



# **Freshwater corridor networks in the conterminous US: a coarse-filter approach**

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Abstract:	Maintaining regional-scale freshwater connectivity is challenging owing to the dendritic, easily fragmented structure of freshwater networks, but is essential for promoting ecological resilience under climate change. Although the importance of stream network connectivity has been recognized, lake-stream network connectivity has largely been ignored. Furthermore, protected areas are generally not designed to maintain or encompass entire freshwater networks. We analyzed freshwater corridor networks, disproportionately important network lakes (i.e., "hubs"), and their protection status in the conterminous US. We calculated connectivity scores for 385 freshwater networks with > 4 lakes ( $\geq 1$ ha) and identified 2080 hub lakes (2% of all network lakes) that are critical for maintaining intact networks. Freshwater connectivity scores were not correlated with any type of protection. Just 3% of networks received high connectivity scores based on their large size and structure (medians of 1303 lakes, 498.6 km north-south stream distance), but these also contained a median of 454 dams. In contrast, undammed networks (17% of networks) were considerably smaller (medians of 6 lakes, 7.2

	<p>km north-south stream distance), indicating that the functional connectivity of the largest potential freshwater corridor networks in the conterminous US currently may be diminished compared to smaller, undammed networks. Network lakes and hubs were protected at similar rates nationally across different levels of protection (8-18% and 6-20%, respectively), but were generally more protected in the western US. Our results indicate that conterminous US protection of major freshwater corridor networks and the hubs that maintain them generally fell short of the international conservation goal of protecting an ecologically representative, well-connected set of fresh waters (<math>\geq 17\%</math>) by 2020 (Aichi Target 11). Conservation planning efforts might consider focusing on hubs, particularly in larger networks, less protected or biodiverse regions, to support connectivity for freshwater biodiversity conservation under climate change.</p>

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Freshwater corridor networks

**Title**

Freshwater corridor networks in the conterminous US: a coarse-filter approach

**Authors**

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**Open research:** All data, metadata, and R analysis scripts are currently available at <https://github.com/cont-limno/TripleC>. Upon publication, this repository will be permanently archived in a publicly accessible online location and cited in our methods.

**Abstract**

Maintaining regional-scale freshwater connectivity is challenging owing to the dendritic, easily fragmented structure of freshwater networks, but is essential for promoting ecological resilience under climate change. Although the importance of stream network connectivity has been recognized, lake-stream network connectivity has largely been ignored. Furthermore, protected areas are generally not designed to maintain or encompass entire freshwater networks. We analyzed freshwater corridor networks, disproportionately important network lakes (i.e., “hubs”), and their protection status in the conterminous US. We calculated connectivity scores for 385 freshwater networks with > 4 lakes ( $\geq 1$  ha) and identified 2080 hub lakes (2% of all network lakes) that are critical for maintaining intact networks. Freshwater connectivity scores were not correlated with any type of protection. Just 3% of networks received high connectivity scores based on their large size and structure (medians of 1303 lakes, 498.6 km north-south stream distance), but these also contained a median of 454 dams. In contrast, undammed networks (17% of networks) were considerably smaller (medians of 6 lakes, 7.2 km north-south stream distance), indicating that the functional connectivity of the largest potential freshwater corridor networks in the conterminous US currently may be diminished compared to smaller, undammed networks. Network lakes and hubs were protected at similar rates nationally across different levels of protection (8-18% and 6-20%, respectively), but were generally more

protected in the western US. Our results indicate that conterminous US protection of major freshwater corridor networks and the hubs that maintain them generally fell short of the international conservation goal of protecting an ecologically representative, well-connected set of fresh waters ( $\geq 17\%$ ) by 2020 (Aichi Target 11). Conservation planning efforts might consider focusing on hubs, particularly in larger networks, less protected or biodiverse regions, to support connectivity for freshwater biodiversity conservation under climate change.

#### **Key Words**

Climate change, coarse-filter, connectivity, corridors, graph theory, lakes, network, protected areas, rivers, streams

53    **Introduction**

54            Connectivity is important for numerous ecological processes, including gene flow,  
55    migrations, and species range shifts, and is therefore often key for promoting ecological  
56    resilience under climate change (Heller and Zavaleta 2009). Such processes operate over a range  
57    of spatial and temporal scales from local to continental and transient to evolutionary (Littlefield  
58    et al. 2019, Armstrong et al. 2021). As habitats are increasingly lost, degraded, or fragmented,  
59    maintaining connectivity among habitats at these various spatial and temporal scales becomes  
60    particularly challenging (Fischer and Lindenmayer 2007). From a biodiversity conservation  
61    perspective, it is often critical to identify, create, or protect corridors to ensure long-term  
62    population maintenance and the potential for species range shifts under climate change (Beier &  
63    Noss 1998, Stralberg et al. 2020).

64            Corridors are natural or human-created features (habitat or non-habitat) that facilitate  
65    connectivity among two or more habitat patches (Beier & Noss 1998, Costanza and Terando  
66    2019). Numerous studies have attempted to identify corridors for conservation purposes. Many  
67    earlier studies focused on landscape-scale modeling of least cost pathways or cost surfaces for  
68    select species among core habitats (often protected areas) based on various methods including  
69    expert opinion, literature review, or observed species-habitat relationships (Beier et al. 2008,  
70    Pullinger and Johnson 2010). Similarly, other studies have applied graph theory to model  
71    connectivity across landscapes reflecting the spatial arrangement of numerous habitat patches  
72    and potential corridors across the underlying landscape (Urban and Keitt 2001, Urban et al.  
73    2009). Over time, graph-based studies have been adapted to incorporate more nuanced  
74    information on the characteristics of both patches (e.g., shape) and the landscape (e.g.,  
75    permeability gradients) (Rayfield et al. 2011).

Whereas such approaches have been successfully applied for landscape-scale conservation planning, researchers have encountered limitations when applying them at larger spatial scales, including computational constraints, inability to resolve patch characteristics (e.g., shape, habitat quality), and the fact that well-studied, candidate focal species rarely range across large spatial extents or adequately represent regional biodiversity (Theobald et al. 2012). Coarse-filter corridor mapping approaches represent a common solution to these challenges for regional- to continental-scale conservation planning, particularly when the goals are to link distant protected areas for multiple taxa (Beier et al. 2011). Such approaches build off fine-filter graph-based or least-cost approaches, but instead rely on generalized surfaces of landscape permeability as a function of natural vegetation or lack of human presence (Theobald et al. 2012). Although such larger-scale, coarse-filter studies often have to make simplifying assumptions about connectivity (e.g., that human presence is broadly representative of fine-scale features such as fences and roads that restrict movements) (Lawler et al. 2013, Nuñez et al. 2013, Belote et al. 2016), coarse-filter approaches can be useful when prioritizing efficiency, relatively mobile, larger-bodied, or generalist species, or diverse abiotic habitat conditions that promote biodiversity (Brost and Beier 2012, Krosby et al. 2014, Costanza and Terando 2019). In more recent years, some studies have also incorporated climate change projections into landscape permeability models to account for climate change effects on habitat distribution and accessibility (i.e., “climate connectivity”) (McGuire et al. 2016, Carroll et al. 2018, Parks et al. 2020).

**Advancing coarse-filter freshwater corridor mapping across lakes, streams, and rivers**

Although there is a rich and growing conservation literature on coarse-filter corridor mapping at broad spatial scales, most of this progress has occurred in the terrestrial realm. Despite the fact that the freshwater biodiversity crisis was identified decades ago (Abell 2002, Dudgeon et al. 2006), freshwater biodiversity continues to experience greater rates of endangerment and extinction than marine or terrestrial biodiversity (Collen et al. 2014, McRae et al. 2017, Williams-Subiza and Epele 2021). Many studies have demonstrated the importance of connectivity within freshwater networks for maintaining freshwater populations and community structure across taxa (Altermatt and Fronhofer 2018, de Mendoza et al. 2018, Schmera et al. 2018). Of existing freshwater corridor mapping studies, the majority has focused on river and stream networks at landscape, watershed, or regional scales, without incorporating lentic waterbodies (Collier 2011, Saunders et al. 2016, but also see Gardner et al. 2019, Harvey and Schmadel 2021).

The lack of broad-scale freshwater corridor studies across both lotic and lentic ecosystems may be explained somewhat by the dendritic nature of freshwater landscapes (i.e., networks of streams, rivers, and lakes). Freshwater networks are easily fragmented by numerous anthropogenic (e.g., impoundments, hydrologic alterations) or natural factors (e.g., flow direction, seasonal hydrology) (Erős et al. 2012, LeMoine et al. 2020), many of which are difficult to represent spatially across multiple regions. Another potential limitation is the imperfect translatability of the terrestrial graph-based approaches to freshwater networks of lakes, streams, and rivers (Nel et al. 2009, Hermoso et al. 2018). Topologically, lakes resemble nodes (i.e., patches) and streams and rivers resemble edges (i.e., corridors) in a traditional graph theory framework, but lakes, streams, or rivers may each represent preferred habitat, with others functioning as marginal habitat or corridors depending on the taxa of interest (Tonn and



Magnuson 1982, Jones 2010, Heim et al. 2019). Regardless, it is important to consider lakes, streams, and rivers together when mapping freshwater corridors due to their important structural and ecological linkages (Saunders et al. 2016, McCullough et al. 2019a, King et al. 2021a). Moreover, such freshwater networks represent the only possible corridors for strictly freshwater taxa without human intervention. In light of these facts, coarse-filter approaches focused on network structural characteristics that broadly influence connectivity among lakes, streams, and rivers may represent a promising avenue for identifying potential freshwater corridors for conservation purposes over large areas.

A concept from terrestrial graph theory that potentially translates well to fresh waters is the important role of particular nodes in maintaining structural landscape connectivity (Urban and Keitt 2001, Rayfield et al. 2011). We refer to these as “hubs”: major nodes within freshwater networks that disproportionately influence and reinforce whole-network structural connectivity (Muirhead & MacIsaac 2005) (Figure 1a). Because lakes are generally ignored in many stream and river connectivity studies, we considered lakes as nodes and streams as edges and therefore lakes as potential hubs, but recognize that it may make sense to designate stream reaches as nodes under some circumstances (e.g., regions with detailed stream habitat data or few lakes). Regardless, network fragmentation increases and whole-network connectivity is considerably reduced if hubs become compromised due to factors such as impoundments or other hydrologic alterations, water quality declines, biological invasions, or shoreline developments (Figure 1b). Terrestrial studies have demonstrated the importance of particular nodes for maintaining network structure, including stepping-stone nodes that represent lower quality habitat (Saura et al. 2014, Dilts et al. 2016). Therefore, protecting and managing hubs to maintain intact freshwater networks for lotic-associated species may be advisable, particularly in a climate change context.

For example, loss of hubs could threaten access to seasonal thermal refuges (Armstrong et al. 2021) or persistent waterbodies in dry landscapes (Jaeger et al. 2014), or the potential for species range shifts (Comte et al. 2013, Lynch et al. 2016, Ebersole et al. 2020). Future work is needed, however, to examine directly the biological importance of hubs within freshwater networks.

Finally, a major impetus for coarse-filter connectivity mapping is to identify, create, or protect corridors among protected areas (Costanza and Terando 2019). Protected areas, however, are generally focused on terrestrial biodiversity (Saunders et al. 2002, Abell et al. 2007); thus perhaps there has been less motivation for coarse-filter freshwater corridor mapping or conservation prioritization. Moreover, freshwater biodiversity and ecosystems are often poorly represented in protected areas, including across the US (Jenkins et al. 2015, Bastin et al. 2019, McCullough et al. 2019b). Notably, global protection targets for freshwater ecosystems (Aichi Target 11; CBD 2010) have been only partly achieved. In 2020, the 5th Global Biodiversity Outlook deemed Target 11 as “partially achieved”: the 17% protection target was likely achieved globally, but not necessarily based on ecologically representative, well-connected fresh waters (Secretariat of the Convention on Biological Diversity 2020). Therefore, protection of freshwater corridors may currently be insufficient in many regions and countries.

**Study objective and research questions**

Our objective was to provide a national-scale, coarse-filter assessment of freshwater corridors in the conterminous US, encompassing characteristics of freshwater networks, potential corridor networks, and their protected status with respect to the 17% Aichi conservation target. We focus on corridor networks owing to the need to link numerous local corridors to achieve regional-scale connectivity (Beier et al. 2008, Beier et al. 2011). This work builds upon the

primarily terrestrially-focused coarse-filter connectivity literature for conservation purposes by extending these practices to fresh waters and explicitly considering the role of major nodes (i.e., hubs) in corridor networks. This work also represents the first conterminous US-wide analysis of freshwater corridor protection, another topic that has been a major focus in the terrestrial realm. Specifically, we asked:

1. What freshwater networks can best represent freshwater corridor networks?
2. What lakes represent freshwater network hubs?
3. How well protected are these freshwater corridor networks and hubs?

Generally, we expected most freshwater networks to be relatively small, heavily dammed, and susceptible to fragmentation, limiting the availability of regional freshwater corridor networks in the conterminous US. We also expected hub lakes to be more prevalent in regions with more lakes overall and for protection of hub lakes and freshwater corridor networks to fall below the 17% Aichi target nationally, except in the western US where large protected areas are concentrated. This analysis represents an important step for freshwater biodiversity conservation in a climate change context and is intended to facilitate future biodiversity-centered work including observations of species and genetic diversity, as well as important processes of gene flow, migrations, and range shifts.

## Methods

### Freshwater connectivity metrics and scoring criteria

A challenge associated with assessing conterminous US-scale freshwater connectivity is obtaining data at ecologically appropriate resolutions across such a large spatial extent. We applied a novel, conterminous US-scale dataset, LAGOS-US-NETWORKS v1.0, that represents

graph-based freshwater networks with lakes as nodes and streams as edges (King et al. 2021b, c). This dataset contains 86511 on-network lakes  $\geq 1$ ha in surface area and approximately 39.5 million stream reaches that comprise a total of 898 networks (Fig 2a). Lakes were defined as permanent, lentic waterbodies  $\geq 1$ ha (both natural lakes and reservoirs) with a geographically defined polygon in the National Hydrography Dataset v2 (Cheruvelil et al. 2021, Smith et al. 2021). LAGOS-US-NETWORKS also includes on-network dams ( $n = 48777$ ) and metrics for the number of total dams within each network and the number of upstream or downstream dams from individual lakes. We calculated additional connectivity metrics described below using all pairs of connected lakes and the stream distances connecting them.

In our representation of freshwater networks, edges were weighted by the total stream course distance (km) and were undirected connections between pairs of nodes such that travel through each network was irrespective of streamflow direction. Subsequently, we analyzed the relationship among nodes within networks using several metrics that broadly represented the density of edges and nodes, accessibility of nodes, susceptibility of networks to fragmentation, and climatic heterogeneity within networks (Table 1). All network connectivity metrics were calculated using the igraph R package (Csardi & Nepusz 2006). We prioritized variables that reflected these phenomena to represent coarse-filter structural connectivity in a climate change context. Although we recognize that only relatively mobile taxa are potentially capable of traveling throughout larger networks (e.g., to reach cooler habitats at higher latitudes), many of our connectivity metrics (e.g., susceptibility to fragmentation, distances between nodes) are also relevant to slow-dispersing taxa whose resilience under climate change relies more on localized movements. Therefore, a coarse-filter structural connectivity analysis of these networks

generally represents a useful step for freshwater biodiversity conservation in a climate change context.

Coarse-filter, broad-scale connectivity studies in the terrestrial realm often require simplifying assumptions at this scale (e.g., that snapshot metrics of generalized human presence reflect landscape permeability; Theobald et al. 2012). Therefore, in the freshwater realm, we made various, similar assumptions about what our freshwater connectivity metrics represent at the scale of the conterminous US. Such assumptions may require revision for studies at finer spatial scales when different data are available or for specific taxa of interest. Specifically, we assumed static hydrology (i.e. not accounting for seasonal or interannual variation) and that all dams are structurally similar and well represented across the US, and we do not include fine-scale barriers such as waterfalls, culverts, or slope gradients. We also did not account for networks that crossed international borders due to data constraints.

We integrated the various freshwater connectivity metrics (described and defined in Table 1) into a composite network connectivity score that could easily be compared across networks using a principal component analysis (PCA). We only performed this analysis for networks with  $> 4$  lakes ( $n = 385$ ); however, we excluded the Mississippi River network due to its exceptional size (containing 37.9% of all network lakes). Prior to the PCA, dam rate and percent articulation points were rescaled such that higher values represented fewer barriers and greater resistance to network fragmentation, respectively (and therefore greater overall connectivity). We then rescaled all input variables (mean of 0 and standard deviation of 1) before PCA calculations. We used 2 principal components, which explained 60% of variation in the data, to calculate connectivity scores. We opted to use 2 components based on agreement between the Kaiser criterion and Horn's parallel analysis for component retention (Dinmo 2018).

To facilitate usefulness of our study for management and policy decision-making processes, we analyzed freshwater connectivity scores across 9 ecoregions used by the US Environmental Protection Agency National Aquatic Resource Survey (NARS) (Herlihy et al. 2008) (Figure 2b). For networks that spanned multiple ecoregions, we assigned ecoregions based on the majority of nodes within those networks.

**Hub lake determination**

Conceptually, hubs within a freshwater network are vital for maintaining connectivity across large expanses. Hub lakes were determined based on individual metrics of lake nodes within networks. We defined hub lakes as lakes that were articulation points in their network and were in the top quintile of total node strength and betweenness centrality within their network (Figure 3). Hence, each network with  $\geq 5$  lakes will contain at least one hub lake using our definition as long as an articulation point exists in the network. Articulation points are by definition bridges among two or more subnetworks, meaning that an organism must travel through an articulation point to move aquatically from one subnetwork to another. High node strength for a lake indicates that it connects a high total network distance among lakes, whether through a multitude of short streams or a handful of long streams. Lakes with high betweenness centrality have shorter aquatic travel distances crossing through them and are more likely to be stepping stones for organisms moving within a network. Combined, these metrics indicate a lake that is necessary for network movement and connects long distances while being a more likely path for biota than other lakes in a network. Finally, although we did not differentiate between natural lakes and reservoirs in aforementioned connectivity metrics, we reported differences in the prevalence of hubs between natural lakes and reservoirs for waterbodies  $\geq 4$  ha.

## **Analysis of protected networks, network lakes, and hub lakes**

Defining protected freshwater ecosystems depends on different levels of legal protection. Therefore, we considered both strict (i.e., managed for biodiversity; Gap Analysis Program (GAP) status 1-2) and multi-use (i.e., managed for both biodiversity and natural resource extraction; GAP status 1-3) protection (Fig 2c) in the US Protected Areas Database v2.0 (US Geological Survey 2018). We also considered protection based on lakes occurring within protected areas (i.e., based on lake centers) and on at least 80% of lake watersheds occurring within protected areas given the importance of watersheds for maintaining freshwater habitats (sensu McCullough et al. 2019b). Under these different definitions of protection, the narrowest is based on strict 80% watershed protection, whereas the loosest is based on lake centers occurring within either strict or multi-use protected areas. Watersheds were based on LAGOS-US-LOCUS v1.0 (Cheruvelil et al. 2021, Smith et al. 2021). Using these definitions, we calculated the percentage of lakes in each network currently protected. Similarly, we analyzed current protection of hub lakes using these same definitions and compared protection of hub lakes to protection of all network lakes. We also compared natural log-transformed network connectivity scores to proportions of networks protected under all definitions of protection using Pearson's correlation coefficients. Finally, we analyzed protection status of whole networks, network lakes, and hub lakes with respect to the 17% Aichi target both nationally and by NARS ecoregions.

All data, metadata, and R analysis scripts are currently available at <https://github.com/cont-limno/TripleC>. We used R version 4.0.4 for analyses (R Core Team 2021). Upon publication, this repository will be permanently archived in a publicly accessible online location and cited in our methods.

**Results**

**Freshwater network characteristics**

Of the 898 freshwater networks across the conterminous US, most were relatively small (medians of 3 lakes, 5.6 km N-S stream distance, and 1 dam). In contrast, larger networks were relatively rare: just 10.0% and 7.6% of networks contained at least 50 lakes or spanned at least 100 km of N-S stream distance, respectively. The Mississippi River network contained 37.9% of all network lakes (32811 lakes) and 51.2% of all network dams (24986 dams). Larger networks also tended to have more dams: number of dams was positively correlated with number of lakes and N-S stream distance across all networks (Pearson’s  $r = 0.94$  and  $0.74$ , respectively,  $p < 0.001$ ) (excluding the Mississippi River network). Aside from dams, larger networks were also generally more susceptible to fragmentation: 32.8% of network lakes were articulation points in networks with  $> 3$  lakes, whereas this value was 18.5% across all networks (Table S1). Similarly, maximum N-S stream connectivity within networks was also susceptible to fragmentation with a median of 1 network cut necessary to undermine the full latitudinal breadth of all networks, as well as those with  $> 3$  lakes. Freshwater network statistics across NARS ecoregions are reported in Table S1. In summary and as expected, our analysis of freshwater networks across the conterminous US indicates that most networks are relatively small and that larger networks generally have more dams and are structurally more susceptible to habitat fragmentation. In other words, the large networks potentially able to represent regional freshwater corridor networks are relatively few in number, heavily dammed, and particularly prone to habitat fragmentation.

**Hub lakes: distribution and characteristics**



We identified 2080 hub lakes across the conterminous US, representing 2.4% of network lakes (Table S1, Figure 4a). This percentage varied marginally across most ecoregions, but was just 0.1% in the Northern Plains (NPL) ecoregion and 1.5 - 3.6% across all other ecoregions. Across NARS ecoregions, abundance of hub lakes was positively correlated with abundance of networks (Pearson's  $r = 0.79$ ,  $p = 0.01$ ). Hubs were generally most abundant in the 3 ecoregions with the most networks (Central Plains (CPL): 528 hubs, Northern Appalachians (NAP): 451 hubs, Upper Midwest (UMW): 260 hubs). Ecoregions with fewer networks were generally dominated by the Mississippi River network and also had generally fewer hubs (NPL: 28 networks/5 hubs, Southern Appalachians (SAP): 10 networks/295 hubs, Southern Plains (SPL): 8 networks/103 hubs, Temperate Plains (TPL): 58 networks/190 hubs). In the western US, which is mostly outside the Mississippi River network, the Western Mountains (WMT) and Xeric (XER) ecoregions had 169 and 79 hubs, respectively. Overall, hub lakes were found throughout the conterminous US, but were generally more abundant in regions with more freshwater networks, consistent with our expectations.

Of all 2080 hub lakes, 1616 (77.7%)  $\geq 4$  ha could be classified as either reservoirs or natural lakes, of which 1168 (72.3%) were reservoirs and 448 (27.7%) were natural lakes. Therefore, hub lakes were considerably more likely to be reservoirs than the general population of lakes; 43.5% of 137465 lakes in the conterminous US  $\geq 4$  ha are classified as reservoirs. Of the 246 networks with hub lakes, just 27 networks (11.0%) had no dams. We found that 357 (21.5%) and 6 (0.4%) hub lakes (excluding the Mississippi network) had one dam or multiple dams directly on the lake, respectively. Additionally, even if a dam was not directly on a hub lake, there were 0 - 301 dams upstream and 1 - 18 dams downstream from hub lakes within the network, respectively. Hub lake surface area was a median of 15.4 ha (min = 1.0 ha; max =

107534.6 ha; Figure S3) compared with a median surface area of 4.0 ha (min = 1.0 ha; max = 129612.0 ha) for all network lakes.

**Network connectivity scores**

Network connectivity scores followed a left-skewed distribution (Figure 4a, b, S2). Of the 385 assessed networks with > 4 lakes (excluding the Mississippi River network), 286 (67.5%) received scores < 2 (low), 112 (29.1%) received scores between 2 and 4 (medium), and 13 (3.4%) received scores > 4 (high). In general, networks received high, medium, and low scores throughout the conterminous US, but greater concentrations of high-scoring networks were found in the western US (Figure 4a, b). Of the 13 networks with high scores, there were 3 in the WMT ecoregion, 2 each in the CPL, SAP, SPL, and XER ecoregions, and 1 each in the NAP and UMW ecoregions (Table 2). The 3 highest-scoring networks were the Colorado River (WMT), Rio Grande (SPL), and Columbia River (WMT) networks. The NPL and TPL ecoregions had no high-scoring networks. Connectivity scores and network characteristics for all 385 scored networks are provided in Table S2.

High-scoring networks were generally larger and contained more lakes and dams (Tables 2, S2). The 13 highest-scoring networks spanned 29.3 - 1330.3 km stream distance N-S (median = 498.6 km) and had 15 - 3241 lakes (median = 1303 lakes) and 0 - 1760 dams (median = 454 dams). Conversely, low- to medium-scoring networks ranged 0.9 - 553.9 km of stream distance N-S (median = 22.4 km) and had 5 - 2604 lakes (median = 13 lakes) and 0 - 1612 dams (median = 4 dams). Similarly, dam rate ranged 0.0 - 88.6% (median = 47.1%) across high-scoring networks and ranged 0.0 - 269.2% (median = 33.3%) across low- to medium-scoring networks. Dam rate was 100% or greater (i.e., at least as many dams as lakes) in 21 (5.5%) of scored

networks. Just 66 (17.1%) of scored networks contained no dams, but these networks were relatively small in terms of lakes (5 - 64 lakes; median = 6 lakes) and N - S stream distance (0.9 - 186.4 km; median = 7.2 km). Finally, high-scoring networks had 0 - 72 hub lakes (median = 24) and low- to medium-scoring networks had 0 - 46 hub lakes (median = 1).

### **Protection of freshwater networks, network lakes, and hub lakes**

Whole freshwater networks are poorly protected across the conterminous US (Tables 3, S3, Figure 5). Median network protection was 0.0% across all networks, except under the loosest definition of protection (14.4%; strict + multi-use, lake center protection) (Figure 5a, c). Fully protected networks were relatively rare and varied across definitions of protection (28 - 122 networks; 3.1 - 13.6% of networks). Under the narrowest and loosest definitions of protection, the WMT (10.1%, 22.0%), CPL (3.3%, 19.8%), and XER (2.3%, 22.1%) ecoregions had the highest rates of full network protection, respectively, and the SAP and SPL ecoregions had no fully protected networks based on any definition of protection. Approximately 13.4 - 47.6% of networks had at least 17% of their lakes protected from the narrowest to loosest definitions of protection, respectively. Across all ecoregions, the CPL ecoregion had the highest number of networks meeting the 17% Aichi target based on lake center protection, whereas the UMW, WMT, and XER ecoregions had the highest, most consistent percentage of networks meeting the 17% Aichi target across all definitions of protection. The SAP and SPL ecoregions consistently had the fewest networks meeting the 17% Aichi target across definitions of protection. The Mississippi River network, approximately 10 times larger than the next-largest network in terms of number of lakes, was 4.3 - 15.1% protected across all definitions of protection. Additionally, network connectivity scores (natural log-transformed) were not correlated with the percent of

network protection under all definitions of protection (absolute Pearson's  $r < 0.1$ ,  $p = 0.21 - 0.72$ ). Overall, although whole network protection varied widely across ecoregions and definitions of protection, most networks were poorly protected as a whole and there is little association between freshwater connectivity and protection. As expected, however, protection rates of whole networks were generally greater in the western US.

Across all network lakes, protection varied from 8.2 - 18.4% from the narrowest to loosest definition of protection (Table S4). Therefore, lake protection in the conterminous US only narrowly met the 17% Aichi target under a generous definition of protection. Network lake protection varied across ecoregions from a low of 0.8% in the SAP and TPL ecoregions to highs of 55.6% in the NPL and 61.4% in WMT ecoregions under the narrowest and loosest definitions of protection, respectively. The WMT and NPL ecoregions were the only ecoregions that met the 17% Aichi target across all definitions of protection. In contrast, The CPL, NAP, SAP, SPL, TPL, and XER ecoregions did not meet the 17% Aichi target under any definition of protection and were often near or below 5% protection. The UMW ecoregion met the 17% Aichi target only when considering both strict and multi-use protected areas.

Of the 2080 hub lakes in the conterminous US, 118 (5.7%) and 413 (19.8%) were protected under the narrowest and loosest definitions of protection, respectively, similar to protection levels of all network lakes (Figure 5b, d, Table S4). Therefore, the 17% Aichi target was only met for hub lakes under the loosest definition of protection. Across ecoregions, the WMT (36.1%), UMW (8.8%), and TPL (3.2%) ecoregions had the highest rates of hub lake protection under the narrowest definition of protection, whereas the WMT (68.0%), UMW (30.0%), and XER (31.6%) ecoregions had the highest rates of hub lake protection under the loosest definition of protection. These results were broadly consistent with our expectation of

greater hub lake protection in the western US. The WMT ecoregion actually had a slightly higher hub lake protection rate under strict + multi-use 80% watershed protection (69.8%) than lake center protection, indicating that a few hubs themselves were not protected, but their watersheds largely were. Notably, the NPL ecoregion had only 5 hub lakes, one of which was protected based on both strict and multi-use lake center protection.

## Discussion

### Freshwater connectivity and dams

We found that the networks with the highest structural connectivity scores tended to be geographically expansive (median = 498.6 km north-south), but with higher dam rates (median = 47.1%). Presumably, dams represent human-made barriers within freshwater corridor networks. Aside from the 12 of 13 networks with high connectivity scores despite dams, the 66 smaller, undammed networks (median = 7.2 km N-S stream distance) provide relatively unimpeded localized corridor networks for organisms and species to move throughout networks. Importantly, many undammed networks were found along the West, East, and Great Lakes Coasts (Figure S1). These networks are important for many species, particularly diadromous fishes that use both fresh and saltwater for different life stages, and potamodromous fishes that use both the Great Lakes and inland waters for various life stages (D'Amelio et al. 2008, Hall et al. 2011). Nonetheless, our broad-scale analysis suggests that the largest freshwater corridor networks in the conterminous US generally contain abundant dams and may therefore limit functional connectivity, particularly for long-distance migrations and species range shifts under climate change.

Another important component of maintaining open freshwater corridor networks is maintaining hubs. Our finding that most hub lakes were reservoirs (72.3%) is not surprising, as reservoirs tend to fall on large rivers and are therefore likely central in freshwater networks. This suggests that connectivity within many networks may be considerably compromised due to the location of dams on or near hub lakes. Likewise, the 27 hub lakes currently within undammed networks may be of high conservation value for maintaining connectivity (Figure S1). Conversely, dams can facilitate biological invasions within networks by altering habitat (Johnson et al. 2008), which is an important consideration when reservoirs are central nodes in many networks. Although outright removal of large reservoir dams is often societally challenging or unfeasible, connectivity mitigation measures (e.g., fish ladders, lifts) or dam modifications to enhance natural flow regimes at or near hubs could help restore some functionality in freshwater corridor networks (Renöfält et al. 2009, Muir & Williams 2012, McKay et al. 2013).

**Graph theory applications for freshwater conservation**

Graph theory has previously been applied toward conservation in river networks (Erös et al. 2011, Erös & Lowe 2019), including to predict current and future species' ranges (Chaput-Bardy et al. 2017), but few studies have applied a similar framework to lakes (Saunders et al. 2016). Thus, our integration of both lake and stream variables in quantifying overall freshwater network connectivity represents a novel, coarse-filter approach to identifying potential freshwater corridor networks across multiple regions of the conterminous US. This repeatable approach leverages publicly available data and can be adjusted to accommodate specific taxa of interest or new or different connectivity variables at different spatial or temporal scales.

A way in which our work advances graph theory applications for freshwater ecology and conservation is through the use of hubs, which in our case were major lake nodes that disproportionately influenced freshwater network structure. The concept of hubs in freshwater ecology (Muirhead and MacIsaac 2005, Bishop-Taylor et al. 2015) or general landscape ecology (Minor & Urban 2008) as highly connected nodes is not new, but our characterization using multiple axes of lake-stream network analysis allows for a unified definition across all freshwater networks in the conterminous US and could be similarly applied elsewhere. Critical nodes, conceptually similar to hubs, have been previously identified for river networks, but without consideration of lakes (Sarker et al. 2019). Analogous efforts to identify important nodes have a longer history for terrestrial landscapes (e.g., Estrada & Bodin 2008, Saura & Rubio 2010), which have also often included ecological attributes of nodes (Saura & Torné 2009) unlike our species-neutral hub identification. “Stepping stone” characterization has been previously quantified using betweenness centrality (Zetterberg et al. 2010) and articulation points (Keitt et al. 1997), and our usage of total node strength is an extension of using the degree of a node with the added information of the distance of those connections. Thus, our multi-metric approach to identifying lakes within a network that are potentially more important for maintaining corridor networks across large expanses extends past research and can help prioritize individual locations for conservation, particularly when whole-network conservation is impractical.

#### **Implications for conservation planning under climate change**

Whereas all freshwater corridor networks can potentially play important roles in supporting the resilience of biodiversity under climate change, many such networks in the

463 conterminous US are relatively small, contain many dams, and are susceptible to fragmentation.  
464 The relatively small number of large corridor networks, which are likely the only networks  
465 capable of supporting regional-scale migrations or species range shifts under climate change,  
466 generally are even more heavily dammed and structurally prone to fragmentation. Moreover,  
467 most freshwater corridor networks are currently poorly protected, not only falling short of the  
468 17% Aichi target under most types of protection, but particularly so in regions with high  
469 freshwater biodiversity (i.e., southern, central, and eastern US). These findings indicate that  
470 considerable conservation effort may be required to facilitate important phenomena such as gene  
471 flow, migrations, and range shifts for freshwater biodiversity in the conterminous US. Given  
472 limited or unpredictable resources for conservation, prioritizing the monitoring and protection of  
473 network hubs could represent a relatively efficient strategy for maintaining freshwater corridor  
474 networks, but our analysis shows that current protection levels of hub lakes are not only similar  
475 to all network lakes in general, but are also relatively low (19.9%; only meeting the 17% Aichi  
476 target under combined strict and multi-use, non-watershed protection). Managers might consider  
477 prioritizing hub ecosystems for future conservation given that maintaining these lakes would  
478 help promote network functionality. Additionally, regular monitoring of network hubs may assist  
479 in water quality maintenance and early detection of aquatic invasive species within networks.

480         The 2020 assessment of progress toward the 17% Aichi conservation target for fresh  
481 waters identified current gaps in ecological representation and connectivity globally. Our  
482 analysis reinforces the notion that current US protected areas do not contain an ecologically  
483 representative portfolio of fresh waters (Jenkins et al. 2015, McCullough et al. 2019b), but also  
484 shows that considerable work is still needed to promote and improve protection of freshwater  
485 connectivity. Under a changing climate, ensuring functional connectivity for freshwater



biodiversity is a key priority. Across the 13 high-scoring freshwater networks, 4 networks met the 17% Aichi target across all definitions of protection, 6 networks did not meet the target under any definition of protection, whereas results were mixed for the remaining 3 networks. This generally reflects the concentration of large protected areas in the western US. For example, the Savannah-Santee, Suwannee River, and James River networks in the eastern US (ranked #7, 9 and 11 nationally by connectivity score, respectively; Figure 4a, b) are 0.0 - 5.2% protected across all definitions of protection (Table 2). In contrast, the 3 highest-scoring networks in the WMT ecoregion (Colorado River, Columbia River, and San Francisco Bay networks, ranked #1, 2, and 4, respectively) were 32.5 - 72.6% protected across all definitions of protection. These findings not only reinforce the previously identified national-scale mismatches between protected areas and freshwater biodiversity (Jenkins et al. 2015), but also indicate regional mismatches between protected areas and freshwater connectivity in the southern, central, and eastern US (Fig 3). On the positive side, however, overlap between freshwater biodiversity and several large freshwater corridor networks in these regions suggests that efforts to maintain or enhance these corridor networks could help support populations and the resilience of regional freshwater biodiversity to climate change (e.g., facilitate seasonal migrations and range shifts). Moreover, conservation prioritization of hub lakes may be disproportionately more beneficial and cost-effective for conservation under climate change as generalized percent network protection targets (17% or otherwise) given their large effects on network intactness.

We envision our data, concepts of freshwater corridor networks and hubs, and analytical approach making foundational contributions to future conservation efforts, including fully data-driven systematic conservation planning or more participatory structured decision-making involving managers and stakeholders. Our use of basic computational techniques (i.e., PCA) and

public data at scales of both individual lakes and whole lake-stream networks creates flexibility for future studies to integrate other relevant datasets at different spatial and temporal scales or to tailor their approaches to species, taxa, or functional groups of interest. Our coarse-filter approach targeting generalized structural connectivity in a climate change context is only one example of many potential applications. For example, studies interested in restoring anadromous fish migrations could integrate a similar structural connectivity scoring approach with more localized data on features such as waterfalls and culverts to identify networks most likely to benefit from interventions to enhance connectivity. Additionally, studies interested in maintaining access to permanent waterbodies in dry climates could integrate structural connectivity data with seasonal hydrology or other habitat data (e.g., lake or stream depth). Moreover, there is potential to analyze the joint freshwater-terrestrial conservation benefits of freshwater corridor networks, given that riparian areas often represent terrestrial corridor networks (Krosby et al. 2018) and regulate water temperature, chemistry, and physical habitat characteristics (Johnson and Almlof 2016). Although such efforts are beyond the scope of this current study, our study and approach demonstrate the potential for future connectivity studies to help advance conservation planning under climate change, particularly for freshwater biodiversity and ecosystems.

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Tables

Table 1. Description of network-scale freshwater connectivity metrics and ecological justification for their use in broad-scale freshwater corridor identification

Variable name	Description	Ecological Justification
Edge density	Ratio of actual stream reaches (edges) connecting lakes to the maximum number of potential stream reaches	Represents availability of pathways for traveling among lakes within a network
Average lake distance (km)	Average stream-course distance between lakes (nodes)	Represents density and accessibility of lakes within a network
Dam rate	Density of dams within a network, calculated as the ratio between the number of lakes (nodes) and number of dams; rescaled such that higher values penalize network connectivity	Represents connectivity barriers within networks Represents more localized climatic heterogeneity accessible within a network for both relatively mobile and sessile species
Elevation range (m)	Maximum minus minimum elevation among network nodes	Represents large-scale climatic heterogeneity accessible within a network for relatively mobile species
Maximum north-south distance (km)	Maximum north-south distance spanned by the network based on lake and stream connections	
Minimum cuts	Minimum number of stream reaches (edges) to cut needed to separate the network into multiple networks (i.e., undermine maximum north-south distance)	Represents susceptibility of a network to fragmentation, particularly in climatic context for relatively mobile species
Percent articulation points	The percent of lakes (nodes) in the network that are articulation points, which are the lakes in the graph that when disconnected lead to separation into multiple networks; rescaled such that higher values represent greater resistance to network fragmentation	Represents susceptibility of a network to fragmentation
Average betweenness centrality	The number of shortest-distance pairwise stream paths in a network that pass through a lake (node), which we averaged across network lakes after normalization by the number of lakes within a network (N) using the formula $(2BC)/(N*N-3N+2)$ .	Represents lake importance according to position within a network and the convergence of stream pathways

Table 2. Freshwater network connectivity scores and statistics and protection status of networks and hub lakes in the conterminous US for high-scoring networks

Rank	Score	Network	Ecoregion	Lakes	Hubs	Dams	Dam rate*	North-South distance (km)
1	12.02	Colorado River	WMT	2027	42	954	47.1%	1,330.34
2	9.49	Rio Grande	SPL	536	13	388	72.4%	1,312.70
3	8.10	Columbia River	WMT	2397	55	915	38.2%	820.36
4	6.70	San Francisco Bay	WMT	1780	49	484	27.2%	629.52
5	6.21	Brazos River	SPL	1529	22	1273	83.3%	611.93
6	5.67	Susquehanna-Hudson	NAP	2659	71	1099	41.3%	505.40
7	5.19	Savannah-Santee	CPL	3241	72	1760	54.3%	491.73
8	5.19	Potomac River	SAP	420	9	372	88.6%	238.12
9	4.94	Suwannee	CPL	1076	38	268	24.9%	245.86
10	4.84	Red River	UMW	754	16	250	33.2%	380.41
11	4.40	James River	SAP	765	24	424	55.4%	173.63
12	4.03	Lake Creek	XER	15	0	0	0.0%	29.30
13	4.01	Humboldt River	XER	21	1	43	204.8%	146.39

\*Dam rate = number of dams/number of lakes. CPL=Coastal Plains, NAP=Northern Appalachians, NPL=Northern Plains, SAP=Southern Appalachians, SPL=Southern Plains, TPL=Temperate Plains, UMW=Upper Midwest, WMT=Western Mountains, XER=Xeric. Strict protection=managed for biodiversity (GAPS 1-2), multi-use=managed for biodiversity and natural resource extraction (GAP 3)

Table 3. Protection status of networks and hub lakes in the conterminous US for high-scoring networks

Rank	Network	Network protection		Strict, 80% watershed	Strict + multi-use, 80% watershed	Hub protection		Strict, 80% watershed	Strict + multi-use, 80% watershed
		Strict, lake center	Strict + multi-use, lake center			Strict, lake center	Strict + multi-use, lake center		
1	Colorado River	41.1%	68.9%	39.1%	72.6%	26.2%	83.3%	26.2%	76.2%
2	Rio Grande	17.2%	30.4%	11.2%	30.0%	0.0%	23.1%	0.0%	30.8%
3	Columbia River	36.3%	67.0%	32.5%	67.0%	12.7%	43.6%	16.4%	47.3%
4	San Francisco Bay	52.9%	65.3%	51.5%	62.4%	46.9%	59.2%	42.9%	46.9%
5	Brazos River	1.8%	2.4%	0.9%	1.0%	22.7%	22.7%	9.1%	9.1%
	Susquehanna-								
6	Hudson	5.3%	11.7%	11.9%	15.8%	12.7%	19.7%	4.2%	9.9%
7	Savannah-Santee	1.8%	2.7%	0.6%	1.2%	6.9%	6.9%	0.0%	0.0%
8	Potomac River	5.2%	11.7%	5.5%	10.0%	11.1%	33.3%	11.1%	22.2%
9	Suwannee	0.5%	1.2%	0.0%	0.2%	2.6%	7.9%	0.0%	0.0%
10	Red River	17.1%	23.9%	3.3%	4.4%	18.8%	18.8%	6.3%	12.5%
11	James River	2.7%	5.2%	0.7%	3.0%	0.0%	8.3%	0.0%	0.0%
12	Lake Creek	6.7%	53.3%	0.0%	20.0%	NA	NA	NA	NA
13	Humboldt River	28.6%	47.6%	23.8%	76.2%	0.0%	0.0%	0.0%	100.0%

CPL=Coastal Plains, NAP=Northern Appalachians, NPL=Northern Plains, SAP=Southern Appalachians, SPL=Southern Plains, TPL=Temperate Plains, UMW=Upper Midwest, WMT=Western Mountains, XER=Xeric. Strict protection=managed for biodiversity (GAPS 1-2), multi-use=managed for biodiversity and natural resource extraction (GAP 3)

## Figure Captions

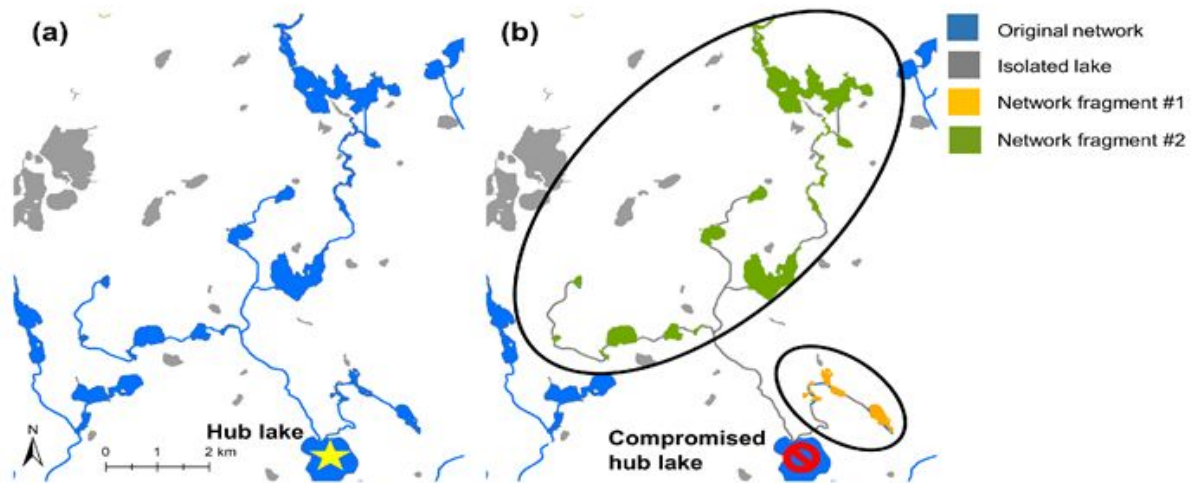
**Figure. 1.** Freshwater connectivity in Michigan, USA based on (a) an intact network with an operational hub lake and (b) a compromised hub lake, which results in network fragmentation and possible upstream habitat loss for freshwater biodiversity. Upstream streams are grayed out in (b) to represent loss of stream habitat. Isolated lakes are not accessible through networks.

**Figure. 2.** (a) Freshwater networks of the conterminous US based on LAGOS-US-NETWORKS v1.0 (King et al. 2021 b, c). Contiguous colors represent individual networks (the largest of which is the Mississippi River basin in green in the central US). Shown are 898 unique networks containing a total of 86511 lakes  $\geq 1$  ha. (b) Ecoregions used by the US Environmental Protection Agency National Aquatic Resource Survey (Herlihy et al. 2008). CPL=Coastal Plains, NAP=Northern Appalachians, NPL=Northern Plains, SAP=Southern Appalachians, SPL=Southern Plains, TPL=Temperate Plains, UMW=Upper Midwest, WMT=Western Mountains, XER=Xeric. (c) Strict (managed for biodiversity; GAPS 1-2) and multi-use (managed for biodiversity and natural resource extraction; GAP 3) protected areas based on the US Protected Areas Database v2.0 (US Geological Survey 2018).

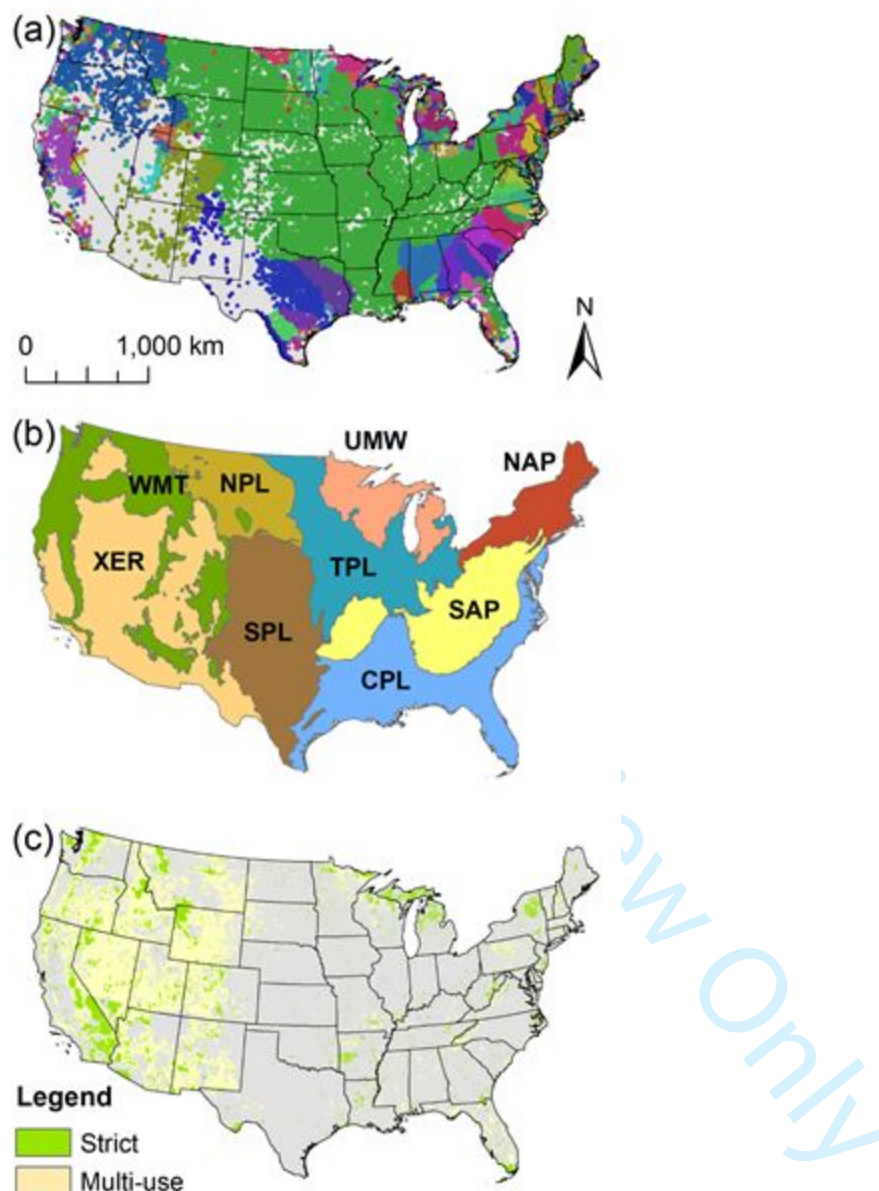
**Figure. 3.** Graphical depiction of a hypothetical network showing the three network metrics used to define a hub lake: (a) vertex strength of each lake colored by quintile, (b) betweenness centrality of each lake colored by quintile, (c) lakes that are articulation points outlined in green and showing the subnetworks created by the removal of the central lake marked by “X”. Hub lakes for the network (d) are those that are in the top quintile of vertex strength, the top quintile of betweenness centrality, and are articulation points.

**Figure. 4.** (a) Freshwater network connectivity scores (for networks > 4 lakes) and hub lakes (n = 2080). The Mississippi River network (unscored) is shown in light blue dots. (b) Highest-ranking freshwater network connectivity scores. Unique mapped colors represent individual, contiguous networks with high connectivity scores (n = 13), which are ranked by connectivity score (1 = highest).

**Figure. 5.** Percent of freshwater networks (lakes within networks) and hub lakes protected by NARS ecoregion and different levels of protection. The Mississippi River network (considered separately) has 7.6% and 15.1% of its lakes protected, respectively, under strict and strict + multi-use lake center protection (a), and 4.3% and 13.8% of its lakes protected, respectively, under strict and strict + multi-use 80% watershed protection, respectively (c). Mississippi River network hubs are reflected in (b) and (d). Dashed lines represent the 17% Aichi conservation target. See Table S1 for number of networks and hub lakes per ecoregion. CPL=Coastal Plains, NAP=Northern Appalachians, NPL=Northern Plains, SAP=Southern Appalachians, SPL=Southern Plains, TPL=Temperate Plains, UMW=Upper Midwest, WMT=Western Mountains, XER=Xeric.

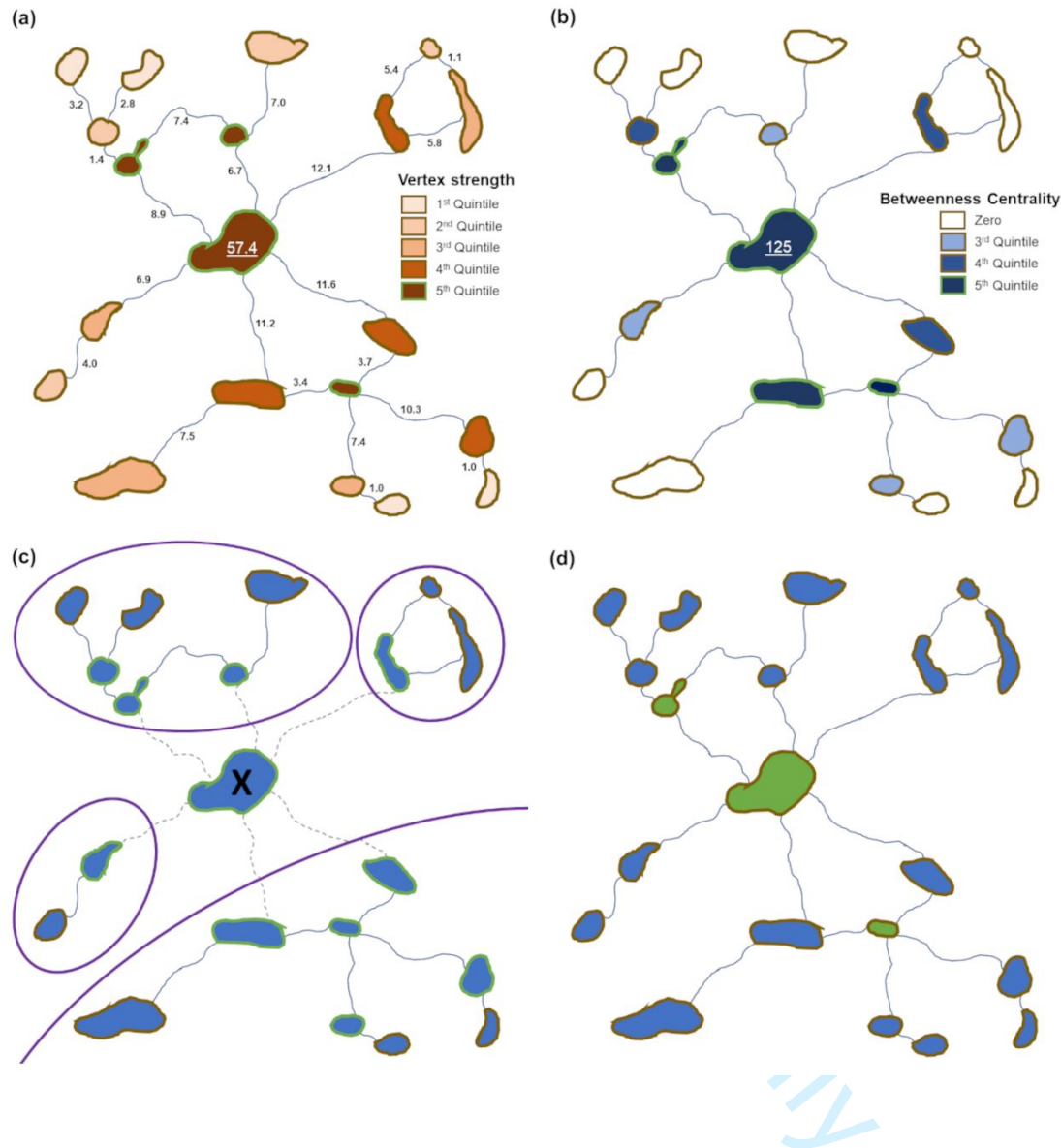
**Figures**

**Figure. 1.** Freshwater connectivity in Michigan, USA based on (a) an intact network with an operational hub lake and (b) a compromised hub lake, which results in network fragmentation and possible upstream habitat loss for freshwater biodiversity. Upstream streams are grayed out in (b) to represent loss of stream habitat. Isolated lakes are not accessible through networks.



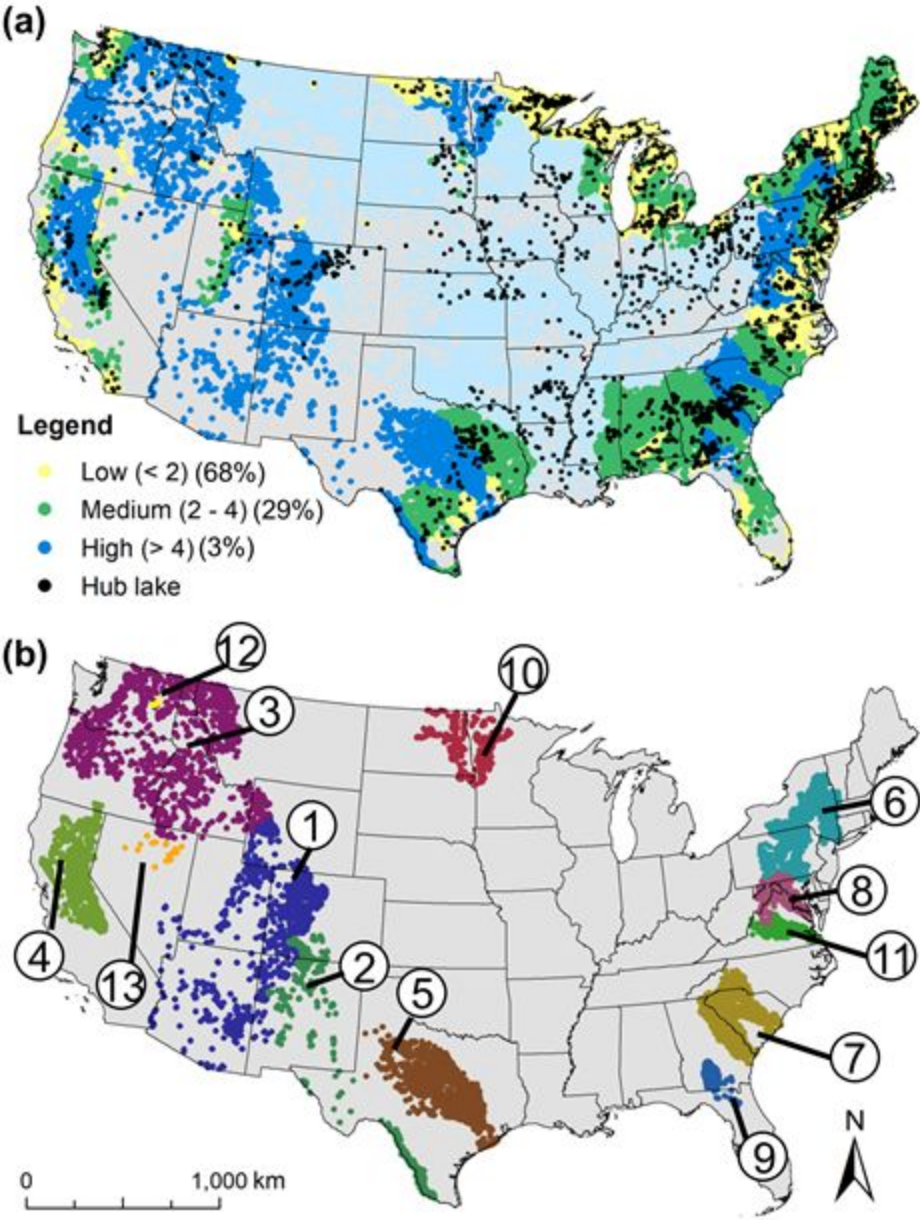
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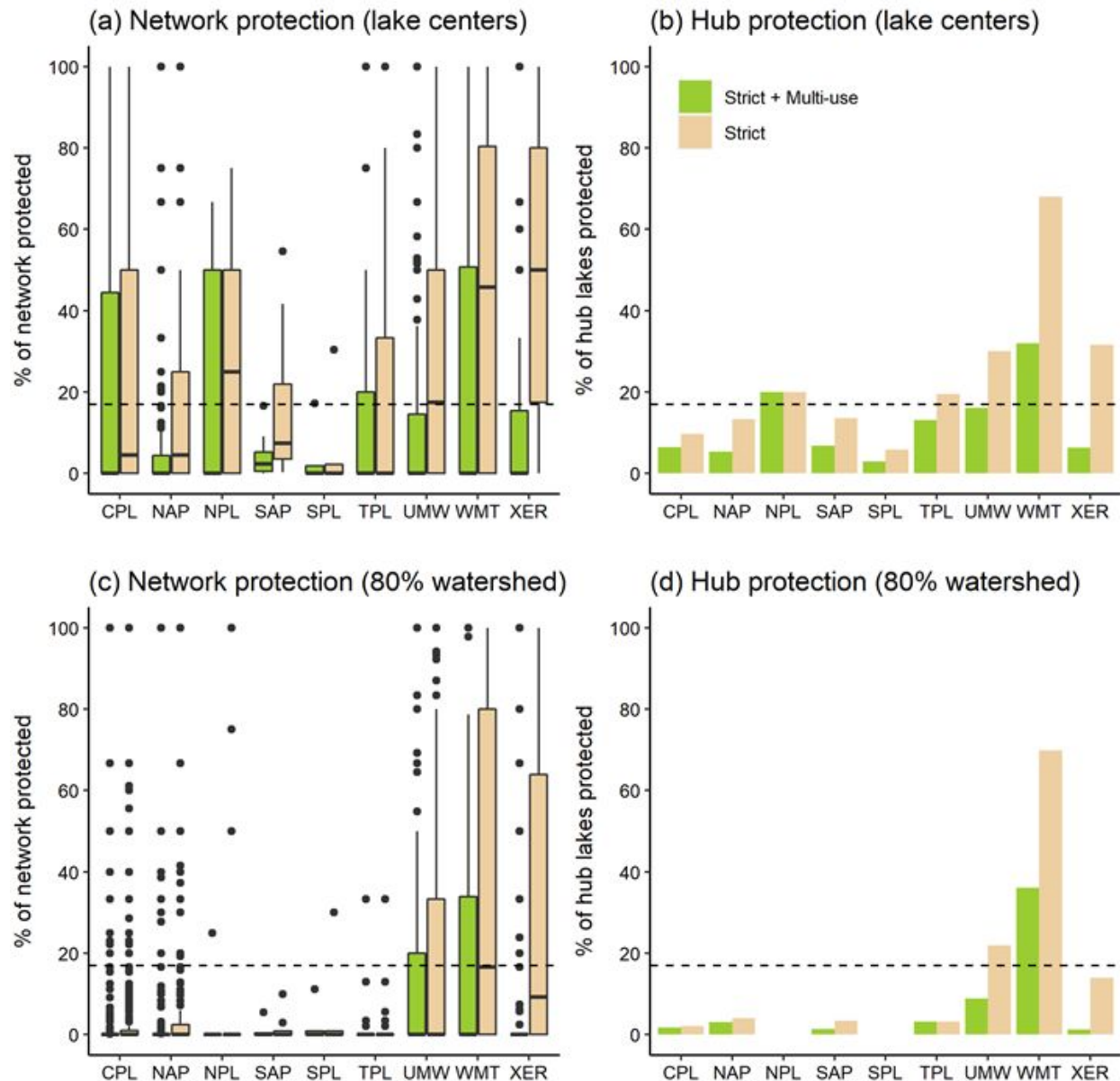


**Figure 3.**

Graphical depiction of a hypothetical network showing the three network metrics used to define a hub lake: (a) vertex strength of each lake colored by quintile, (b) betweenness centrality of each lake colored by quintile, (c) lakes that are articulation points outlined in green and showing the subnetworks created by the removal of the central lake marked by "X". Hub lakes for the network (d) are those that are in the top quintile of vertex strength, the top quintile of betweenness centrality, and are articulation points.

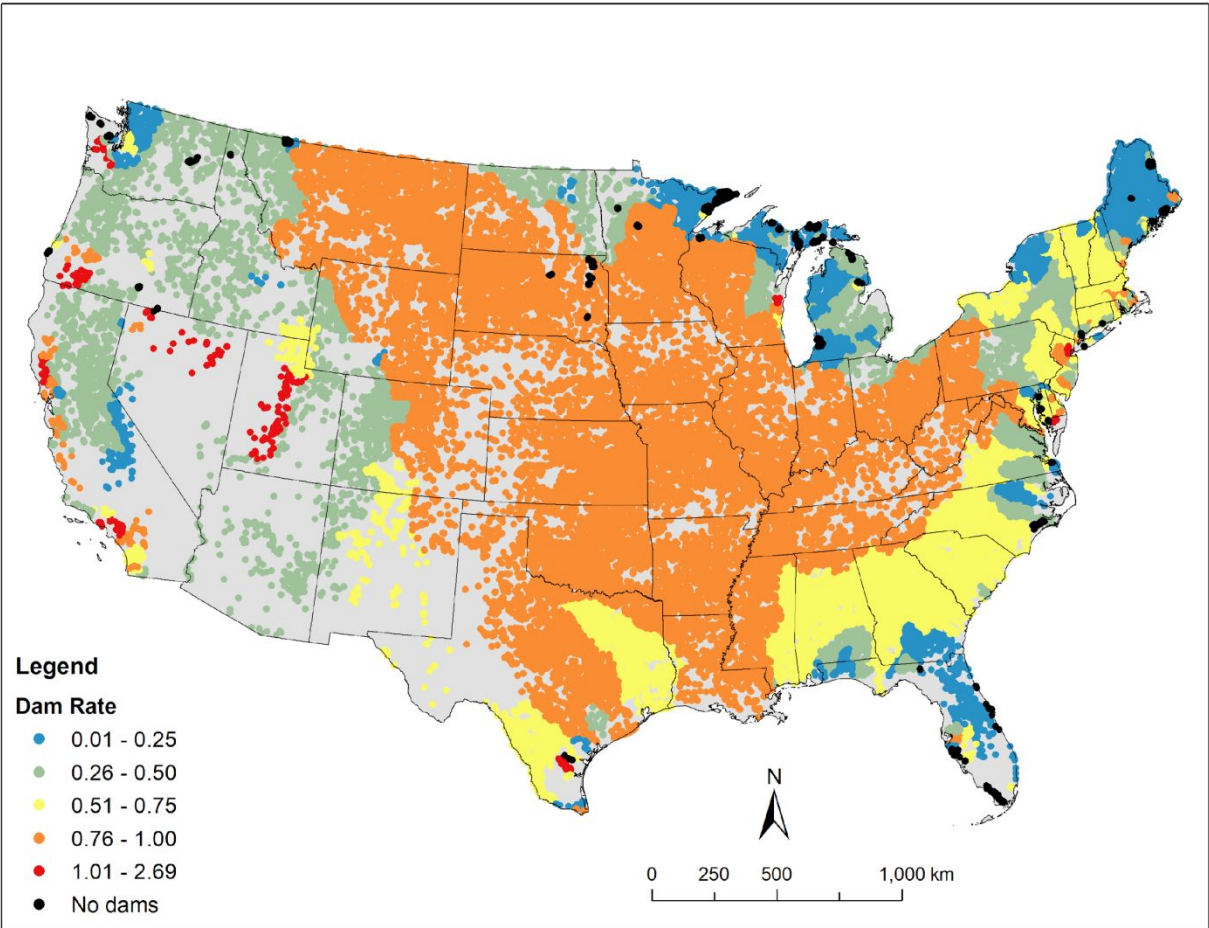


**Figure. 4.** (a) Freshwater network connectivity scores (for networks > 4 lakes) and hub lakes (n = 2080). The Mississippi River network (unscored) is shown in light blue dots. (b) Highest-ranking freshwater network connectivity scores. Unique mapped colors represent individual, contiguous networks with high connectivity scores (n = 13), which are ranked by connectivity score (1 = highest).



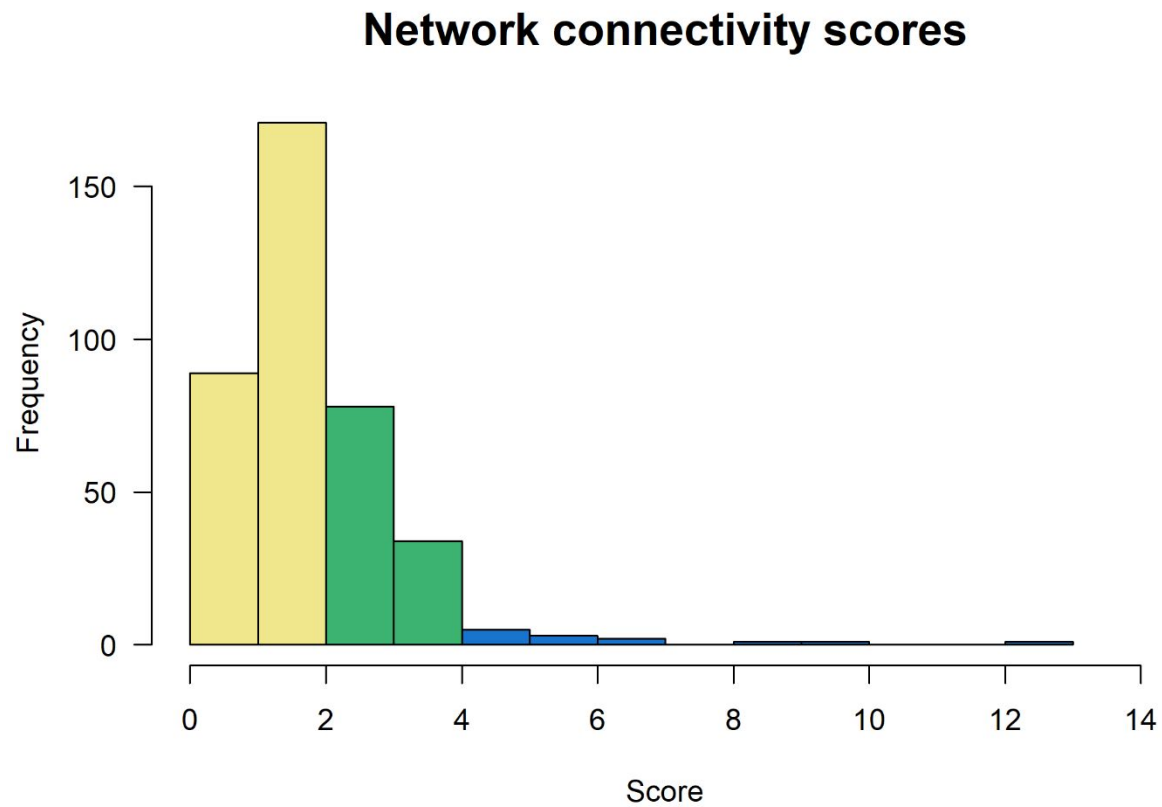
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Supporting information

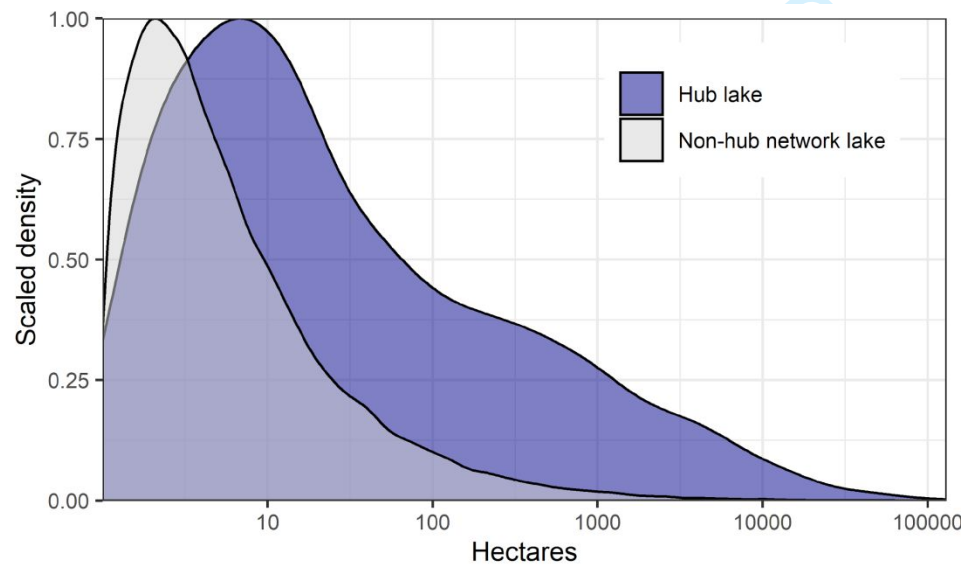


**Figure. S1.** Dam rate (number of lakes  $\geq 1$  ha divided by number of dams; unmodified before use in principal component analysis) in freshwater networks of the conterminous US. Shown are networks with  $> 4$  lakes  $\geq 1$  ha per network (386 networks). Of these, 66 have no dams.





**Figure. S2.** Frequency distribution of freshwater network connectivity scores ( $n=385$ ). Colors correspond to Fig. 4a.



**Figure. S3.** Scaled density plot of the surface area (ha) of hub lakes ( $n = 2080$ ) and non-hub lakes ( $n = 84431$ ) in freshwater networks.

Table S1. Descriptive statistics of freshwater networks in the conterminous US

Ecoregion <sup>a</sup>	Total Networks <sup>b</sup>	Number of lakes (min, median, max)	North-South distance (km) (min, median, max)	Number of dams (min, median, max)	% Articulation points (min, median, max)	Min cuts to disrupt max N-S distance (min, median, max)	Network lakes (number and % outside of MS River network)	Total network lakes (including MS River network)	Total hub lakes	% Hub lakes
CPL	243	2, 3, 3241	0.0, 3.1, 539.4	0, 1, 1760	0.0, 0.0, 77.8	1, 1, 550	14862 (81.1%)	18336	528	2.9%
NAP	206	2, 4, 2659	0.0, 7.0, 505.4	0, 2, 1099	0.0, 31.2, 62.5	1, 1, 44	11934 (95.8%)	12464	451	3.6%
NPL	28	2, 2, 6	0.2, 2.5, 15.1	0, 0, 2	0.0, 0.0, 66.7	1, 1, 3	93 (1.1%)	8166	5	0.1%
SAP	10	11, 362, 1665	27.4, 139.7, 553.9	3, 159, 944	10.2, 21.1, 66.7	1, 4, 426	8287 (69.8%)	11872	295	2.5%
SPL	8	2, 166, 1529	0.6, 97.3, 1312.7	1, 132, 1273	0.0, 22.3, 40.0	1, 1, 65	2692 (39.2%)	6871	103	1.5%
TPL	58	2, 3, 0147	0.2, 4.4, 147.5	0, 0, 58	0.0, 33.3, 77.8	1, 1, 84	1073 (12.9%)	8297	190	2.3%
UMW	150	2, 4, 1190	0.0, 7.4, 380.4	0, 0, 250	0.0, 25.0, 75.0	1, 1, 30	6115 (63.1%)	9691	260	2.7%
WMT	108	2, 3, 2397	0.0, 8.5, 1330.3	0, 1, 954	0.0, 0.0, 60.0	1, 1, 131	6614 (78.0%)	8476	169	2.0%
XER	86	2, 3, 0105	0.2, 13.3, 216.8	0, 2, 68	0.0, 11.0, 86.7	1, 1, 18	2030 (86.8%)	2338	79	3.4%
Overall	897	2, 3, 3241	0.0, 5.9, 1330.3	0, 1, 1760	0.0, 21.1, 86.7	1, 1, 550	53700 (62.07%)	86511	2080	2.4%

<sup>a</sup>CPL=Coastal Plains, NAP=Northern Appalachians, NPL=Northern Plains, SAP=Southern Appalachians, SPL=Southern Plains, TPL=Temperate Plains, UMW=Upper Midwest, XER=Xeric

<sup>b</sup>Mississippi River basin network removed (32811 lakes, 24986 dams) in calculating columns 2-7

Table S2. Freshwater network connectivity scores and statistics and protection status<sup>a</sup> of networks and hub lakes in the conterminous US

Net ID <sup>b</sup>	Rank	Score	Level	Ecoregion <sup>c</sup>	Lakes	Hubs	Dams	Dam rate <sup>d</sup>	Network protection				Hub protection				
									North-South distance (km)	Strict, lake center	Strict + multi-use, lake center	Strict, 80% watershed	Strict + multi-use, 80% watershed	Strict, lake center	Strict + multi-use, lake center	Strict, 80% watershed	Strict + multi-use, 80% watershed
3	1	12.02	High	WMT	2027	42	954	47.1%	1,330.34	41.1%	68.9%	39.1%	72.6%	26.2%	83.3%	26.2%	76.2%
52	2	9.49	High	SPL	536	13	388	72.4%	1,312.70	17.2%	30.4%	11.2%	30.0%	0.0%	23.1%	0.0%	30.8%
34	3	8.10	High	WMT	2397	55	915	38.2%	820.36	36.3%	67.0%	32.5%	67.0%	12.7%	43.6%	16.4%	47.3%
59	4	6.70	High	WMT	1780	49	484	27.2%	629.52	52.9%	65.3%	51.5%	62.4%	46.9%	59.2%	42.9%	46.9%
50	5	6.21	High	SPL	1529	22	1273	83.3%	611.93	1.8%	2.4%	0.9%	1.0%	22.7%	22.7%	9.1%	9.1%
10	6	5.67	High	NAP	2659	71	1099	41.3%	505.40	5.3%	11.7%	11.9%	15.8%	12.7%	19.7%	4.2%	9.9%
2	7	5.19	High	CPL	3241	72	1760	54.3%	491.73	1.8%	2.7%	0.6%	1.2%	6.9%	6.9%	0.0%	0.0%
90	8	5.19	High	SAP	420	9	372	88.6%	238.12	5.2%	11.7%	5.5%	10.0%	11.1%	33.3%	11.1%	22.2%
36	9	4.94	High	CPL	1076	38	268	24.9%	245.86	0.5%	1.2%	0.0%	0.2%	2.6%	7.9%	0.0%	0.0%
11	10	4.84	High	UMW	754	16	250	33.2%	380.41	17.1%	23.9%	3.3%	4.4%	18.8%	18.8%	6.3%	12.5%
15	11	4.40	High	SAP	765	24	424	55.4%	173.63	2.7%	5.2%	0.7%	3.0%	0.0%	8.3%	0.0%	0.0%
106	12	4.03	High	XER	15	0	0	0.0%	29.30	6.7%	53.3%	0.0%	20.0%	NA	NA	NA	NA
95	13	4.01	High	XER	21	1	43	204.8%	146.39	28.6%	47.6%	23.8%	76.2%	0.0%	0.0%	0.0%	100.0%
6	14	3.67	Medium	CPL	2604	66	1612	61.9%	482.56	1.3%	2.0%	1.1%	2.1%	1.5%	3.0%	0.0%	0.0%
20	15	3.63	Medium	NAP	1118	37	746	66.7%	434.21	4.4%	22.4%	1.5%	9.7%	0.0%	10.8%	0.0%	0.0%
279	16	3.59	Medium	TPL	9	0	1	11.1%	4.48	11.1%	33.3%	0.0%	0.0%	NA	NA	NA	NA
24	17	3.58	Medium	CPL	1810	61	910	50.3%	316.38	2.5%	3.3%	1.0%	1.6%	8.2%	9.8%	4.9%	4.9%
313	18	3.49	Medium	UMW	8	0	0	0.0%	6.67	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
112	19	3.49	Medium	TPL	5	0	9	180.0%	17.39	20.0%	20.0%	0.0%	0.0%	NA	NA	NA	NA
28	20	3.46	Medium	SAP	1665	37	944	56.7%	553.87	2.0%	2.6%	0.5%	0.9%	0.0%	0.0%	0.0%	0.0%
47	21	3.40	Medium	NAP	1463	38	754	51.5%	355.69	6.4%	13.7%	2.3%	4.2%	7.9%	13.2%	2.6%	2.6%
32	22	3.40	Medium	WMT	122	6	49	40.2%	289.10	55.7%	71.3%	52.5%	65.6%	16.7%	50.0%	16.7%	33.3%
21	23	3.38	Medium	CPL	516	7	107	20.7%	539.44	3.9%	10.1%	1.7%	6.4%	14.3%	28.6%	0.0%	0.0%
192	24	3.37	Medium	CPL	26	0	18	69.2%	30.59	0.0%	7.7%	0.0%	11.5%	NA	NA	NA	NA
423	25	3.33	Medium	CPL	9	0	7	77.8%	8.36	100.0%	100.0%	22.2%	22.2%	NA	NA	NA	NA
766	26	3.32	Medium	CPL	5	0	0	0.0%	3.92	20.0%	40.0%	0.0%	60.0%	NA	NA	NA	NA
721	27	3.32	Medium	CPL	5	0	0	0.0%	3.13	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
247	28	3.32	Medium	NAP	6	0	2	33.3%	6.29	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
627	29	3.30	Medium	CPL	6	0	1	16.7%	13.85	0.0%	0.0%	0.0%	16.7%	NA	NA	NA	NA
48	30	3.30	Medium	CPL	1603	67	1176	73.4%	452.01	0.9%	2.6%	0.6%	0.9%	0.0%	0.0%	0.0%	0.0%

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406	31	3.30	Medium	UMW	10	0	1	10.0%	8.35	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
342	32	3.30	Medium	CPL	8	0	2	25.0%	16.62	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
77	33	3.29	Medium	TPL	7	0	2	28.6%	22.42	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
355	34	3.27	Medium	CPL	10	0	5	50.0%	44.63	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
248	35	3.27	Medium	CPL	6	0	2	33.3%	20.58	0.0%	16.7%	0.0%	0.0%	NA	NA	NA	NA
382	36	3.27	Medium	WMT	5	0	2	40.0%	19.30	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
411	37	3.26	Medium	CPL	9	0	0	0.0%	18.43	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
256	38	3.25	Medium	CPL	5	0	0	0.0%	18.09	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
132	39	3.24	Medium	WMT	108	4	12	11.1%	206.64	71.3%	97.2%	78.7%	95.4%	0.0%	75.0%	25.0%	75.0%
9	40	3.23	Medium	CPL	2247	36	1209	53.8%	315.88	1.5%	4.5%	1.2%	1.7%	5.6%	11.1%	0.0%	0.0%
673	41	3.20	Medium	WMT	6	0	2	33.3%	17.11	0.0%	33.3%	0.0%	33.3%	NA	NA	NA	NA
100	42	3.18	Medium	CPL	249	11	93	37.3%	187.67	0.8%	1.2%	0.4%	0.8%	0.0%	0.0%	0.0%	0.0%
58	43	3.14	Medium	CPL	441	12	255	57.8%	260.08	4.3%	5.2%	1.8%	3.2%	0.0%	0.0%	0.0%	0.0%
376	44	3.13	Medium	CPL	9	0	0	0.0%	186.40	44.4%	66.7%	33.3%	55.6%	NA	NA	NA	NA
33	45	3.07	Medium	NAP	1731	76	286	16.5%	392.07	3.8%	8.4%	6.8%	11.1%	1.3%	5.3%	2.6%	2.6%
66	46	3.07	Medium	NPL	6	0	0	0.0%	5.12	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
94	47	3.04	Medium	CPL	7	0	5	71.4%	7.46	14.3%	14.3%	0.0%	28.6%	NA	NA	NA	NA
371	48	2.99	Medium	WMT	16	0	17	106.3%	91.36	0.0%	18.8%	0.0%	6.3%	NA	NA	NA	NA
64	49	2.98	Medium	UMW	825	16	220	26.7%	266.80	2.2%	7.6%	1.0%	1.0%	0.0%	0.0%	0.0%	0.0%
69	50	2.98	Medium	CPL	26	0	11	42.3%	38.73	3.8%	3.8%	0.0%	0.0%	NA	NA	NA	NA
189	51	2.93	Medium	WMT	133	7	2	1.5%	141.71	97.7%	99.2%	97.7%	98.5%	100.0%	100.0%	100.0%	100.0%
93	52	2.93	Medium	CPL	23	0	9	39.1%	36.70	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
136	53	2.92	Medium	XER	21	1	30	142.9%	101.57	4.8%	9.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
99	54	2.89	Medium	XER	105	3	68	64.8%	216.83	13.3%	29.5%	5.7%	31.4%	0.0%	0.0%	0.0%	0.0%
800	55	2.80	Medium	CPL	5	0	0	0.0%	0.86	100.0%	100.0%	0.0%	0.0%	NA	NA	NA	NA
407	56	2.79	Medium	NAP	5	0	0	0.0%	3.31	20.0%	20.0%	0.0%	0.0%	NA	NA	NA	NA
685	57	2.79	Medium	CPL	5	1	0	0.0%	3.37	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
550	58	2.79	Medium	TPL	5	0	0	0.0%	4.63	20.0%	20.0%	0.0%	0.0%	NA	NA	NA	NA
287	59	2.78	Medium	TPL	5	0	0	0.0%	5.51	20.0%	20.0%	0.0%	0.0%	NA	NA	NA	NA
364	60	2.78	Medium	TPL	5	0	0	0.0%	6.43	20.0%	80.0%	0.0%	0.0%	NA	NA	NA	NA
457	61	2.76	Medium	TPL	5	0	0	0.0%	7.27	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
314	62	2.75	Medium	CPL	72	1	9	12.5%	29.84	100.0%	100.0%	4.2%	4.2%	100.0%	100.0%	0.0%	0.0%
762	63	2.73	Medium	XER	5	0	0	0.0%	17.56	0.0%	80.0%	0.0%	100.0%	NA	NA	NA	NA
264	64	2.72	Medium	WMT	5	0	0	0.0%	5.26	0.0%	20.0%	0.0%	0.0%	NA	NA	NA	NA
282	65	2.72	Medium	NAP	5	1	0	0.0%	3.05	0.0%	0.0%	40.0%	40.0%	0.0%	0.0%	0.0%	0.0%
30	66	2.68	Medium	UMW	20	1	4	20.0%	46.90	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
516	67	2.68	Medium	WMT	5	1	1	20.0%	2.65	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
681	68	2.63	Medium	XER	7	2	0	0.0%	2.91	0.0%	100.0%	0.0%	14.3%	0.0%	100.0%	0.0%	0.0%
827	69	2.63	Medium	NAP	5	0	2	40.0%	1.86	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA



119	70	2.61	Medium	WMT	45	3	55	122.2%	220.24	2.2%	40.0%	2.2%	55.6%	0.0%	33.3%	0.0%	33.3%
280	71	2.60	Medium	NAP	14	0	0	0.0%	19.52	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
760	72	2.60	Medium	NPL	5	1	2	40.0%	5.18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
67	73	2.59	Medium	TPL	146	7	58	39.7%	147.49	5.5%	10.3%	3.4%	3.4%	14.3%	28.6%	14.3%	14.3%
761	74	2.57	Medium	NAP	8	1	4	50.0%	7.86	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
139	75	2.52	Medium	NAP	271	10	162	59.8%	194.84	2.2%	7.0%	2.2%	2.6%	0.0%	0.0%	0.0%	0.0%
198	76	2.52	Medium	NAP	5	0	3	60.0%	6.97	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
105	77	2.52	Medium	CPL	36	2	13	36.1%	39.43	5.6%	22.2%	5.6%	11.1%	0.0%	0.0%	0.0%	0.0%
296	78	2.49	Medium	UMW	7	1	0	0.0%	7.19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
19	79	2.49	Medium	SAP	21	1	13	61.9%	28.68	0.0%	9.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
109	80	2.47	Medium	WMT	52	3	8	15.4%	66.11	67.3%	71.2%	67.3%	71.2%	66.7%	66.7%	66.7%	66.7%
524	81	2.46	Medium	CPL	5	0	4	80.0%	2.05	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
227	82	2.46	Medium	XER	16	0	14	87.5%	54.89	18.8%	50.0%	6.3%	6.3%	NA	NA	NA	NA
178	83	2.45	Medium	CPL	5	0	4	80.0%	8.40	20.0%	20.0%	0.0%	0.0%	NA	NA	NA	NA
65	84	2.45	Medium	CPL	48	0	13	27.1%	54.71	0.0%	8.3%	0.0%	8.3%	NA	NA	NA	NA
152	85	2.43	Medium	NAP	5	0	4	80.0%	7.65	20.0%	20.0%	20.0%	20.0%	NA	NA	NA	NA
31	86	2.42	Medium	SPL	454	14	288	63.4%	253.01	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
427	87	2.40	Medium	NAP	10	0	9	90.0%	34.10	0.0%	10.0%	0.0%	0.0%	NA	NA	NA	NA
150	88	2.39	Medium	NAP	29	0	11	37.9%	30.82	3.4%	10.3%	0.0%	0.0%	NA	NA	NA	NA
40	89	2.38	Medium	WMT	200	1	13	6.5%	72.84	70.5%	77.5%	60.5%	65.5%	100.0%	100.0%	100.0%	100.0%
210	90	2.36	Medium	TPL	7	0	0	0.0%	3.46	0.0%	28.6%	0.0%	0.0%	NA	NA	NA	NA
277	91	2.34	Medium	UMW	50	3	0	0.0%	15.35	36.0%	96.0%	26.0%	100.0%	33.3%	100.0%	33.3%	100.0%
45	92	2.31	Medium	SPL	326	11	261	80.1%	185.41	2.1%	2.1%	0.9%	0.9%	9.1%	9.1%	0.0%	0.0%
781	93	2.30	Medium	CPL	7	0	4	57.1%	3.54	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
57	94	2.29	Medium	NAP	749	23	436	58.2%	215.67	1.2%	14.6%	0.4%	6.0%	0.0%	0.0%	0.0%	0.0%
108	95	2.29	Medium	XER	5	0	5	100.0%	14.52	100.0%	100.0%	0.0%	80.0%	NA	NA	NA	NA
78	96	2.27	Medium	NAP	16	0	15	93.8%	27.65	0.0%	31.3%	0.0%	0.0%	NA	NA	NA	NA
118	97	2.26	Medium	WMT	28	1	31	110.7%	82.28	21.4%	42.9%	10.7%	46.4%	0.0%	100.0%	0.0%	100.0%
196	98	2.25	Medium	CPL	18	1	4	22.2%	61.81	11.1%	11.1%	11.1%	11.1%	0.0%	0.0%	0.0%	0.0%
134	99	2.24	Medium	XER	40	1	40	100.0%	70.38	5.0%	42.5%	2.5%	15.0%	0.0%	0.0%	0.0%	0.0%
35	100	2.23	Medium	CPL	609	29	332	54.5%	179.95	0.5%	0.5%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%
156	101	2.23	Medium	NAP	17	2	7	41.2%	25.89	5.9%	17.6%	0.0%	5.9%	0.0%	50.0%	0.0%	0.0%
648	102	2.22	Medium	XER	5	0	4	80.0%	24.32	60.0%	80.0%	0.0%	0.0%	NA	NA	NA	NA
133	103	2.20	Medium	CPL	172	7	35	20.3%	97.07	0.6%	1.2%	0.0%	1.2%	0.0%	0.0%	0.0%	0.0%
544	104	2.19	Medium	WMT	10	0	0	0.0%	21.22	60.0%	60.0%	0.0%	0.0%	NA	NA	NA	NA
271	105	2.18	Medium	NAP	9	0	3	33.3%	8.57	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
591	106	2.18	Medium	UMW	6	1	0	0.0%	4.59	0.0%	100.0%	33.3%	33.3%	0.0%	100.0%	0.0%	0.0%
289	107	2.17	Medium	UMW	13	2	2	15.4%	19.07	0.0%	7.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
858	108	2.13	Medium	TPL	6	0	0	0.0%	4.40	16.7%	16.7%	0.0%	0.0%	NA	NA	NA	NA

Ecological Applications

389	109	2.13	Medium	CPL	7	1	0	0.0%	2.68	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
232	110	2.12	Medium	WMT	13	0	35	%	52.23	15.4%	69.2%	0.0%	46.2%	NA	NA	NA	NA
29	111	2.12	Medium	NAP	736	22	126	17.1%	159.94	7.3%	9.5%	38.6%	41.6%	13.6%	13.6%	31.8%	31.8%
68	112	2.11	Medium	UMW	364	11	113	31.0%	241.04	9.1%	12.4%	6.6%	8.0%	9.1%	9.1%	0.0%	0.0%
261	113	2.11	Medium	WMT	55	2	12	21.8%	118.49	60.0%	78.2%	63.6%	89.1%	0.0%	0.0%	0.0%	0.0%
527	114	2.08	Medium	WMT	7	0	6	85.7%	74.60	0.0%	42.9%	0.0%	0.0%	NA	NA	NA	NA
388	115	2.08	Medium	XER	16	1	4	25.0%	24.53	6.3%	12.5%	6.3%	6.3%	0.0%	0.0%	0.0%	0.0%
144	116	2.08	Medium	UMW	15	0	0	0.0%	18.11	0.0%	80.0%	0.0%	26.7%	NA	NA	NA	NA
211	117	2.06	Medium	XER	8	1	5	62.5%	21.18	12.5%	37.5%	0.0%	12.5%	100.0%	100.0%	0.0%	0.0%
582	118	2.06	Medium	CPL	7	0	3	42.9%	12.01	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
375	119	2.05	Medium	NAP	10	0	8	80.0%	11.96	10.0%	10.0%	10.0%	10.0%	NA	NA	NA	NA
140	120	2.05	Medium	WMT	41	3	56	%	120.00	12.2%	48.8%	12.2%	48.8%	0.0%	33.3%	0.0%	33.3%
71	121	2.05	Medium	WMT	40	2	20	50.0%	134.60	22.5%	62.5%	15.0%	70.0%	0.0%	0.0%	0.0%	50.0%
249	122	2.05	Medium	NAP	9	1	6	66.7%	12.01	0.0%	22.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
98	123	2.03	Medium	WMT	92	2	11	12.0%	111.78	73.9%	85.9%	72.8%	85.9%	0.0%	50.0%	0.0%	50.0%
263	124	2.03	Medium	WMT	14	0	2	14.3%	39.21	64.3%	78.6%	71.4%	78.6%	NA	NA	NA	NA
240	125	2.01	Medium	CPL	19	2	10	52.6%	124.88	10.5%	15.8%	5.3%	15.8%	50.0%	50.0%	50.0%	50.0%
220	126	1.99	Low	UMW	7	0	4	57.1%	9.43	42.9%	71.4%	0.0%	0.0%	NA	NA	NA	NA
164	127	1.99	Low	UMW	30	1	0	0.0%	18.81	6.7%	76.7%	3.3%	93.3%	0.0%	100.0%	0.0%	100.0%
309	128	1.98	Low	UMW	27	1	4	14.8%	22.47	0.0%	3.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
145	129	1.98	Low	WMT	23	2	21	91.3%	72.48	21.7%	65.2%	21.7%	47.8%	50.0%	100.0%	50.0%	100.0%
165	130	1.97	Low	CPL	24	2	8	33.3%	112.31	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
238	131	1.96	Low	TPL	10	1	0	0.0%	6.95	10.0%	20.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
448	132	1.95	Low	WMT	12	2	11	91.7%	71.45	8.3%	33.3%	8.3%	41.7%	0.0%	50.0%	0.0%	50.0%
284	133	1.95	Low	NAP	6	0	0	0.0%	2.46	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
529	134	1.93	Low	TPL	6	0	0	0.0%	4.90	33.3%	33.3%	0.0%	0.0%	NA	NA	NA	NA
38	135	1.92	Low	CPL	6	0	4	66.7%	2.75	33.3%	66.7%	0.0%	0.0%	NA	NA	NA	NA
5	136	1.91	Low	SAP	483	11	249	51.6%	168.70	1.2%	3.1%	0.2%	0.8%	0.0%	9.1%	0.0%	0.0%
357	137	1.91	Low	NAP	18	0	0	0.0%	14.76	0.0%	11.1%	27.8%	33.3%	NA	NA	NA	NA
581	138	1.90	Low	UMW	6	0	0	0.0%	2.91	0.0%	83.3%	0.0%	83.3%	NA	NA	NA	NA
200	139	1.89	Low	UMW	64	4	0	0.0%	22.55	51.6%	90.6%	42.2%	92.2%	25.0%	50.0%	50.0%	100.0%
410	140	1.89	Low	WMT	10	1	1	10.0%	26.27	0.0%	70.0%	20.0%	80.0%	0.0%	0.0%	0.0%	100.0%
158	141	1.89	Low	CPL	6	0	4	66.7%	2.14	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
160	142	1.88	Low	TPL	147	8	52	35.4%	122.73	16.3%	19.0%	2.0%	2.0%	37.5%	37.5%	12.5%	12.5%
14	143	1.88	Low	WMT	65	3	28	43.1%	143.11	44.6%	76.9%	38.5%	80.0%	0.0%	66.7%	0.0%	33.3%
486	144	1.88	Low	CPL	7	2	0	0.0%	3.16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
633	145	1.88	Low	CPL	5	0	0	0.0%	4.24	100.0%	100.0%	0.0%	0.0%	NA	NA	NA	NA
141	146	1.87	Low	CPL	25	2	2	8.0%	4.04	40.0%	72.0%	4.0%	4.0%	100.0%	100.0%	0.0%	0.0%
573	147	1.86	Low	UMW	6	0	1	16.7%	11.17	0.0%	16.7%	0.0%	0.0%	NA	NA	NA	NA
195	148	1.86	Low	CPL	6	0	3	50.0%	8.97	33.3%	50.0%	0.0%	0.0%	NA	NA	NA	NA

383	149	1.86	Low	UMW	6	1	0	0.0%	7.50	0.0%	0.0%	16.7%	16.7%	0.0%	0.0%	0.0%	0.0%
437	150	1.85	Low	UMW	6	0	1	16.7%	11.68	83.3%	83.3%	83.3%	83.3%	NA	NA	NA	NA
236	151	1.84	Low	XER	14	0	12	85.7%	189.16	7.1%	21.4%	0.0%	0.0%	NA	NA	NA	NA
338	152	1.83	Low	UMW	6	1	1	16.7%	9.31	0.0%	16.7%	0.0%	33.3%	0.0%	0.0%	0.0%	100.0%
443	153	1.82	Low	WMT	7	1	0	0.0%	10.87	57.1%	100.0%	42.9%	71.4%	0.0%	100.0%	0.0%	100.0%
480	154	1.81	Low	NAP	6	0	2	33.3%	12.69	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
324	155	1.80	Low	CPL	6	0	1	16.7%	26.96	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
44	156	1.78	Low	CPL	36	0	19	52.8%	66.55	2.8%	2.8%	0.0%	5.6%	NA	NA	NA	NA
42	157	1.78	Low	NAP	8	0	4	50.0%	6.05	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
129	158	1.78	Low	CPL	23	0	23	100.0%	45.88	8.7%	21.7%	4.3%	4.3%	NA	NA	NA	NA
465	159	1.77	Low	NAP	6	0	2	33.3%	22.43	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
369	160	1.76	Low	WMT	6	0	4	66.7%	23.22	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
704	161	1.76	Low	CPL	5	0	0	0.0%	1.96	40.0%	40.0%	40.0%	40.0%	NA	NA	NA	NA
166	162	1.76	Low	CPL	186	2	93	50.0%	143.16	2.7%	2.7%	0.5%	0.5%	0.0%	0.0%	0.0%	0.0%
253	163	1.75	Low	WMT	42	3	10	23.8%	33.87	73.8%	92.9%	57.1%	76.2%	0.0%	66.7%	0.0%	66.7%
661	164	1.75	Low	CPL	6	0	3	50.0%	1.07	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
463	165	1.74	Low	XER	5	0	0	0.0%	4.67	0.0%	100.0%	0.0%	80.0%	NA	NA	NA	NA
356	166	1.74	Low	TPL	5	1	1	20.0%	13.44	20.0%	20.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
651	167	1.74	Low	UMW	5	1	0	0.0%	5.10	80.0%	80.0%	80.0%	80.0%	100.0%	100.0%	100.0%	100.0%
272	168	1.73	Low	UMW	19	2	2	10.5%	6.15	10.5%	31.6%	10.5%	10.5%	0.0%	0.0%	0.0%	0.0%
394	169	1.73	Low	NAP	6	0	5	83.3%	10.68	16.7%	16.7%	0.0%	0.0%	NA	NA	NA	NA
621	170	1.72	Low	NAP	8	1	3	37.5%	5.52	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
323	171	1.72	Low	UMW	5	1	1	20.0%	10.41	0.0%	60.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
366	172	1.71	Low	NAP	6	0	3	50.0%	6.79	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
639	173	1.71	Low	NAP	5	0	0	0.0%	2.12	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
285	174	1.70	Low	NAP	5	0	1	20.0%	3.72	20.0%	40.0%	0.0%	0.0%	NA	NA	NA	NA
53	175	1.70	Low	NAP	338	8	170	50.3%	187.95	7.7%	17.5%	16.6%	19.2%	0.0%	25.0%	0.0%	0.0%
75	176	1.69	Low	CPL	382	16	165	43.2%	120.32	0.5%	0.8%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%
295	177	1.68	Low	NAP	5	0	2	40.0%	7.03	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
293	178	1.67	Low	UMW	23	1	2	8.7%	19.50	0.0%	34.8%	0.0%	87.0%	0.0%	0.0%	0.0%	100.0%
223	179	1.67	Low	WMT	14	1	0	0.0%	11.57	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
43	180	1.66	Low	UMW	1190	46	30	2.5%	180.01	52.9%	83.1%	49.9%	71.3%	37.0%	67.4%	23.9%	50.0%
420	181	1.66	Low	WMT	6	1	4	66.7%	18.12	0.0%	0.0%	0.0%	16.7%	0.0%	0.0%	0.0%	0.0%
126	182	1.66	Low	SAP	304	10	69	22.7%	110.80	0.3%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
254	183	1.63	Low	NAP	22	1	7	31.8%	35.87	4.5%	4.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
60	184	1.62	Low	SAP	586	18	278	47.4%	180.43	0.3%	4.8%	0.0%	0.2%	5.6%	33.3%	0.0%	0.0%
110	185	1.62	Low	UMW	142	8	31	21.8%	67.97	4.2%	15.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
543	186	1.62	Low	XER	5	1	0	0.0%	8.28	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
16	187	1.61	Low	CPL	400	17	134	33.5%	128.32	0.3%	0.5%	0.0%	1.3%	0.0%	0.0%	0.0%	11.8%
421	188	1.61	Low	XER	9	1	4	44.4%	26.21	11.1%	44.4%	0.0%	11.1%	0.0%	100.0%	0.0%	0.0%

450	189	1.61	Low	CPL	17	1	6	35.3%	16.27	0.0%	17.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
252	190	1.61	Low	XER	6	0	2	33.3%	56.53	50.0%	50.0%	16.7%	50.0%	NA	NA	NA	NA
541	191	1.60	Low	XER	6	1	4	66.7%	38.15	0.0%	16.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
								130.0									
500	192	1.59	Low	XER	10	0	13	%	27.44	60.0%	90.0%	80.0%	100.0%	NA	NA	NA	NA
468	193	1.58	Low	NAP	5	1	3	60.0%	6.77	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
326	194	1.58	Low	NAP	22	0	8	36.4%	17.10	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
469	195	1.58	Low	UMW	5	1	0	0.0%	4.98	20.0%	40.0%	20.0%	20.0%	0.0%	0.0%	0.0%	0.0%
162	196	1.57	Low	NAP	33	3	27	81.8%	16.21	3.0%	30.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
173	197	1.56	Low	CPL	20	0	3	15.0%	27.93	5.0%	15.0%	5.0%	10.0%	NA	NA	NA	NA
588	198	1.54	Low	UMW	6	0	0	0.0%	7.00	0.0%	83.3%	66.7%	66.7%	NA	NA	NA	NA
386	199	1.53	Low	NPL	5	1	2	40.0%	15.13	40.0%	40.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%
161	200	1.53	Low	CPL	8	1	2	25.0%	131.65	12.5%	12.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
534	201	1.53	Low	NAP	5	0	3	60.0%	10.32	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
593	202	1.52	Low	CPL	7	0	2	28.6%	2.06	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
336	203	1.52	Low	NAP	8	1	4	50.0%	13.35	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
632	204	1.52	Low	UMW	17	2	4	23.5%	18.08	11.8%	29.4%	5.9%	5.9%	0.0%	0.0%	0.0%	0.0%
547	205	1.51	Low	NAP	5	0	4	80.0%	7.04	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
23	206	1.50	Low	UMW	237	14	1	0.4%	41.65	58.2%	94.5%	54.9%	94.1%	28.6%	78.6%	21.4%	92.9%
517	207	1.49	Low	UMW	5	1	1	20.0%	3.19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
56	208	1.48	Low	UMW	453	16	59	13.0%	182.22	12.4%	22.5%	12.4%	16.3%	6.3%	6.3%	0.0%	0.0%
705	209	1.48	Low	NAP	9	0	7	77.8%	8.45	0.0%	44.4%	0.0%	0.0%	NA	NA	NA	NA
354	210	1.47	Low	SPL	5	1	4	80.0%	6.08	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
494	211	1.47	Low	NAP	8	2	4	50.0%	14.46	12.5%	12.5%	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%
								100.0									
821	212	1.46	Low	XER	5	0	5	%	14.66	0.0%	60.0%	0.0%	0.0%	NA	NA	NA	NA
79	213	1.45	Low	NAP	325	21	255	78.5%	80.79	3.1%	11.4%	0.0%	1.5%	4.8%	4.8%	0.0%	0.0%
436	214	1.44	Low	NAP	27	2	3	11.1%	38.74	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
175	215	1.43	Low	UMW	9	0	3	33.3%	20.31	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
265	216	1.43	Low	WMT	20	1	1	5.0%	34.29	15.0%	50.0%	10.0%	55.0%	0.0%	0.0%	0.0%	0.0%
626	217	1.42	Low	NAP	5	0	0	0.0%	11.99	20.0%	20.0%	0.0%	20.0%	NA	NA	NA	NA
237	218	1.41	Low	WMT	28	3	19	67.9%	106.23	7.1%	17.9%	3.6%	10.7%	0.0%	33.3%	0.0%	0.0%
379	219	1.40	Low	UMW	13	1	0	0.0%	14.59	30.8%	76.9%	69.2%	69.2%	0.0%	100.0%	0.0%	0.0%
843	220	1.40	Low	NAP	6	1	4	66.7%	14.90	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
83	221	1.39	Low	TPL	23	2	8	34.8%	81.88	13.0%	13.0%	13.0%	13.0%	0.0%	0.0%	0.0%	0.0%
17	222	1.38	Low	CPL	222	10	66	29.7%	166.94	0.0%	1.4%	0.0%	0.5%	0.0%	10.0%	0.0%	0.0%
665	223	1.37	Low	CPL	5	1	3	60.0%	42.12	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
61	224	1.37	Low	NAP	9	1	5	55.6%	7.72	11.1%	22.2%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
403	225	1.37	Low	CPL	13	1	7	53.8%	7.66	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
660	226	1.37	Low	WMT	6	0	0	0.0%	14.17	0.0%	16.7%	0.0%	0.0%	NA	NA	NA	NA
91	227	1.37	Low	CPL	9	1	7	77.8%	12.34	33.3%	66.7%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
731	228	1.35	Low	NAP	7	1	4	57.1%	6.18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

97	229	1.33	Low	UMW	14	1	0	0.0%	29.73	0.0%	21.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
115	230	1.33	Low	UMW	47	2	1	2.1%	35.97	36.2%	36.2%	31.9%	31.9%	100.0%	100.0%	0.0%	0.0%
276	231	1.33	Low	NAP	7	1	1	14.3%	7.09	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
275	232	1.32	Low	UMW	11	0	8	72.7%	13.16	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
202	233	1.30	Low	CPL	23	1	18	78.3%	42.08	21.7%	30.4%	4.3%	4.3%	0.0%	100.0%	0.0%	0.0%
39	234	1.29	Low	TPL	7	0	0	0.0%	5.33	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
604	235	1.28	Low	WMT	8	0	2	25.0%	13.35	0.0%	0.0%	0.0%	12.5%	NA	NA	NA	NA
283	236	1.28	Low	NAP	6	1	0	0.0%	5.90	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
63	237	1.27	Low	UMW	454	18	86	18.9%	116.11	3.7%	5.3%	0.9%	0.9%	0.0%	0.0%	0.0%	0.0%
185	238	1.27	Low	NAP	14	1	5	35.7%	15.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
188	239	1.27	Low	CPL	66	3	18	27.3%	39.39	37.9%	43.9%	9.1%	9.1%	100.0%	100.0%	0.0%	0.0%
257	240	1.27	Low	NAP	113	3	76	67.3%	40.10	5.3%	27.4%	0.0%	3.5%	0.0%	0.0%	0.0%	0.0%
88	241	1.26	Low	NAP	380	15	214	56.3%	97.72	3.4%	9.2%	0.3%	4.7%	13.3%	20.0%	0.0%	0.0%
92	242	1.25	Low	NAP	75	4	33	44.0%	50.59	2.7%	8.0%	2.7%	2.7%	0.0%	25.0%	0.0%	0.0%
435	243	1.25	Low	NAP	6	0	4	66.7%	6.09	0.0%	50.0%	0.0%	0.0%	NA	NA	NA	NA
187	244	1.24	Low	CPL	25	1	2	8.0%	9.01	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
114	245	1.24	Low	UMW	50	3	20	40.0%	41.64	0.0%	6.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
368	246	1.24	Low	XER	12	0	4	33.3%	35.46	0.0%	41.7%	0.0%	33.3%	NA	NA	NA	NA
489	247	1.22	Low	UMW	6	1	0	0.0%	8.77	0.0%	16.7%	16.7%	16.7%	0.0%	100.0%	0.0%	0.0%
363	248	1.21	Low	WMT	5	0	1	20.0%	21.51	0.0%	20.0%	20.0%	60.0%	NA	NA	NA	NA
26	249	1.20	Low	NAP	418	11	225	53.8%	142.51	4.8%	12.9%	2.2%	5.7%	0.0%	18.2%	0.0%	0.0%
72	250	1.19	Low	NAP	12	1	3	25.0%	11.88	33.3%	33.3%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%
214	251	1.17	Low	NAP	43	4	15	34.9%	55.27	2.3%	2.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
440	252	1.17	Low	XER	9	1	8	88.9%	12.79	11.1%	88.9%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
204	253	1.17	Low	NAP	28	2	11	39.3%	20.29	3.6%	3.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
302	254	1.17	Low	CPL	19	0	3	15.8%	91.01	0.0%	21.1%	0.0%	10.5%	NA	NA	NA	NA
522	255	1.16	Low	CPL	10	0	0	0.0%	12.54	10.0%	10.0%	0.0%	0.0%	NA	NA	NA	NA
595	256	1.15	Low	NAP	13	1	6	46.2%	7.82	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
570	257	1.15	Low	UMW	6	0	1	16.7%	16.18	16.7%	16.7%	50.0%	50.0%	NA	NA	NA	NA
438	258	1.15	Low	CPL	6	0	0	0.0%	13.52	33.3%	33.3%	16.7%	16.7%	NA	NA	NA	NA
7	259	1.15	Low	UMW	153	5	30	19.6%	139.15	4.6%	12.4%	3.3%	3.3%	20.0%	20.0%	0.0%	0.0%
358	260	1.15	Low	NAP	6	0	3	50.0%	10.92	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
559	261	1.15	Low	NAP	7	1	2	28.6%	7.24	0.0%	14.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
37	262	1.14	Low	NAP	261	10	81	31.0%	98.36	0.8%	5.4%	0.8%	3.8%	0.0%	0.0%	0.0%	0.0%
266	263	1.14	Low	CPL	40	0	27	67.5%	107.98	25.0%	25.0%	12.5%	12.5%	NA	NA	NA	NA
519	264	1.14	Low	CPL	7	1	7	%	15.29	0.0%	14.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
122	265	1.14	Low	XER	27	1	12	44.4%	90.13	11.1%	22.2%	7.4%	7.4%	100.0%	100.0%	0.0%	0.0%
13	266	1.13	Low	UMW	240	10	26	10.8%	119.26	0.4%	30.8%	0.0%	1.3%	0.0%	20.0%	0.0%	0.0%
460	267	1.13	Low	WMT	6	0	2	33.3%	9.69	0.0%	16.7%	0.0%	0.0%	NA	NA	NA	NA
307	268	1.12	Low	UMW	12	1	0	0.0%	44.34	8.3%	8.3%	25.0%	25.0%	0.0%	0.0%	100.0%	100.0%

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18	269	1.11	Low	CPL	410	16	99	24.1%	130.19	0.5%	1.2%	0.5%	1.0%	0.0%	0.0%	0.0%	0.0%
274	270	1.11	Low	NAP	30	3	7	23.3%	16.41	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
80	271	1.11	Low	UMW	20	0	5	25.0%	43.14	15.0%	35.0%	35.0%	35.0%	NA	NA	NA	NA
224	272	1.10	Low	UMW	23	0	0	0.0%	32.53	0.0%	4.3%	4.3%	4.3%	NA	NA	NA	NA
62	273	1.09	Low	NAP	26	0	14	53.8%	15.53	0.0%	7.7%	0.0%	0.0%	NA	NA	NA	NA
104	274	1.09	Low	TPL	17	1	14	82.4%	36.14	5.9%	11.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
125	275	1.09	Low	NAP	10	1	3	30.0%	10.53	0.0%	30.0%	30.0%	30.0%	0.0%	0.0%	0.0%	0.0%
49	276	1.09	Low	NAP	62	3	38	61.3%	29.95	16.1%	22.6%	3.2%	12.9%	0.0%	0.0%	0.0%	0.0%
653	277	1.08	Low	UMW	6	1	1	16.7%	6.69	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
455	278	1.08	Low	NAP	12	2	1	8.3%	19.58	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
752	279	1.08	Low	UMW	7	1	0	0.0%	15.34	0.0%	42.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
27	280	1.08	Low	CPL	31	1	21	67.7%	48.20	32.3%	35.5%	3.2%	3.2%	100.0%	100.0%	0.0%	0.0%
565	281	1.08	Low	UMW	6	0	0	0.0%	14.96	33.3%	33.3%	83.3%	83.3%	NA	NA	NA	NA
221	282	1.07	Low	CPL	15	0	1	6.7%	31.04	13.3%	20.0%	6.7%	6.7%	NA	NA	NA	NA
127	283	1.06	Low	UMW	30	0	6	20.0%	36.88	3.3%	6.7%	0.0%	0.0%	NA	NA	NA	NA
180	284	1.06	Low	UMW	11	0	0	0.0%	16.19	9.1%	90.9%	0.0%	36.4%	NA	NA	NA	NA
452	285	1.05	Low	UMW	8	1	0	0.0%	4.75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
25	286	1.05	Low	CPL	98	1	64	65.3%	129.12	1.0%	3.1%	1.0%	2.0%	0.0%	0.0%	0.0%	0.0%
344	287	1.05	Low	UMW	8	1	3	37.5%	11.54	0.0%	25.0%	25.0%	25.0%	0.0%	0.0%	0.0%	0.0%
255	288	1.04	Low	CPL	5	0	5	100.0%	10.05	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
184	289	1.04	Low	CPL	57	1	34	59.6%	86.65	7.0%	26.3%	0.0%	3.5%	0.0%	0.0%	0.0%	0.0%
151	290	1.04	Low	CPL	22	3	24	109.1%	50.63	4.5%	4.5%	0.0%	0.0%	33.3%	33.3%	0.0%	0.0%
85	291	1.04	Low	NAP	7	0	4	57.1%	10.36	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
46	292	1.03	Low	NAP	258	14	175	67.8%	74.07	6.2%	41.9%	1.9%	1.9%	0.0%	14.3%	0.0%	0.0%
8	293	1.02	Low	NAP	32	1	15	46.9%	31.55	0.0%	18.8%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
244	294	1.02	Low	UMW	50	4	14	28.0%	70.12	6.0%	30.0%	28.0%	28.0%	0.0%	0.0%	0.0%	0.0%
474	295	1.01	Low	CPL	12	1	7	58.3%	8.73	0.0%	8.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
239	296	1.01	Low	CPL	13	1	6	46.2%	13.26	0.0%	30.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
434	297	0.97	Low	NAP	6	0	4	66.7%	6.99	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
191	298	0.97	Low	WMT	8	0	2	25.0%	23.91	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
113	299	0.96	Low	CPL	10	0	0	0.0%	30.28	30.0%	30.0%	20.0%	20.0%	NA	NA	NA	NA
301	300	0.96	Low	CPL	7	0	10	142.9%	15.53	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
387	301	0.96	Low	CPL	6	0	4	66.7%	10.01	66.7%	66.7%	16.7%	16.7%	NA	NA	NA	NA
750	302	0.94	Low	NAP	6	0	5	83.3%	22.62	33.3%	33.3%	16.7%	16.7%	NA	NA	NA	NA
576	303	0.93	Low	CPL	6	1	6	100.0%	7.99	16.7%	16.7%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%
147	304	0.93	Low	CPL	24	1	0	0.0%	47.74	95.8%	100.0%	12.5%	12.5%	100.0%	100.0%	100.0%	100.0%
225	305	0.92	Low	NAP	28	4	11	39.3%	23.33	21.4%	21.4%	10.7%	10.7%	25.0%	25.0%	0.0%	0.0%
87	306	0.92	Low	NAP	181	5	18	9.9%	74.97	1.7%	4.4%	1.7%	5.5%	20.0%	20.0%	20.0%	20.0%
153	307	0.92	Low	UMW	174	8	36	20.7%	85.76	1.1%	2.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

54	308	0.90	Low	CPL	18	1	1	5.6%	15.30	44.4%	55.6%	22.2%	61.1%	0.0%	100.0%	0.0%	100.0%
361	309	0.90	Low	NAP	7	1	2	28.6%	15.46	0.0%	42.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
207	310	0.88	Low	NAP	83	6	8	9.6%	52.00	20.5%	21.7%	27.7%	37.3%	16.7%	16.7%	16.7%	16.7%
137	311	0.87	Low	XER	5	1	2	40.0%	8.83	20.0%	20.0%	20.0%	40.0%	0.0%	0.0%	0.0%	0.0%
230	312	0.86	Low	NAP	23	2	10	43.5%	14.16	4.3%	4.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
496	313	0.86	Low	NAP	10	0	5	50.0%	14.77	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
490	314	0.84	Low	XER	7	0	3	42.9%	23.39	0.0%	42.9%	0.0%	42.9%	NA	NA	NA	NA
242	315	0.84	Low	UMW	6	0	4	66.7%	19.57	0.0%	0.0%	0.0%	16.7%	NA	NA	NA	NA
154	316	0.83	Low	NAP	15	1	5	33.3%	29.65	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
405	317	0.83	Low	CPL	23	1	6	26.1%	29.09	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
96	318	0.83	Low	NAP	13	1	2	15.4%	22.38	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
								100.0									
545	319	0.83	Low	XER	7	1	7	%	33.95	0.0%	71.4%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
495	320	0.82	Low	UMW	9	0	1	11.1%	22.39	66.7%	66.7%	33.3%	33.3%	NA	NA	NA	NA
103	321	0.82	Low	CPL	27	1	7	25.9%	31.87	3.7%	3.7%	0.0%	7.4%	0.0%	0.0%	0.0%	0.0%
216	322	0.82	Low	UMW	7	1	1	14.3%	22.78	0.0%	14.3%	0.0%	14.3%	0.0%	0.0%	0.0%	0.0%
339	323	0.81	Low	WMT	22	1	1	4.5%	23.71	22.7%	40.9%	13.6%	31.8%	0.0%	0.0%	0.0%	0.0%
190	324	0.79	Low	NAP	9	2	6	66.7%	10.30	11.1%	22.2%	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%
209	325	0.78	Low	NAP	17	1	11	64.7%	14.44	0.0%	5.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
142	326	0.78	Low	CPL	26	1	15	57.7%	19.81	46.2%	46.2%	15.4%	15.4%	0.0%	0.0%	0.0%	0.0%
51	327	0.78	Low	CPL	13	1	5	38.5%	9.84	46.2%	61.5%	23.1%	23.1%	0.0%	100.0%	0.0%	0.0%
269	328	0.77	Low	NAP	8	1	6	75.0%	8.10	12.5%	12.5%	0.0%	12.5%	0.0%	0.0%	0.0%	0.0%
321	329	0.76	Low	UMW	14	1	3	21.4%	21.38	0.0%	7.1%	7.1%	7.1%	0.0%	0.0%	0.0%	0.0%
102	330	0.76	Low	NAP	72	4	14	19.4%	87.57	1.4%	2.8%	1.4%	2.8%	0.0%	0.0%	0.0%	0.0%
643	331	0.75	Low	XER	8	1	2	25.0%	44.44	0.0%	50.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%
521	332	0.75	Low	XER	6	0	2	33.3%	19.49	0.0%	16.7%	0.0%	33.3%	NA	NA	NA	NA
148	333	0.74	Low	CPL	21	1	12	57.1%	51.42	28.6%	28.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
213	334	0.71	Low	NAP	9	0	7	77.8%	5.18	0.0%	11.1%	0.0%	33.3%	NA	NA	NA	NA
41	335	0.71	Low	UMW	100	6	20	20.0%	65.89	14.0%	25.0%	20.0%	20.0%	0.0%	16.7%	0.0%	0.0%
201	336	0.68	Low	NAP	39	4	20	51.3%	36.94	2.6%	5.1%	0.0%	2.6%	0.0%	0.0%	0.0%	0.0%
772	337	0.67	Low	XER	7	0	4	57.1%	58.14	0.0%	57.1%	0.0%	85.7%	NA	NA	NA	NA
317	338	0.65	Low	CPL	26	1	0	0.0%	11.40	100.0%	100.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%
81	339	0.64	Low	UMW	15	2	2	13.3%	9.03	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
390	340	0.64	Low	NAP	11	0	2	18.2%	45.50	9.1%	9.1%	0.0%	0.0%	NA	NA	NA	NA
73	341	0.64	Low	NAP	74	5	38	51.4%	43.47	8.1%	24.3%	0.0%	1.4%	0.0%	20.0%	0.0%	0.0%
130	342	0.63	Low	UMW	45	3	7	15.6%	42.37	26.7%	28.9%	40.0%	40.0%	33.3%	33.3%	0.0%	0.0%
250	343	0.63	Low	NAP	19	1	10	52.6%	16.77	10.5%	15.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
584	344	0.63	Low	XER	5	1	3	60.0%	13.71	0.0%	40.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
413	345	0.62	Low	WMT	9	0	6	66.7%	20.09	0.0%	66.7%	0.0%	77.8%	NA	NA	NA	NA
431	346	0.62	Low	NAP	17	1	1	5.9%	18.44	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
325	347	0.62	Low	CPL	13	0	2	15.4%	44.69	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA

Ecological Applications

484	348	0.61	Low	TPL	9	2	1	11.1%	61.15	11.1%	33.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
177	349	0.61	Low	UMW	55	3	9	16.4%	96.63	7.3%	29.1%	20.0%	20.0%	0.0%	33.3%	0.0%	0.0%
168	350	0.60	Low	SAP	79	4	62	78.5%	72.12	5.1%	25.3%	0.0%	0.0%	25.0%	50.0%	0.0%	0.0%
536	351	0.58	Low	UMW	10	0	1	10.0%	13.38	50.0%	50.0%	50.0%	50.0%	NA	NA	NA	NA
120	352	0.56	Low	NAP	134	7	72	53.7%	73.69	3.7%	15.7%	0.0%	3.7%	14.3%	14.3%	0.0%	0.0%
347	353	0.56	Low	NAP	12	2	1	8.3%	34.38	0.0%	25.0%	8.3%	8.3%	0.0%	0.0%	0.0%	0.0%
764	354	0.55	Low	XER	6	1	7	116.7%	12.69	16.7%	33.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
476	355	0.55	Low	WMT	18	0	3	16.7%	39.64	0.0%	11.1%	0.0%	11.1%	NA	NA	NA	NA
194	356	0.53	Low	UMW	62	4	24	38.7%	57.82	1.6%	16.1%	16.1%	16.1%	0.0%	0.0%	0.0%	0.0%
359	357	0.53	Low	NAP	18	1	2	11.1%	24.92	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
466	358	0.52	Low	XER	14	1	9	64.3%	21.79	14.3%	64.3%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
305	359	0.49	Low	WMT	69	2	2	2.9%	44.83	60.9%	60.9%	60.9%	60.9%	50.0%	50.0%	50.0%	50.0%
117	360	0.48	Low	UMW	49	4	10	20.4%	97.05	8.2%	18.4%	6.1%	6.1%	0.0%	0.0%	0.0%	0.0%
328	361	0.48	Low	WMT	20	1	0	0.0%	16.99	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
243	362	0.46	Low	UMW	15	1	5	33.3%	36.36	0.0%	20.0%	0.0%	20.0%	0.0%	0.0%	0.0%	0.0%
222	363	0.46	Low	XER	9	2	4	44.4%	30.57	0.0%	55.6%	0.0%	55.6%	0.0%	100.0%	0.0%	100.0%
123	364	0.44	Low	UMW	82	3	18	22.0%	63.82	37.8%	46.3%	43.9%	43.9%	33.3%	66.7%	0.0%	0.0%
233	365	0.42	Low	NAP	47	2	9	19.1%	36.80	2.1%	6.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
419	366	0.42	Low	SAP	11	1	14	127.3%	27.43	9.1%	54.5%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
215	367	0.40	Low	SAP	12	2	3	25.0%	31.35	16.7%	41.7%	0.0%	0.0%	0.0%	50.0%	0.0%	0.0%
146	368	0.39	Low	TPL	33	1	14	42.4%	23.79	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
381	369	0.39	Low	UMW	28	3	7	25.0%	32.49	14.3%	14.3%	0.0%	0.0%	33.3%	33.3%	0.0%	0.0%
235	370	0.39	Low	UMW	79	5	10	12.7%	54.60	51.9%	51.9%	64.6%	64.6%	0.0%	0.0%	40.0%	40.0%
205	371	0.39	Low	NAP	14	1	8	57.1%	30.48	7.1%	21.4%	7.1%	7.1%	0.0%	0.0%	0.0%	0.0%
478	372	0.36	Low	WMT	6	0	2	33.3%	36.22	0.0%	0.0%	0.0%	0.0%	NA	NA	NA	NA
169	373	0.35	Low	UMW	34	2	1	2.9%	43.10	14.7%	58.8%	41.2%	41.2%	50.0%	100.0%	0.0%	0.0%
304	374	0.35	Low	UMW	16	1	4	25.0%	21.71	6.3%	56.3%	0.0%	43.8%	100.0%	100.0%	0.0%	0.0%
315	375	0.34	Low	NAP	44	0	14	31.8%	42.08	11.4%	22.7%	2.3%	2.3%	NA	NA	NA	NA
74	376	0.31	Low	UMW	58	1	19	32.8%	62.44	1.7%	25.9%	5.2%	5.2%	0.0%	0.0%	0.0%	0.0%
329	377	0.29	Low	XER	19	2	7	36.8%	41.33	15.8%	31.6%	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%
70	378	0.29	Low	NAP	29	2	17	58.6%	20.24	10.3%	27.6%	0.0%	3.4%	0.0%	0.0%	0.0%	0.0%
199	379	0.28	Low	NAP	89	6	35	39.3%	67.31	2.2%	20.2%	0.0%	0.0%	16.7%	50.0%	0.0%	0.0%
212	380	0.28	Low	UMW	33	2	5	15.2%	16.51	12.1%	15.2%	12.1%	12.1%	0.0%	0.0%	0.0%	0.0%
135	381	0.25	Low	NAP	24	1	6	25.0%	33.32	0.0%	16.7%	8.3%	8.3%	0.0%	0.0%	0.0%	0.0%
111	382	0.23	Low	WMT	18	1	12	66.7%	54.53	5.6%	5.6%	16.7%	16.7%	0.0%	0.0%	0.0%	0.0%
353	383	0.21	Low	NAP	26	1	5	19.2%	22.40	0.0%	7.7%	0.0%	3.8%	0.0%	0.0%	0.0%	0.0%
86	384	0.18	Low	TPL	36	2	19	52.8%	54.77	5.6%	5.6%	0.0%	5.6%	0.0%	0.0%	0.0%	0.0%
234	385	0.12	Low	CPL	46	1	13	28.3%	53.60	2.2%	2.2%	0.0%	4.3%	0.0%	0.0%	0.0%	0.0%



<sup>a</sup>Strict protection=managed for biodiversity (GAPS 1-2), multi-use=managed for biodiversity and natural resource extraction (GAP 3)

<sup>b</sup> Network ID = unique network identifier in LAGOS-US-NETWORKS,

<sup>c</sup> CPL=Coastal Plains, NAP=Northern Appalachians, NPL=Northern Plains, SAP=Southern Appalachians, SPL=Southern Plains, TPL=Temperate Plains, UMW=Upper Midwest, WMT=Western Mountains, XER=Xeric

<sup>d</sup> Dam rate = number of dams/number of lakes in a network

For Review Only

Table S3. Freshwater networks in the conterminous US that meet conservation targets<sup>a</sup>

Ecoregion <sup>b</sup>	17% Aichi target				30% by 2030				Total networks <sup>c</sup>
	Strict, lake center	Strict + multi-use, lake center	Strict, 80% watershed	Strict + multi-use, 80% watershed	Strict, lake center	Strict + multi-use, lake center	Strict, 80% watershed	Strict + multi-use, 80% watershed	
CPL	88 (36.2%)	106 (43.6%)	21 (8.6%)	28 (11.5%)	81 (33.3%)	94 (38.7%)	16 (6.6%)	23 (9.5%)	243
NAP	29 (14.1%)	73 (35.4%)	15 (7.3%)	26 (12.6%)	19 (9.2%)	48 (23.3%)	12 (5.8%)	23 (11.2%)	206
NPL	11 (39.3%)	15 (53.6%)	1 (3.6%)	3 (10.7%)	10 (35.7%)	13 (46.4%)	0 (0.0%)	3 (10.7%)	28
SAP	0 (0.0%)	3 (30.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (20.0%)	0 (0.0%)	0 (0.0%)	10
SPL	1 (12.5%)	1 (12.5%)	0 (0.0%)	1 (12.5%)	0 (0.0%)	1 (12.5%)	0 (0.0%)	1 (12.5%)	8
TPL	16 (27.6%)	23 (39.7%)	2 (3.5%)	2 (3.5%)	11 (19.0%)	16 (27.6%)	2 (3.5%)	2 (3.5%)	58
UMW	35 (23.3%)	75 (50.05%)	39 (26.0%)	52 (34.7%)	30 (20.0%)	63 (20.0%)	32 (21.3%)	43 (28.7%)	150
WMT	41 (38.0%)	67 (62.0%)	31 (28.7%)	53 (49.1%)	37 (34.3%)	63 (42.0%)	28 (26.0%)	53 (49.1%)	108
XER	20 (23.3%)	64 (74.4%)	11 (12.8%)	39 (45.4%)	17 (19.8%)	59 (68.6%)	9 (10.5%)	38 (44.2%)	86
Overall	241 (26.9%)	427 (47.6%)	120 (13.4%)	204 (22.7%)	205 (22.9%)	359 (40.0%)	99 (11.0%)	186 (20.7%)	897

<sup>a</sup>Strict protection=managed for biodiversity (GAPS 1-2), multi-use=managed for biodiversity and natural resource extraction (GAP 3)

<sup>b</sup>CPL=Coastal Plains, NAP=Northern Appalachians, NPL=Northern Plains, SAP=Southern Appalachians, SPL=Southern Plains, TPL=Temperate Plains, UMW=Upper Midwest, XER=Xeric

<sup>c</sup>All freshwater networks in the conterminous US except the Mississippi River network

Table S4. Lake protection<sup>a</sup> across all freshwater networks in the conterminous US

Ecoregion <sup>b</sup>	Network lakes					Hub lakes				
	Strict, lake center	Strict + multi-use, lake center	Strict, 80% watershed	Strict + multi-use, 80% watershed	Total network lakes	Strict, lake center	Strict + multi-use, lake center	Strict, 80% watershed	Strict + multi-use, 80% watershed	Total hub lakes
CPL	636 (3.5%)	949 (5.2%)	203 (1.1%)	362 (2.0%)	18336	34 (6.4%)	51 (9.7%)	9 (1.7%)	11 (2.1%)	528
NAP	635 (5.1%)	1737 (13.9%)	917 (7.4%)	1389 (11.1%)	12464	24 (5.3%)	60 (13.3%)	14 (3.1%)	18 (4.0%)	451
NPL	2507 (30.7%)	4981 (61.0%)	1407 (17.2%)	4537 (55.6%)	8166	1 (20.0%)	1 (20.0%)	0 (0.0%)	0 (0.0%)	5
SAP	92 (0.8%)	210 (1.8%)	38 (0.3%)	85 (0.7%)	11872	20 (6.8%)	40 (13.6%)	4 (1.4%)	10 (3.4%)	295
SPL	126 (1.8%)	207 (3.0%)	77 (1.1%)	179 (2.6%)	6871	3 (2.9%)	6 (5.8%)	0 (0.0%)	0 (0.0%)	103
TPL	63 (0.8%)	90 (1.1%)	13 (0.2%)	15 (0.2%)	8297	25 (13.2%)	37 (19.5%)	6 (3.2%)	6 (3.2%)	190
UMW	1302 (13.4%)	2304 (23.8%)	1165 (12.0%)	1698 (17.5%)	9691	42 (16.2%)	78 (30.0%)	23 (8.8%)	57 (21.9%)	260
WMT	3430 (40.5%)	5205 (61.4%)	3220 (38.0%)	5183 (61.1%)	8476	54 (32.0%)	115 (68.0%)	61 (36.1%)	118 (69.8%)	169
XER	81 (3.5%)	253 (10.8%)	39 (1.7%)	170 (7.3%)	2338	5 (6.3%)	25 (31.6%)	1 (1.3%)	11 (13.9%)	79
Overall	8872 (10.2%)	15936 (18.4%)	7079 (8.2%)	13618 (15.7%)	86511	208 (10.0%)	413 (19.9%)	118 (5.7%)	231 (11.1%)	2080

<sup>a</sup>Strict protection=managed for biodiversity (GAPS 1-2), multi-use=managed for biodiversity and natural resource extraction (GAP 3)

<sup>b</sup>CPL=Coastal Plains, NAP=Northern Appalachians, NPL=Northern Plains, SAP=Southern Appalachians, SPL=Southern Plains, TPL=Temperate Plains, UMW=Upper Midwest, XER=Xeric