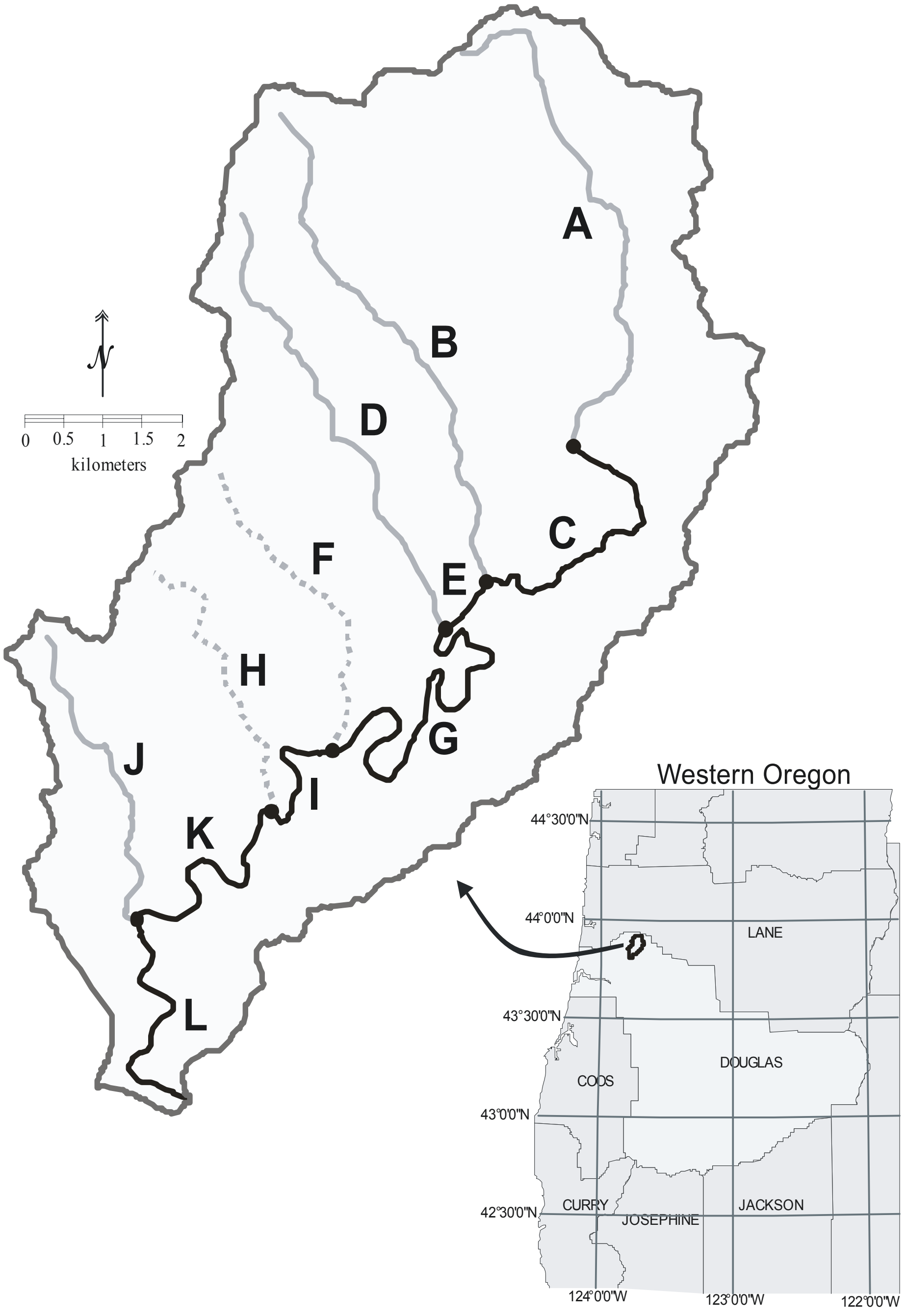

***Figure 4.*** *Watershed and stream network for the West Fork Smith River, Oregon. Lighter colored streams are perennial (solid) or intermittent (dotted) NNSAWs. Darker colored reaches represent the mainstem river. Letters correspond to intermittent and perennial streams and mainstem reaches in Table 1.*

To avoid these problems, for sinks functions we define *b* as the maximum net amount of material an NNSAW could remove if sufficient amounts of the material were present. To illustrate this, we estimate nitrogen removal capacity for the NNSAW classes in the WFSR (Figure 4). We assume that maximum loadings would occur if the entire basin were covered with nitrogen-fixing alder. We then use a first-order decay equation (Alexander *et al.* 2007) to calculate N removal (Table 1). Assuming that this represents nitrogen that would have been transported to the mainstem if it was not removed (i.e., $k=1$), then $b^*$ values for intermittent, perennial, and mainstem classes are 11, 43, and 59 metric tons, respectively. This gives *B* values of 10, 38, and 52%, respectively.

For refuge functions, *b* represents the net output of organisms from waters other than the NNSAW class, given the presence of NNSAW refugia, minus the output if the refugia were absent. As an illustration of this function, Labbe and Fausch (2000) found that NNSAWs that were refugia from northern pike (*Esox lucius*) had Arkansas darter (*Etheostoma cragini*) present in 85% of sampled pools, compared to 36% of pools in NNSAWs where pike was present. Combining such data with densities and estimates of *k* could be used to calculate *b*.

The flux of materials between NNSAWs and navigable waters varies over time (Figure 1). Therefore, an NNSAW's greatest effect on navigable waters will frequently not occur during "average" conditions. In determining whether such a contribution is significant, both the recurrence interval (*r*) and duration (*d*) of the downstream benefit need to be considered. This can be evaluated with the metric:

$$\tau = \min(d/r, 1)$$

where $\tau$ is the proportion of time that a navigable water receives benefits from an NNSAW (Figure 5).

In applying *B* and $\tau$, several issues must be considered:

- We have removed some of the influence of watershed and stream condition by defining *b* as a capacity, rather than actual removal, for sink functions. Yet condition can still affect function (e.g., higher carrying capacities in less degraded waters). Thus, these metrics need to be calculated relative to some standard condition, e.g., current, reference, or restorable condition.

- Neither metric addresses the importance of a material to the integrity of a navigable water. For example, $B = 0.4$ for a limiting nutrient could be more significant than $B = 0.8$ for a non-limiting nutrient. Materials must be selected that are known to play important roles in maintaining the integrity of navigable waters.

**Table 1. Estimated maximum annual nitrogen delivery, retention, and downstream export for intermittent and perennial streams and mainstem reaches of the West Fork Smith River, Oregon. N values as metric tons.**

| *Map Location*[a] | *Reach Type* | *Local delivery*[b] | *Upstream delivery*[c] | *Total retention*[d] | *Downstream export*[e] |
|---|---|---|---|---|---|
| A | Perennial | 295 | 0 | 18 | 277 |
| B | Perennial | 172 | 0 | 12 | 160 |
| C | Mainstem | 131 | 277 | 15 | 393 |
| D | Perennial | 159 | 0 | 5 | 154 |
| E | Mainstem | 6 | 553 | 2 | 557 |
| F | Intermittent | 92 | 0 | 6 | 86 |
| G | Mainstem | 122 | 711 | 9 | 824 |
| H | Intermittent | 89 | 0 | 5 | 84 |
| I | Mainstem | 53 | 910 | 7 | 955 |
| J | Perennial | 102 | 0 | 8 | 93 |
| K | Mainstem | 68 | 1040 | 13 | 1095 |
| L | Mainstem | 70 | 1188 | 13 | 1245 |

[a] Letters correspond to locations in Figure 4.

[b] The maximum N load to the incremental drainage area (reach drainage area minus the drainage area of upstream reaches). Maximum N loadings estimated as the amount of N that would be delivered if the entire basin were covered with nitrogen-fixing alder, using a rate of 200 kg $ha^{-1}$ $yr^{-1}$ (Wigington *et al.* 1998).

[c] Equal to downstream export from reaches that directly feed into the target reach.

[d] Sum of N retention from local and upstream delivery. Retention from each of these sources is equal to the product of the delivery and retention rates. Retention rates estimated as a first-order decay processes (Alexander *et al.* 2007), equal to $1 - \exp(-0.0513Z^{-1.319}T)$, where $Z$ is mean water depth and $T$ is time of travel. $T$ estimated as a function of drainage area, discharge, and slope based on Jobson (1996). Time of travel for local delivery taken as one-half of the reach value (i.e., local delivery is assumed to be introduced at the reach midpoint).

[e] Equal to local plus upstream N delivery minus total N retention.

- Both metrics evaluate a single material. An NNSAW class processes many different materials. A large benefit from a single material could be sufficient to establish significant nexus. Alternatively, significant nexus might arise from the accumulation of multiple benefits.

- How to legally define the navigable water to which significant nexus is established will presumably be clarified by the EPA, Corps, and courts. For example, it might be the entire navigable water or the uppermost navigable reach.

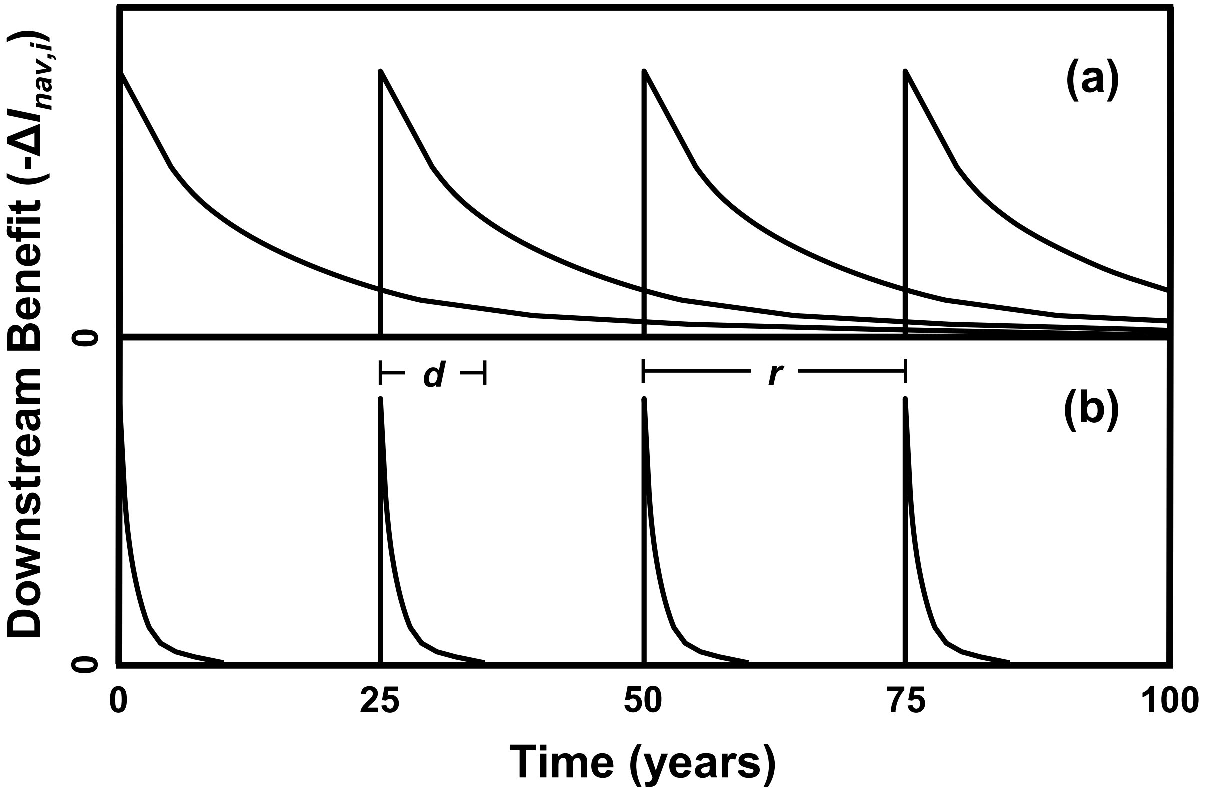

***Figure 5.*** *Illustration of different timing effects in delivery of downstream benefit from a non-navigable stream and adjacent wetland (NNSAW) class to a navigable water. We define* $\tau$ *to be the proportion of time that a navigable water receives benefits from an NNSAW. If the duration of the effect,* d*, is less than the recurrence frequency,* r*, then* $\tau = d/r$. *If* $d \geq r$*, then* $\tau = 1$. *(a)* $\tau = 1$ *for a recurrence interval of 25 years and duration of 100 years. (b)* $\tau = 0.4$ *for a recurrence interval of 25 years and a duration of 10 years.*

## Research needs

To be used by regulators, any approach to evaluating hydrological permanence and significant nexus, including our metrics, must be inexpensive and easily applied with minimal data collection. Meeting these criteria requires two critical areas of research:

- Development of methods and indicators that vary in level of effort and accuracy (Table 2) for use in evaluating the metrics.

- Dualistic and hierarchical classification approaches are needed to assess hydrological permanence and significant nexus, because it is impractical to evaluate NNSAWs individually and because of the need to focus on aggregate function. Researchers will then need to describe classes and functions for the NNSAWs in their region.

Research is also necessary in several other areas:

- Fundamental research into the interactions between upstream and downstream components of stream networks, including the factors influencing the integrity of navigable waters at various spatial and temporal scales, and the dependence of navigable waters on NNSAWs.

- Case studies within various regional settings that quantify and document hydrological permanence and significant nexus and illustrate application of the metrics.

- Although the metrics can quantify hydrological permanence and significant nexus, the threshold values that would meet the Scalia and Kennedy standards are legal and policy matters. However, research that evaluates the consequences of adopting different threshold values could be helpful.

## Conclusions

Based on an understanding of integrated hydrological-ecological systems, we have developed four metrics that could help assess hydrological permanence and significant nexus. We include hyporheic waters in evaluating hydrological permanence because they are so integrally linked to stream waters. Our approach could be generalized and applied to other issues, including jurisdiction of isolated wetlands, managing and establishing TMDLs (total maximum daily loads), and impact assessment. Critical to any successful application is further research and development of indicators and classification systems. Successfully meeting the challenges of *Rapanos* will also require more research on the functional relationship among upper streams, wetlands, and downstream waters. This information could help inform future policies, rulemaking, or legislation that might result from the Court's decision.

**Table 2. Examples of methods that can generate data that vary in their levels of effort and accuracy[1] and that can be used to evaluate metrics of hydrological permanence and significant nexus for non-navigable streams and adjacent wetlands (NNSAWs).**

| *Category* | *Method* | *Metric*[2] | *Availability* | *References* |
|---|---|---|---|---|
| Direct Measurement | Discharge (stream gage) and presence of flow or connection (pressure, temperature, or electrical resistivity sensors) | $D_{max,q}$, $D_{max,c}$, $B$, $\tau$ | Methods exist and records are readily available, but usually for limited time periods and locations | Wahl *et al.* 1995; Constantz *et al.* 2001; Fritz *et al.* 2006 |
| | Flux measurements | $B$, $\tau$ | Fluxes of many different materials (e.g., sediment, large woody debris, nutrients, and fish) have been studied using a variety of measurements | May and Gresswell 2004; Rains *et al.* 2006; Wigington *et al.* 2006 |
| | Tracers (e.g., stable isotopes, dyes, molecular contaminant tracers) | $D_{max,q}$, $D_{max,c}$, $B$, $\tau$ | Method has promise but may be limited to specific materials and landscape settings | Flury and Wai 2003; Gibson *et al.* 2005; Aufdenkampe *et al.* 2006 |
| | Paired watershed/pre-post-impact assessment | $B$ | Can be used to assess the effect of land use change (loss or conversion) on stream condition but results can be confounded by other factors | Loftis *et al.* 2001; Meals and Hopkins 2002 |

**Table 2. Continued.**

| *Category* | *Method* | *Metric*[2] | *Availability* | *References* |
|---|---|---|---|---|
| Model-based estimates[3] | Estimation of long-term averages | $D_{max,q}$, $D_{max,c}$, $B$, $\tau$ | Has been used to quantify nitrogen fluxes and transformations and to quantify water and solute fluxes | Pint *et al.* 2003; Alexander *et al.* 2007 |
| | Extension of streamflow records to sparsely-gaged or ungaged basins | $D_{max,q}$, $D_{max,c}$ | Process is being simplified by map-based web applications, but land use change can introduce error; an active area of research | Mosley and McKerchar 1993; Xevi *et al.* 1997; Sivapalan *et al.* 2003 |
| | Empirical water quality models | $B$ | Results are inferential and can be confounded by other factors | Montreuil and Merot 2006; Alexander *et al.* 2007 |
| | Geostatistical tools | $B$ | Spatial autocorrelation in water quality may allow effective distance of NNSAW influence to be determined | Dent and Grimm 1999; Gardner *et al.* 2003 |

**Table 2. Continued.**

| *Category* | *Method* | *Metric*$^2$ | *Availability* | *References* |
|---|---|---|---|---|
| Indirect indicators | Remote sensing | $D_{max,q}$, $D_{max,c}$ | Soil moisture and vegetation characteristics may be able to serve as indicators if water cannot be directly observed | Mertes 2002 |
| | Presence of hydric soil, hydric vegetation, and aquatic biota | $D_{max,q}$, $D_{max,c}$ | Long used to determine wetland/upland boundaries; research will be needed to apply this to determining hydrological permanence | Reed 1988; Fritz *et al.* 2006; Hurt and Vasilas 2006 |
| | Classification | $D_{max,q}$, $D_{max,c}$, $B$, $\tau$ | System that addresses both NNSAWs and navigable waters needs to be developed and class characteristics need to be determined | Brinson 1993; Bedford 1996; Snelder and Biggs 2002; Wolock *et al.* 2004 |

[1] Methods that vary in levels of effort and accuracy include, at the upper end, direct measurements from process-based studies that could produce definitive regional case studies and quantitatively describe the functioning of NNSAW systems; however, these would be costly and could take years for completion. At the other extreme are indirect indicators of function that are easy to use and adequate for day-to-day, non-controversial regulatory decisions.

[2] $D_{max,q}$ = maximum duration (in days) of continuous stream or hyporheic flow; $D_{max,c}$ = maximum duration (in days) of continuous surface or hyporheic connection; $B$ = proportion of total benefit to the navigable water contributed by an NNSAW class; $\tau$ = proportion of time that a navigable water receives benefits from an NNSAW class.

[3] Includes statistical, numerical, and simulation modeling.

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