Appendices to the Technical Support Document for the Proposed "Revised Definition of 'Waters of the United States'" Rule

U.S. Environmental Protection Agency

and

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Appendices

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Appendix A: Glossary

Most of the terms in this glossary are derived directly from the Science Report. Some terms are denoted by Clean Water Act, NWPR, or Science Report to indicate if they are being defined in the context of the Clean Water Act (including under the agencies longstanding regulations and the proposed rule defining "waters of the United States"), the Navigable Waters Protection Rule, or the Science Report, respectively.

Allochthonous: Describing organic material that originates from outside of streams, rivers, wetlands, or lakes (e.g., terrestrial plant litter, soil).

Alluvial Aquifer: An aquifer with geologic materials deposited by a stream or river (alluvium) that retains a hydraulic connection with the depositing stream.

Alluvial Deposits: *See* Alluvium.

Alluvium: Deposits of clay, silt, sand, gravel, or other particulate materials that have been deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain. *See* Colluvium.

Aquatic Ecosystem: Any aquatic environment, including all of the environment's living and nonliving constituents and the interactions among them.

Aquifer: A geologic formation (e.g., soil, rock, alluvium) with permeable materials partially or fully saturated with ground water that yields ground water to a well, spring, or stream.

Autochthonous: Describing organic matter that originates from production within streams, rivers, wetlands, or lakes (e.g., periphyton, macrophytes, phytoplankton).

Bank Storage: Storage of water that flows from a stream to an alluvial aquifer during a flood or period of high streamflow. The volume of water is stored and released after the high-water event over days to months. The volume of water stored and the timing of release depends on the hydraulic properties of the alluvial aquifer.

Baseflow: Sustained flow of a stream (or river) in the absence of stormflow (direct runoff). Natural baseflow is sustained by ground-water discharge in the stream network. Baseflow also can be sustained by human sources (e.g., irrigation recharges to ground water).

Carolina Bays: Elliptical, ponded, depressional wetlands that range along the Atlantic Coastal Plain from northern Florida to New Jersey. *See* Delmarva Bays.

Catchment: The area drained by a stream, river, or other water body; typically defined by the topographic divides between one water body and another. *Synonymous with* Watershed *and* Drainage Basin.

Channel: A natural or constructed passageway or depression of perceptible linear extent that conveys water and associated material downgradient.

Channelization: A type of artificial drainage in which complex channels are straightened to increase the rate of water flow from an area.

Channelized Flow: Flow that occurs in a natural or artificial channel.

Colluvium: A layer of unconsolidated soils, sediment and rock fragments deposited by surface runoff and gravitational processes; colluvium generally occurs as a blanket of poorly sorted sediment and rock fragments on the lower parts of hillslopes underlain by bedrock. *See* Alluvium.

Condition: General health or quality of an ecosystem, typically assessed using one or more indicators.

Confined Aquifer: An aquifer bounded above and below by confining units of distinctly lower permeability than that of the aquifer itself.

Confluence: The point at which two stream channels intersect to form a single channel.

Connectivity: The degree to which components of a river system are joined, or connected, by various transport mechanisms; connectivity is determined by the characteristics of both the physical landscape and the biota of the specific system.

Connectivity Descriptors (for streams and wetlands): The frequency, duration, magnitude, timing, and rate of change of fluxes to and biological exchanges with downstream waters.

Contributing Area: Location within a watershed/river network that serves as a source of stream flow or material flux.

Contaminants: Any material that might be harmful to humans or other organisms when released to the environment.

Deep Ground Water: Ground-water flow systems having the deepest and longest flowpaths; also referred to as regional ground-water flow systems, they can occur beneath local and intermediate ground-water flow systems. *See* Local Ground Water, Regional Ground Water.

Delmarva Bays: Carolina bays that are geographically specific to the Delmarva Peninsula. These wetlands frequently have the same elliptical shape and orientation as Carolina bays. *See* Carolina Bays.

Dendritic Stream Network: A stream network pattern of branching tributaries (see Figure 2-19B).

Depressional Wetland: A wetland occupying a topographic low point that allows the accumulation of surface water. Depressional wetlands can have any combination of inlets and outlets or lack them completely. Examples include kettles, prairie potholes, and Carolina bays. This category also includes slope wetlands (wetlands associated with surface discharge of ground water or saturated overflow with no channel formation).

Diadromous: Migratory between fresh and salt waters.

Direct Runoff: Runoff that occurs in direct response to precipitation. *See* Stormflow.

Discharge (Science Report): The volume of water (surface water or ground water) that passes a given location over a given period of time; the rate of runoff. Often expressed as cubic feet per second ($ft^3\ s^{-1}$) or cubic meters per second ($m^3\ s^{-1}$).

Discharge (Clean Water Act): The term "discharge" when used without qualification includes a discharge of a pollutant, and a discharge of pollutants. Clean Water Act section 502(16).

Discharge of a pollutant (Clean Water Act): The term "discharge of a pollutant" and the term "discharge of pollutants" each means (A) any addition of any pollutant to navigable waters from any point source, (B) any addition of any pollutant to the waters of the contiguous zone or the ocean from any point source other than a vessel or other floating craft. Clean Water Act section 502(12).

Discontinuous Flow: Refers to stream and river reaches that have flow in one part of the reach but not another part of the reach. *See* Reach.

Dispersal: Movement from natal breeding sites to new breeding sites.

Drainage Area: The spatial extent of a drainage basin. Typically expressed in square miles (mi^2) or square kilometers (km^2).

Drainage Basin: The area drained by a stream, river, or other water body; typically defined by the topographic divides between one water body and another. *Synonymous with* Catchment *and* Watershed.

Drainage Density: The total length of stream channels per unit drainage area (e.g., per mi2 or km2).

Drainage Network: *See* River Network.

Egg Bank: Viable dormant eggs that accumulate in soil or in sediments under water. *See* Seed bank.

Endorheic Basins: A closed drainage basin with no outflows to other water bodies.

Endorheic Stream: A stream or river reach that experiences a net loss of water to a ground-water system. *See* Losing Stream or Wetland.

Ephemeral (NWPR): The term *ephemeral* means surface water flowing or pooling only in direct response to precipitation (*e.g.*, rain or snow fall). 85 FR 22338; 33 CFR 328.3(c)(3) (2021).

Ephemeral Stream (Science Report): A stream or river that flows briefly in direct response to precipitation; these channels are always above the water table.

Eutrophication: Natural or artificial enrichment of a water body by nutrients, typically phosphates and nitrates. If enrichment leads to impairment (*e.g.*, toxic algal blooms), eutrophication is a form of pollution.

Evapotranspiration: The combined loss of water to the atmosphere due to evaporation and transpiration losses. Transpiration is the loss of water vapor to air by plants.

Fen: A peat-accumulating wetland characterized by mineral-rich water inputs.

Flood: The occurrence of stream or river flow of such magnitude that it overtops the natural or artificial banks in a reach of the stream or river; where a floodplain exists, a flood is any flow that spreads over or inundates the floodplain. Floods also can result from rising stages in lakes and other water bodies.

Flood (100-year): Flood level (stage or discharge) with a 1% probability of being equaled or exceeded in a given year.

Flood Flows: Discharge or flow of sufficient (or greater) magnitude to cause a flood.

Flood Recurrence Interval: The average number of years between floods of a certain size is the recurrence interval or return period. The actual number of years between floods of any given size varies a lot because of the naturally changing climate. USGS.

Flood Stage: The stage at which streams or rivers overtop their natural or artificial banks.

Floodwater: Water associated with a flood event.

Floodplain: A level area bordering a stream or river channel that was built by sediment deposition from the stream or river under present climatic conditions and is inundated during moderate to high flow events. Floodplains formed under historic or prehistoric climatic conditions can be abandoned by rivers and form terraces.

Floodplain Wetland: Portions of floodplains that meet the Cowardin *et al.* (1979) three-attribute definition of a wetland (*i.e.*, having wetland hydrology, hydrophytic vegetation, or hydric soils). *See* Wetland.

Flow: Water movement above ground or below ground.

Flow Duration Class: A classification that assigns streamflow duration to ephemeral, intermittent, or perennial classes.

Flow Regime: Descriptor of flow types in a temporal or magnitude sense (i.e., slow-flow regime, low-flow regime)

Flowpath: *See* Hydrologic Flowpath.

Fluvial: Refers to or pertains to streams; *e.g.*, stream processes (fluvial processes), fluvial landforms, such as fluvial islands and bars, and biota living in and near stream channels.

Flux: Flow of materials between system components per unit time.

Gaining Stream or Wetland: A wetland or a stream or river reach that experiences a net gain of water from ground water (see Figure 2-5). In this situation, the water table elevation near the stream or wetland is higher than the stream or wetland water surface. Conditions conducive to losing or gaining streams and wetlands can change over short distances within river networks and river basins. *See* Losing Stream or Wetland.

Geographically Isolated Wetland: A wetland that is completely surrounded by uplands; for example, hydrophytic plant communities surrounded by terrestrial plant communities or undrained hydric soils surrounded by nonhydric soils. This term often is mistakenly understood to mean hydrologically isolated. Geographically isolated wetlands vary in their degree of hydrologic and biotic connectivity.

Ground Water: Any water that occurs and flows in the saturated zone. *See* Saturated Zone.

Ground-water Discharge: The flow of ground water to surface waters; discharge areas occur where the water tables intersect land surfaces. *See* Seep, Spring.

Ground-water Discharge Wetland: A wetland that receives ground-water discharge.

Ground-water Flow: Flow of water in the subsurface saturated zone.

Ground-water Recharge: The process by which ground water is replenished; a recharge area occurs where precipitation or surface water infiltrates and is transmitted downward to the saturated zone (aquifer). *See* Infiltration, Percolation, Transmission.

Ground-water Recharge Wetland: A wetland that recharges ground water.

Ground-water System: Reference to the ground water and geologic materials comprising the saturated zone; the ground-water system, as a whole, is a three-dimensional flow field.

Ground water–Surface water Interactions: Movement of water between surface-water bodies and ground-water systems. Flows can occur in either direction.

Ground-water Withdrawal: Pumping of water from aquifers for human uses.

Habitat: Environment (place and conditions) in which organisms reside.

Headwater: Areas from which water originates within a river or stream network. This term typically refers to stream channels but can also describe wetlands or open waters, such as ponds.

Headwater Stream: Headwater streams are first- to third-order streams. Headwater streams can be ephemeral, intermittent, or perennial. *See* Stream Order, Flow Duration Class.

Hillslope: A sloping segment of land surface.

Hydraulic Conductivity: A measure of the permeability of a porous medium. For a given hydraulic gradient, water moves more rapidly through media with high hydraulic conductivity than low hydraulic conductivity.

Hydraulic Gradient: Slope of the water table. *See* Water Table.

Hydraulic Head: The height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point; for a well, the hydraulic head is the height of the water level in the well compared to a datum elevation.

Hydraulics: The physics of water in its liquid state.

Hydric: An area, environment, or habitat that is generally very wet with plenty of moisture.

Hydrograph: A graph of stream or river discharge over time. Stage or water table elevation also can be plotted.

Hydrologic Event: An increase in streamflow resulting from precipitation or snowmelt.

Hydrologic Flowpath: The pathway that water follows as it moves over the watershed surface or through the subsurface environment.

Hydrology: The study of the properties, distribution, and effects of water as a liquid, solid, and gas on Earth's surface, in the soils and underlying rocks, and in the atmosphere.

Hydrologic Landscape: A landscape with a combination of geology, soils, topography, and climate that has characteristic influences on surface water and ground water.

Hydrologic Permanence: The frequency and duration of streamflow in channels or the frequency and duration of standing water in wetlands.

Hyporheic Flow: Water from a stream or river channel that enters subsurface materials of the streambed and bank and then returns to the stream or river.

Hyporheic Exchange: Water and solutes exchanged between a surface channel and the shallow subsurface. *See* Hyporheic Flow.

Hyporheic Zone: The area adjacent to and beneath a stream or river in which hyporheic flow occurs. The dimensions of the hyporheic zone are controlled by the distribution and characteristics of alluvium and hydraulic gradients between streams and local ground water.

Hypoxia: The condition in which dissolved oxygen is below the level necessary to sustain most animal life. *See* Anoxic Conditions.

Infiltration: The downward entry of water from the land surface into the subsurface.

Intermittent (NWPR): The term *intermittent* means surface water flowing continuously during certain times of the year and more than in direct response to precipitation (*e.g.*, seasonally when the groundwater table is elevated or when snowpack melts).

Intermittent (Science Report): This term also can be applied to other surface-water bodies and ground-water flow or level. *See* Intermittent Stream.

Intermittent Stream: A stream or portion of a stream that flows continuously only at certain times of year; for example, when it receives water from a spring, ground-water source, or a surface source such as melting snow. At low flow, dry segments alternating with flowing segments can be present.

Inundation: To cover dry land with floodwaters.

Isolation: Condition defined by reduced or nonexistent transport mechanisms between system components.

Lag Function: Any function within a stream or wetland that provides temporary storage and subsequent release of materials without affecting cumulative flux (exports = imports); delivery is delayed and can be prolonged.

Lateral Source Stream: A first-order stream that flows into a higher order stream.

Lentic: Of, relating to, or living in still water. *See* Lotic.

Levee (Artificial): An engineered structure built next to a stream or river from various materials to prevent flooding of surrounding areas. The levee raises the elevation of the channel height to convey greater discharge of water without flooding.

Levee (Natural): A broad, low ridge or embankment of coarse silt and sand that is deposited by a stream on its floodplain and along either bank of its channel. Natural levees are formed by reduced velocity of flood flows as they spill onto floodplain surfaces and can no longer transport the coarse fraction of the suspended sediment load.

Local Ground Water: Ground water with a local flow system. Water that recharges at a high point in the water table that discharges to a nearby lowland. Local ground-water flow is the most dynamic and shallowest of ground-water flow systems. Therefore, it has the greatest interchange with surface water. Local flow systems can be underlain by intermediate and regional flow systems. Water in these deeper flow systems have longer flowpaths and longer contact time with subsurface materials. Deeper flow systems also eventually discharge to surface waters and influence their condition.

Losing Stream or Wetland: A stream, wetland, or river reach that experiences a net loss of water to a ground-water system (*see* Figure 2-5 of the Science Report). In this situation, the water table elevation near the stream or wetland is lower than the stream or wetland water surface. Conditions conducive to losing or gaining streams and wetlands can change over short distances within river networks and river basins. *See* Gaining Stream or Wetland.

Lotic: Of, relating to, or living in moving water. *See* Lentic.

Mainstem: Term used to distinguish the larger (in terms of discharge) of two intersecting channels in a river network.

Materials: Any physical, chemical, or biological entity, including but not limited to water, heat energy, sediment, wood, organic matter, nutrients, chemical contaminants, and organisms.

Meltwater: Liquid water that results from the melting of snow, snowpacks, ice, or glaciers.

Migration: Long-distance movements undertaken by organisms on a seasonal basis.

Non-floodplain Wetland: An area outside of the floodplain that meets the Cowardin *et al*. (1979) three-attribute definition of a wetland (i.e., having wetland hydrology, hydrophytic vegetation, or hydric soils). For the purposes of this report, riparian wetlands that occur outside of the floodplain are not included as non-floodplain wetlands, since these wetlands are subject to bidirectional, lateral hydrologic flows. *See* Floodplain, Wetland.

Nutrients (In Aquatic Systems): Elemental forms of nitrogen, phosphorus, and trace elements, including sulfur, potassium, calcium, and magnesium, that are essential for the growth of organisms but can be contaminants when present in high concentrations.

Nutrient Spiraling: Longitudinal cycles ("spirals") of nutrient uptake and release along the stream or river continuum. The spirals are created as aquatic organisms consume, transform, and regenerate nutrients, altering the rates of nutrient transport to downstream waters.

Open-channel Flow: Water flowing within natural or artificial channels.

Open Waters: Nontidal lentic water bodies such as lakes and oxbow lakes that are frequently small or shallow.

Overbank Flow: Streamflow that overtops a stream or river channel.

Overland Flow: The portion of streamflow derived from net precipitation that fails to infiltrate the land surface at any point and runs over the surface to the nearest stream channel.

Oxbow Lakes: Water bodies that originate from the cutoff meanders of rivers; such lakes are common in floodplains of large rivers.

Peatland: A wetland that accumulates partially decayed organic matter. Fens and bogs are common examples.

Perched Ground Water: Unconfined ground water separated from an underlying body of ground water by an unsaturated zone; perched ground water is supported by a perching layer (bed) for which the permeability is so low that water percolating downward to the underlying unsaturated zone is restricted.

Percolation: The downward movement of water through soil or rock formations.

Perennial (NWPR): The term *perennial* means surface water flowing continuously year-round.

Perennial (Science Report): *See* Perennial Stream. This term can be applied to other surface-water bodies and to ground-water flow or level.

Perennial Stream: A stream or portion of a stream that flows year-round and is maintained by local, intermediate, or regional ground-water discharge or flow from higher in the river network.

Permanent Waters: Water bodies that contain water year-round; perennial waters.

Permeability: Property of a porous medium that enables it to transmit fluids under a hydraulic gradient. For a given hydraulic gradient, water will move more rapidly through high permeability materials than low permeability materials.

Potential Evapotranspiration: The amount of water that would be lost to the atmosphere over a given area through evaporation and transpiration, assuming no limits on the water supply. *See* Evapotranspiration.

Prairie Potholes: Complex of glacially formed wetlands, usually lacking natural outlets, found in the central United States and Canada.

Precipitation: Water that condenses in the atmosphere and falls to a land surface. Common types include rain, snow, hail, and sleet.

Precipitation Intensity: The rate at which precipitation occurs; generally refers to rainfall intensity.

Primary Production: The fixation of inorganic carbon into organic carbon (*e.g.*, plant and algae biomass) through the process of photosynthesis. Primary production is the first level of the food web, and provides most of the autochthonous carbon produced in ecosystems. The rate of fixation is referred to as gross primary productivity (GPP) or net primary productivity (NPP), where NPP is equal to GPP minus respiration. *See* Respiration, Secondary Production.

Propagule: Any part of an organism that can give rise to a new individual organism. Seeds, eggs, and spores are propagules.

Reach (Science Report): A length of stream channel with relatively uniform discharge, depth, area, and slope.

Recession [of Flow]: Decrease in flow following a hydrologic event.

Recharge Area: An area in which water infiltrates the surface and reaches the zone of saturation.

Refuge Function: The protective function of a stream or wetland that allows an organism (or material) to avoid mortality (or loss) in a nearby sink area, thereby preventing the net decrease in material flux that otherwise would have occurred (exports = imports). This term typically refers to organisms but can be used for nonliving materials. *See* Sink Function.

Regional Ground Water: Ground water with a deep, regional-scale flow system; also referred to as deep ground water. These flow systems can occur beneath local and intermediate ground-water flow systems. *See* Local Ground Water, Deep Ground Water.

Respiration: The chemical process by which organisms break down organic matter and produce energy for growth, movement, and other biological processes. Aerobic respiration uses oxygen and produces carbon dioxide.

Return Flow: Water that infiltrates into a land surface and moves to the saturated zone and then returns to the land surface (or displaces water that returns to the soil surface).

Riparian Areas: Transition areas or zones between terrestrial and aquatic ecosystems that are distinguished by gradients in biophysical conditions, ecological processes, and organisms. They are areas through which surface hydrology and subsurface hydrology connect water bodies with their uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems. Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine-marine shorelines. *See* Upland.

Riparian Wetland: Portions of riparian areas that meet the Cowardin et al. (1979) three-attribute definition of a wetland (i.e., having wetland hydrology, hydrophytic vegetation, hydric soils). *See* Wetland.

River: A relatively large volume of flowing water within a visible channel, including subsurface water moving in the same direction as the surface water, and lateral flows exchanged with associated floodplain and riparian areas. *See* Stream.

River Network: A hierarchical, interconnected population of channels or swales that drain water to a river. Flow through these channels can be perennial, intermittent, or ephemeral.

River Network Expansion/Contraction: The extent of flowing water in a river network increases during wet seasons and large precipitation events and decreases during dry periods. *See* Variable Source Area.

River System: A river and its entire drainage basin, including its river network, associated riparian areas, floodplains, alluvial aquifers, regional aquifers, connected water bodies, geographically isolated water, and terrestrial ecosystems.

Runoff: The part of precipitation, snowmelt, or other flow contributions (e.g., irrigation water) that appears in surface streams at the outlet of a drainage basin; it can originate from both above land surface (e.g., overland flow) and below land surface sources (e.g., ground water). Units of runoff are depth of water (similar to precipitation units, e.g., mm). This measurement is the depth of water if it were spread across the entire drainage basin. Can also be expressed as a volume of water (i.e., m3, feet3, acre-ft).

Saturated Zone: The zone below the land surface where the voids in soil and geologic material are completely filled with water. Water in the saturated zone is referred to as ground water. The upper surface of the saturated zone is referred to as the water table. *See* Ground Water, Unsaturated Zone, Water Table.

Saturation Overland Flow: Water that falls onto a saturated land surface and moves overland to the nearest stream or river.

Seasonality: Refers to the seasonal distribution of water surplus of a river system. *See* Water Surplus.

Secondary Production: The generation of biomass of consumer organisms that feed on organic material from primary producers (algae, microbes, aquatic and terrestrial plants), and biomass of predators that feed on consumer organisms. *See* Primary Production.

Seed Bank: Viable dormant seeds that accumulate in soil or in sediments under water. *See* Egg bank.

Seep: A small area where water slowly flows from the subsurface to the surface. A seep can also refer to a wetland formed by a seep; such a wetland is referred to as a ground-water slope wetland.

Seepage: Water that flows from a seep.

Shallow Ground Water: Ground water with shallow hydrologic flowpaths. *See* Local Ground Water.

Sink Function: Any function within a stream or wetland that causes a net decrease in material flux (imports exceed exports).

Snowpack (Science Report): Accumulation of snow during the winter season; an important source of water for streams and rivers in the western United States.

Snowmelt: The complete or partial melting and release of liquid water from seasonal snowpacks.

Solute: A substance that is dissolved in water.

Source Area: The originating location of water or other materials that move through a river system.

Source Function: Any function within a stream or wetland that causes a net increase in material flux (exports exceed imports).

Spillage: Overflow of water from a depressional wetland to a swale or channel.

Spring: A surface-water body formed when the side of a hill, a valley bottom, or other excavation intersects a flowing body of ground water at or below the local water table.

Stable Isotope Tracer: Certain elements such as oxygen, hydrogen, carbon, and nitrogen have multiple isotopes that occur in nature that do not undergo radioactive decay. These isotopes can be used to track the source and movement of water and other substances.

Stage: The elevation of the top of a water surface.

Stream: A relatively small volume of flowing water within a visible channel, including subsurface water moving in the same direction as the surface water, and lateral flows exchanged with associated floodplain and riparian areas. *See* River.

Stream Burial: The process of incorporating streams—particularly headwaters—into storm sewer systems, usually by routing through underground pipes.

Stream Power: A measure of the erosive capacity of flowing water in stream channels or the rate of energy dissipation against the stream bed or banks per unit of channel length that has the mathematical form: $\omega a = \rho gQS$ where ωa is the stream power, ρ is the density of water (1000 kg/m3), g is acceleration due to gravity (9.8 m/s2), Q is discharge (m3/s), and S is the channel slope.

Stream Network—*See* River Network. A stream network is the same as river network, but typically refers to a smaller spatial scale.

Stream Reach: *See* Reach.

Storm: A precipitation event that produces an increase in streamflow.

Stormflow: The part of flow through a channel that occurs in direct response to precipitation; it includes surface and subsurface sources of flow. *See* Direct Runoff.

Stream Order (Strahler): A method for stream classification based on relative position within a river network, when streams lacking upstream tributaries (*i.e.*, headwater streams) are first-order streams and the junction of two streams of the same order results in an increase in stream order (*i.e.*, two first-order streams join to form a second-order stream, two second-order streams join to form a third-order stream, and so on). When streams of different order join, the order of the larger stream is retained. Stream-order classifications can differ, depending on the map scale used to determine order.

Streamflow: Flow of water through a stream or river channel. *See* Discharge.

Subsurface Water: All water that occurs below the land surface.

Surface Runoff: *See* Overland Flow.

Surface Water: Water that occurs on Earth's surface (e.g., springs, streams, rivers, lakes, wetlands, estuaries, oceans).

Surface-water Bodies: Types of water bodies that comprise surface water. *See* Surface Water.

Swale (Science Report): A nonchannelized, shallow trough-like depression that carries water mainly during rainstorms or snowmelt. A swale might or might not be considered a wetland depending on whether it meets the Cowardin *et al.* (1979) three-attribute wetland criteria. *See* Wetland.

Symmetry Ratio: The size ratio of a minor tributary ($T2$) to a major tributary ($T1$) at a confluence. Discharge ($Q2/Q1$), drainage area ($A2/A1$), or channel width ($W2/W1$) can be used to characterize the ratio of tributary size.

Terminal Source Stream: A first-order stream that intersects another first-order stream.

Terrace: An historic or prehistoric floodplain that has been abandoned by its river and is not currently in the active floodplain. *See* Floodplain.

Tracer: A substance that can be used to track the source and movement of water and other substances.

Transformation Function: Any function within a stream or wetland that converts a material into a different form; the amount of the base material is unchanged (base exports equal base imports), but the mass of the different forms can vary.

Transmission Loss: The loss of runoff water by infiltration into stream and river channel beds as water moves downstream; this process is common in arid and semiarid environments.

Transport Mechanism: Any physical mechanism, such as moving water, wind, or movement of organisms, which can transport materials or energy. As used in this report, the term specifically refers to physical mechanisms that move material or energy between streams or wetlands and downstream waters.

Tributary (Science Report): A stream or river that flows into a higher order stream or river.

Unconfined Aquifer: An aquifer that has a water table; the aquifer is not bounded by lower permeability layers. *See* Confined Aquifer.

Unsaturated Zone: Also referred to as the vadose zone. The zone between land surface and the water table within which the moisture content is less than saturation and pressure is less than atmospheric. Soil pore spaces also typically contain air or other gases. *See* Saturated Zone.

Uplands: (1) Higher elevation lands surrounding streams and their floodplains. (2) Within the wetland literature, specifically refers to any area that is not a water body and does not meet the Cowardin et al. (1979)-attribute wetland definition. *See* Wetland.

Uptake Length (for dissolved nitrogen in streams): The distance traveled in the water column before algal and microbial assimilation occurs.

Valley: A depression of the earth's surface that drains water between two upland areas.

Variable Source Area: Neither stormflow nor baseflow is uniformly produced from the entire surface or subsurface area of a basin. Instead, the flow of water in a stream at any given moment is influenced by dynamic, expanding or shrinking source areas, normally representing only a few percent of the total basin areas. The source area is highly variable during stormflow. During large rainfall or snowmelt events, the flowing portions of the river network, and associated source areas, expand. As the event ends, the network and source areas contract.

Vernal Pool: Shallow seasonal wetlands that generally accumulate water during colder, wetter months and gradually dry down during warmer, dryer months.

Water Balance: The accounting of the volume of water that enters, leaves, and is stored in a hydrologic unit, area, or arbitrarily defined control volume, typically a drainage basin or aquifer, during a specified period of time.

Water Body: Any sizable accumulation of water on the land surface, including streams, rivers, lakes, and wetlands.

Water Surplus: Water that is available for streamflow or recharge of ground water; precipitation minus evapotranspiration.

Water Table: The top of the zone of saturation of an unconfined aquifer.

Watershed: The area drained by a stream, river, or other water body; typically defined by the topographic divides between one water body and another. *Synonymous with* Catchment *and* Drainage Basin.

Wet Channel: Channel with flowing or standing water.

Wetland (Science Report): An area that generally exhibits at least one of the following three attributes (Cowardin *et al*., 1979): (1) is inundated or saturated at a frequency sufficient to support, at least periodically, plants adapted to a wet environment; (2) contains undrained hydric soil; or (3) contains nonsoil saturated by shallow water for part of the growing season.

Wetlands (Clean Water Act): The term *wetlands* means areas that are nundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Wetland Storage: The capacity of a wetland to detain or retain water from various sources.

Appendix B: References

Note that the below references are only those that were cited in this technical support document. In addition, EPA's Office of Research and Development considered additional peer-reviewed literature for the completion of the Science Report and in the review of literature published since the Science Report's publication. The references for the Science Report are available in that Report, which is available in the Docket for the proposed rule and on EPA's website at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=296414. The references considered for the literature update are available in Appendix C. The agencies solicit comment on whether additional citations should be added to the Technical Support Document.

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Appendix C: References from the Literature Update Screening

As discussed in section II.C of the Technical Support Document, subject-matter experts from the U.S. Environmental Protection Agency's Office of Research and Development conducted a screening analysis to identify papers that were relevant to the major conclusions of the Science Report. Appendix C1 contains those references that the screeners believed were relevant to the conclusions of aquatic systems: (1) ephemeral, intermittent, and perennial streams; (2) floodplain wetlands and open waters; and (3) non-floodplain wetlands and open waters and is broken out by aquatic system. Appendix C2 contains 36 additional references identified by the screeners as being relevant to the Science Report's major conclusions. Appendix C3 contains pain-text summaries of the abstracts for a sample of the relevant literature. The agencies solicit comment on the scientific literature contained in Appendix C and if additional scientific literature and references published since 2014 are relevant to the Science Report's conclusions on the connectivity and effects of streams, wetlands, and open waters on the chemical, physical, and biological integrity of downstream water.

Appendix C1: References Relevant to the Conclusions of the Science Report Published Since 2014

The below references are references that the agencies believe are relevant to conclusions of the Science Report and have been published since 2014. The agencies are seeking comment on this list of references and if additional references are relevant to the report's conclusions but are not listed below. This list of references is derived mainly from the agencies' screening process, which is discussed in section II.C. of this document. That screening process yielded 2,022 unique citations that were found to be relevant to the conclusions of the Report. The results of that screening process have been supplemented with additional literature published since 2014 that the agencies believe are relevant to the findings of the Report but that were not captured through the screening process. For purposes of the screening, the agencies conducted screenings for references that were relevant to the Science Reports conclusions on (1) streams; (2) riparian and floodplain wetlands and open waters, and (3) riparian and non-floodplain wetlands and open waters. Note that some references are relevant to more than one system but may not be denoted as such in the below appendix.

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Appendix C3: Plain-Text Language from the Abstracts of Illustrative Scientific Papers

Illustrative peer-reviewed papers for each of the three aquatic systems analyzed by the screeners (as discussed in section II.C of the Technical Support Document) were identified during the screening process. Screeners further provided a "Plain Text" summary of the content based on the abstract. The papers are not ordered or prioritized and represent a sample of the references screened.

Ephemeral, Intermittent, and Perennial Streams

Reference	Plain Text Summary
Ebersole, J. L., P. J. Wigington, S. G. Leibowitz, R. L. Comeleo and J. Van Sickle (2015). "Predicting the occurrence of cold-water patches at intermittent and ephemeral tributary confluences with warm rivers." *Freshwater Science* 34(1): 111-124	Small tributary streams, including ephemeral channels when they do not contain surface flow, serve as sources of cold water to warmer downstream waters. Tributary basins with higher water surpluses at the end of the preceding wet season were more likely to serve as summer cold water sources; basin area and the presence of surface flow at the time of sampling were not strong predictors. Continued release of groundwater from tributary basins creates refuges for cold-water taxa.
Chara-Serna, A. N. and J. S. Richardson (2021). "Multiple-Stressor Interactions in Tributaries Alter Downstream Ecosystems in Stream Mesocosm Networks." *Water* 13(9)	Using a mesocosm study, researchers examined how stressor interactions in tributaries affected downstream second-order channels. Results showed that (1) Ephemeroptera, Plecoptera, and Trichoptera (EPT) density and richness were higher in downstream channels when stressors were applied separately in tributaries, rather than in combination, and (2) combined stressors within a tributary reduced macroinvertebrate drift into downstream channel. These results support the hypothesis that cumulative upstream disturbance can influence downstream systems.
Shogren, A. J., J. P. Zarnetske, B. W. Abbott, F. Iannucci, R. J. Frei, N. A. Griffin and W. B. Bowden (2019). "Revealing biogeochemical signatures of Arctic landscapes with river chemistry." *Scientific Reports* 9(1): 12894.	The dominant spatial scale controlling organic carbon and inorganic nutrient concentrations within three Alaska watersheds was 3-30 km2, indicating that fine scale landscape patches and a continuum of diffuse and discrete sourcing and processing dynamics are driving solute generation and transport.
Chiu, M. C., B. i. Li, K. e. Nukazawa, V. H. Resh, T. Carvajal and K. Watanabe (2020). "Branching networks can have opposing influences on genetic variation in riverine metapopulations." *Diversity and Distributions* 26(12): 1813-1824	This study was designed to examine how branching complexity within stream networks can simultaneously increase and decrease genetic divergence of macroinvertebrate metapopulations. Simulation experiments showed that more branched stream networks had both greater landscape connectivity (resulting from shorter watercourse distance) and greater isolation of headwater streams. These two spatial features have negative and positive influences on genetic divergence, with their relative importance varying among species and dispersal characteristics.

Reference	Plain Text Summary
Seymour, M., E. A. Fronhofer and F. Altermatt (2015). “Dendritic network structure and dispersal affect temporal dynamics of diversity and species persistence.” *Oikos* 124(7): 908-916	This study examined the effect of dendritic versus linear network structures on local (alpha), regional (beta) and total (gamma) diversity, using protist and rotifer assemblages as a test community. Local diversity remained higher in dendritic networks over time, especially at highly connected sites. Regional diversity was initially greater in linear networks due to dispersal limitation, but over time became more similar to regional diversity in dendritic networks. Results indicate that dispersal and network connectivity alone may, to a large extent, explain diversity dynamics.
Brennan, S. R., D. E. Schindler, T. J. Cline, T. E. Walsworth, G. Buck and D. P. Fernandez (2019). “Shifting habitat mosaics and fish production across river basins.” *Science* 364(6442): 783-786	Researchers quantified how habitat mosaics (including headwaters) are expressed across a range of spatial scales within a large, free-flowing river in Alaska. The relative productivity of locations across the river network varies widely among years and across a broad range of spatial scales, and these shifts in natal and juvenile rearing habitat help stabilize interannual Pacific salmon production at the scale of the entire basin.
Sarker, S., A. Veremyev, V. Boginski and A. Singh (2019). “Critical Nodes in River Networks.” *Scientific Reports* 9(1): 11178	In this study, researchers used an algorithm to determine the set of critical nodes (channel intersections) along river networks whose removal results in maximum network fragmentation. Results based on both simulated and natural basins in the US indicated a power-law relationship between the number of connected node pairs in the remaining river network and the number of removed critical nodes (i.e., one varies as a power of the other).
Teachey, M. E., J. M. McDonald and E. A. Ottesen (2019). “Rapid and Stable Microbial Community Assembly in the Headwaters of a Third-Order Stream.” *Applied and Environmental Microbiology* 85(11)	This study examined the development and stability of microbial communities along a first- through third order stream in Georgia. Results show that the bacterioplankton community develops rapidly and predictably from the headwater population with increasing total stream length. Along the length of the stream, the microbial community exhibits substantial diversity loss and enriches repeatedly for select taxa across days and years, although the relative abundances of individual taxa vary over time and space. This repeated enrichment of a stable stream community likely contributes to the stability and flexibility of downstream communities.
Samia, Y. and F. Lutscher (2017). “Downstream flow and upstream movement determine the value of a stream reach for potadromous fish populations.” *Theoretical Ecology* 10(1): 21-34	Because water flow transports certain local conditions downstream and individuals move upstream and downstream through river networks, the overall effects of disturbances should be examined at the scale of the entire network. Results from a fish population model show that upper stream reaches can be highly significant for population persistence if downstream transport of abiotic conditions or upstream movement of individuals is strong.

Reference	Plain Text Summary
Chezik, K. A., S. C. Anderson and J. W. Moore (2017). “River networks dampen long-term hydrological signals of climate change.” *Geophysical Research Letters* 44(14): 7256-7264	Trends over 37 years between climate and daily flow data from 55 river gauging stations within the Fraser River network in British Columbia, Canada were examined to see if flow trends diminish with increasing river size or aggregation of tributary contributions. Long-term changes in discharge variability was dampened by >91% in larger rivers than in smaller tributaries and was >3.1 times the dampening when accounting for differences in sample size (more small tributaries than large rivers in a river network). The authors suggest their findings show that integration of the contributions in a river network (i.e., river network portfolio) has a stabilizing influence on long-term hydrologic trends of downstream rivers.
Rupp, D. E., O. S. Chegwidden, B. Nijssen and M. P. Clark (2021). “Changing River Network Synchrony Modulates Projected Increases in High Flows.” *Water Resources Research* 57(4): e2020WR028713	Daily streamflow along the Columbia River and its tributaries were simulated (without dams and irrigation) to understand how climate change scenarios could influence downstream flood magnitude. One mechanism that affects flood magnitude is timing or synchrony of flooding between on a river and its branches or tributaries. Under moderate warming scenarios, synchrony and flooding was predicted to be lower for coldwater tributaries. However, under sufficient warming the main flow source is expected to transition from mixture of snowmelt and rain to rain-dominated which leads to higher synchrony and downstream flood magnitudes.
Jaeger, K. L., J. D. Olden and N. A. Pelland (2014). “Climate change poised to threaten hydrologic connectivity and endemic fishes in dryland streams.” *Proceedings of the National Academy of Sciences* 111(38): 13894	The authors used a surface water model to forecast future streamflows within Verde River Basin and characterized the change in temporal and spatial dimensions of streamflow or hydrologic connectivity or fragmentation throughout the river network. The model predicted that the number of days which the river stops flowing to increase by 27% in 2050 and the frequency of river drying events to increase by 17%. The overall length of flowing stretches within the Verde River network was predicted to drop between 8% and 20% in spring and early summer with greater declines during the drier portions of the year. This will result in less spawning habitat and refuge from seasonal drying. Using dispersal models to contextualize the impact from climate change projections, the authors estimated the Verde River network will have 6-9% and 12-18% lower hydrologic connectivity during the year and spring spawning months, respectively. This finding has strong implications on the persistence of endemic fish fauna under climate change.

Reference	Plain Text Summary
Marcarelli, A. M., A. A. Coble, K. M. Meingast, E. S. Kane, C. N. Brooks, I. Buffam, S. A. Green, C. J. Huckins, D. Toczydlowski and R. Stottlemyer (2019). “Of Small Streams and Great Lakes: Integrating Tributaries to Understand the Ecology and Biogeochemistry of Lake Superior.” *Journal of the American Water Resources Association* 55(2): 442-458	Approximately 2,800 tributaries flow into and contribute nutrients and dissolved organic matter to the nearshore areas of Lake Superior. Tributaries contribute bulk of these materials to Lake Superior during snowmelt-driven flows in the spring and rain-driven flows following rain during other times of the year. Temporary storage and transformations of these material occur during transport in the tributaries prior to entering Lake Superior. Despite being such a large water body, distinct physical and chemistry signals are detected where tributaries enter Lake Superior during periods of high runoff but are quickly transported and mixed with the bulk of the lake volume. The use of different technologies (e.g., automated sampling, remote imagery, drones) will enhance the monitoring and understanding of tributary-lake connections.
Kelson, S. J. and S. M. Carlson (2019). “Do precipitation extremes drive growth and migration timing of a Pacific salmonid fish in Mediterranean-climate streams?” *Ecosphere* 10(3)	Climate change is expected to cause more frequent weather extremes leading to more severe droughts and floods. Steelhead are migratory trout that live in the South Fork Eel River and its tributaries in California. This study examined extremely wet and dry years over the period of 2015-2018 to see how stream flow affected the steelhead growth, health, and migration timing. Despite strong differences in the timing and magnitude of winter-spring floods and summer low-flows between years, the growth, health, migration timing was not affected. The authors attributed the lack of impact on steelhead detected between extremes was due to the high quality of habitat provided by groundwater-fed tributaries that provided cool and stable base flows even in the driest years.
Marteau, B., R. J. Batalla, D. Vericat and C. Gibbins (2017). “The importance of a small ephemeral tributary for fine sediment dynamics in a main-stem river.” *River Research and Applications* 33(10): 1564-1574	An ephemeral tributary in the United Kingdom had key moments of influence on a downstream river (River Ehen) through the temporal mismatch between sediment transport from an ephemeral tributary and flooding in a mainstem river. Despite draining only 1.2% of the river catchment and flowing only ephemerally, the recently reconnected ephemeral tributary increased annual sediment yield in the downstream river by 65%.
Xu, J. (2016). “Sediment jamming of a trunk stream by hyperconcentrated floods from small tributaries: case of the Upper Yellow River, China.” *Hydrological Sciences Journal* 61(10): 1926-1940	The study describes floods in ten small desert tributaries that transport large amounts of sediment which exacerbates downstream flooding in the Yellow River in China. The authors investigated in detail one such flooding event and developed a tool to understand the downstream influence of flood-driven sediment from tributaries over immediate (days to weeks) and longer time periods (decades).

Reference	Plain Text Summary
Swanson, B. J. and G. Meyer (2014). “Tributary confluences and discontinuities in channel form and sediment texture: Rio Chama, NM.” *Earth Surface Processes and Landforms* 39(14): 1927-1943	Tributaries (arroyos) periodically deliver sediment downstream to the Rio Chama in northern New Mexico. The sediment is delivered by floods induced by summer thunderstorms. Channel measurements were collected from 203 cross-sections located upstream and downstream from 26 tributary confluences over a 17-km reach of the Rio Chama. The slope, bed sediment size, and cross-sectional area of the river channel was affected by tributaries and influence the transport and storage of sediment along the river. On a larger scale, tributaries have a stronger influence on the Rio Charma in the upper two-thirds of the 17-km reach than the lower third which had fewer tributaries and was dominated by canyon narrows. Tributaries and their associated watershed characteristics (e.g., geology) contribute the morphology of downstream rivers.
Marteau, B., C. Gibbins, D. Vericat and R. J. Batalla (2020). “Geomorphological response to system-scale river rehabilitation I: Sediment supply from a reconnected tributary.” *River Research and Applications* 36(8): 1488-1503	An ephemeral tributary (Ben Gill) in the United Kingdom was reconnected to its sediment-limited downstream river (River Ehen) and the subsequent 2 years sediment transport from the tributary to the river was measured. Sufficient coarse sediment is critical to maintaining economically and culturally important salmonid habitat. An estimated minimum of 384 m3 of coarse sediment was exported to the downstream river and contributed to the habitat formation. The small, ephemeral stream (0.55 km2 or 1.2% of the river’s drainage area) which flows only ~20% of the year approximately doubled the volume of coarse sediment estimated to occur in the confluence area prior to reconnection and so is providing needed critical material for salmonid habitat in the downstream river.
French, D. W., D. E. Schindler, S. R. Brennan and D. Whited (2020). “Headwater Catchments Govern Biogeochemistry in America’s Largest Free-Flowing River Network.” *Journal of Geophysical Research: Biogeosciences* 125(12)	Water chemistry samples collected from the Kuskokwim River (largest U.S. river without dams), Alaska was studied to understand the influence of the surrounding watershed and instream conditions from different parts of the river network. The conditions in small, headwater streams play a disproportionately important role in predicting the streamwater chemistry throughout the river network. Nutrients that are rapidly used by algae and microbes are spatially more variable in the river network when compared to chemicals that have lower biological demand.
Koizumi, I., Y. Tanaka and Y. Kanazawa (2017). “Mass immigration of juvenile fishes into a small, once-dried tributary demonstrates the importance of remnant tributaries as wintering habitats.” *Ichthyological Research* 64(3): 353-356	A small tributary of the Otofuke River in northern Japan went dry during the summer. Four months after resuming flow more than 10,000 immature fish of three species, including rainbow trout used the tributary for wintering habitat.

Reference	Plain Text Summary
Fovet, O., D. M. Cooper, D. L. Jones, T. G. Jones and C. D. Evans (2020). "Dynamics of dissolved organic matter in headwaters: comparison of headwater streams with contrasting DOM and nutrient composition." *Aquatic Sciences* 82(2)	The processes by which headwater streams functionally alter terrestrial dissolved organic matter (carbon and nutrients) are influenced by local factors, including soils, land-use, and human pressures. This study compared the effects of sunlight, presence/absence of aquatic biota, and nutrient supplementation on DOM processing in two contrasting stream types – one, a headwater with low inorganic nutrient loadings (peatland stream) and the other a headwater with high nutrient loadings (an agricultural grassland stream). Exposure to sunlight resulted in net abiotic organic matter loss (removal) in the peatland stream but net biological production (increase) of organic matter in the agricultural stream. Nutrient addition accelerated DOM production in both streams. These results show that the quantity and quality of net DOM exported from headwaters are influenced by the composition of terrestrial DOM inputs, landscape setting, and exposure to sunlight. The author suggest that these results indicate that headwaters may be more active processors of carbon and nutrients than previously thought.
Gallo, E. L., T. Meixner, K. A. Lohse and H. Nicholas (2020). "Estimating Surface Water Presence and Infiltration in Ephemeral to Intermittent Streams in the Southwestern US." *Frontiers in Water* 2(47)	Streamflow in arid and semi-arid regions is predominantly temporary, and of significant importance for groundwater recharge and biogeochemical processes. However, temporary streamflow, especially ephemeral flows, remain poorly quantified. The authors used in-stream streamflow data loggers and USGS stream gauge data in 15 southern Arizona streams spanning a climate gradient (mean annual precipitation from 160 to 750 mm) to quantify temporary streamflow as (a) streamflow presence and (b) water presence, which included streamflow, ponding and soil moisture. In addition, stream channel sediment data were used to estimate saturated hydraulic conductivity and potential annual infiltration. Annual streamflow ranged 0.6–82.4% or 2–301 days; while water presence ranged from 2.6 to 82.4% or 10 to over 301 days, or 4–33 times longer than streamflow. These data were used to develop 5 statistically distinct flow regimes based on the annual percent streamflow and water presence: (1) dry-ephemeral, (2) wet-ephemeral, (3) dry-intermittent, (4) wet-intermittent, and (5) seasonally-intermittent. Stream channel density was a better predictor of annual streamflow and water presence than annual rainfall alone. The dry-ephemeral and wet-ephemeral flow regimes varied with seasonal precipitation, while the dry-intermittent, wet intermittent and seasonally-intermittent flow regimes did not. These results coupled with the potential infiltration estimates indicate that streamflow at the driest sites occurs in response to rainfall and overland flow while groundwater discharge and vadose zone contributions enhance streamflow at the wetter sites. Flow regime classifications that include both stream flow and water presence, rather than on stream flow alone, may be important for predicting thresholds in ecological functions and refugia in these dryland systems.

Reference	Plain Text Summary
Hill, B. H., R. K. Kolka, F. H. McCormick and M. A. Starry (2014). "A synoptic survey of ecosystem services from headwater catchments in the United States." *Ecosystem Services* 7: 106-115	"Ecosystem production functions for water supply, climate regulation, and water purification were estimated for 568 headwater streams and their catchments. Results are reported for nine USA ecoregions. Headwater streams represented 74-80% of total catchment stream length. Water supply per unit catchment area was highest in the Northern Appalachian Mountains ecoregion and lowest in the Northern Plains. C, N, and P sequestered in trees were highest in Northern and Southern Appalachian and Western Mountain catchments, but C, N, and P sequestered in soils were highest in the Upper Midwest ecoregion. Catchment denitrification was highest in the Western Mountains. In-stream denitrification was highest in the Temperate Plains. Ecological production functions paired with published economic values for these services revealed the importance of mountain catchments for water supply, climate regulation, and water purification per unit catchment area. The larger catchment sizes of the plains ecoregions resulted in their higher economic value compared to the other ecoregions. The combined potential economic value across headwater catchments was INT $14,000 ha(-1) yr(-1), or INT $30 million yr(-1) per catchment. The economic importance of headwater catchments is even greater considering that our study catchments statistically represent more than 2 million headwater catchments in the continental United States."
Jones, C. S., J. K. Nielsen, K. E. Schilling and L. J. Weber (2018). "Iowa stream nitrate and the Gulf of Mexico." *PLoS ONE* 13(4): e0195930	The objective of this study was to quantify and update Iowa's contribution of nitrate-nitrogen to the Mississippi River stream network against the backdrop of Gulf of Mexico hypoxia. Stream nitrate and discharge data collected from 1999 until 2016 at 23 Iowa stream sites near watershed outlets, along with publicly available data for sites downstream of Iowa on the Missouri and Mississippi Rivers shows that Iowa contributes between 11 and 52% of the long-term nitrate load to the Mississippi-Atchafalaya Basin, 20 to 63% to the Upper Mississippi River Basin, and 20 to 89% to the Missouri River Basin, with averages of 29, 45 and 55% respectively. Since 1999, nitrate loads in the Iowa inclusive basins have increased and these increases do not appear to be driven by changes in discharge and cropping intensity unique to Iowa. The 5-year running annual average of Iowa nitrate loading has been above the 2003 level for ten consecutive years.

Reference	Plain Text Summary
Jones, E. F., N. Griffin, J. E. Kelso, G. T. Carling, M. A. Baker and Z. T. Aanderud (2020). "Stream Microbial Community Structured by Trace Elements, Headwater Dispersal, and Large Reservoirs in Sub-Alpine and Urban Ecosystems." *Frontiers in Microbiology* 11: 491425	Functional stream bacterioplankton communities are needed to maintain surface water quality and other aquatic ecosystem services. The diversity and composition of stream bacterioplankton communities influence their function. This study quantified the role of environmental conditions, bacterioplankton dispersal, and human infrastructure (dams) on community composition in rivers from sub-alpine to urban environments in three watersheds (Utah, United States) across three seasons. Bacterioplankton community diversity decreased downstream along parts of the stream continuum but was disrupted where large reservoirs increased water residence time by orders of magnitude, potentially indicating a shift in the relative importance of environmental selection and dispersal at these sites. Reservoirs also had substantial effects on community composition, similarity, and species interactions. Communities downstream of reservoirs were enriched with anaerobic Sporichthyaceae, methanotrophic Methylococcaceae, and iron-transforming Acidimicrobiales, suggesting alternative metabolic pathways became active in the hypolimnion of large reservoirs. The results identify that human activity affects river microbial communities, with potential impacts on water quality through modified biogeochemical cycling.
Larson, J. H., J. M. Vallazza and B. C. Knights (2019). "Estimating the degree to which distance and temperature differences drive changes in fish community composition over time in the upper Mississippi River." *PLoS ONE* 14(12): e0225630	Similarity in aquatic communities often declines with increasing distance between habitat locations. In addition to spatial separation, distance-dissimilarity relationships are driven by the presence of environmental gradients that alter habitat suitability for particular species. The Mississippi River is aligned mostly north-to-south so greater distances along the river roughly correspond to differences in latitude, which in turn correspond to different thermal regimes, which are important determinants of fish community structure. The authors of this study used a 21-year dataset of fish communities in the upper Mississippi River to examine the effect of distance on variation in community composition and to assess whether the effect of distance is primarily due to its effect on thermal regime. The results showed a moderate distance-similarity relationship, suggesting greater distance leads to less similarity, which appeared to increase slightly over time. Using a subset of data for which air temperature was available, models that incorporated both difference among sites in degree days (a surrogate for thermal regime) and physical distance (river km) found that temperature alone appears to be more strongly associated with differences in the Mississippi River fish community than spatial distance alone.

Reference	Plain Text Summary
Mooney, R. J., E. H. Stanley, W. C. Rosenthal, P. C. Esselman, A. D. Kendall and P. B. McIntyre (2020). "Outsized nutrient contributions from small tributaries to a Great Lake." *Proceedings of the National Academy of Sciences of the United States of America* 117(45): 28175-28182	For lakes across the United States, eutrophication is driven largely by nonpoint nutrient sources from tributaries that drain surrounding watersheds, which are relatively understudied in lake systems despite their ubiquity and potential importance to lake water quality. The authors of this study quantified a 'snapshot' of nutrient inputs from nearly all tributaries of Lake Michigan – the world's fifth largest freshwater lake by volume – to determine how land cover and dams alter nutrient inputs across different watershed sizes. Loads, concentrations, stoichiometry, and bioavailability (percentage dissolved inorganic nutrients) varied by orders of magnitude among tributaries, creating a mosaic of coastal nutrient inputs. The six largest of 235 tributaries accounted for approximately 70% of the daily nitrogen and phosphorus delivered to Lake Michigan. However, small tributaries exhibited nutrient loads that were high for their size and biased toward dissolved inorganic forms. Higher bioavailability of nutrients from small watersheds suggests greater potential to fuel algal blooms in coastal areas, especially given the likelihood that their plumes become trapped and then overlap in the nearshore zone. The findings reveal an underappreciated role that small streams may play in driving coastal eutrophication in large water bodies.
Schilling, K. E. and C. S. Jones (2019). "Hydrograph separation of subsurface tile discharge." *Environmental Monitoring and Assessment* 191(4): 231	Baseflow is an important component of streamflow and watershed hydrologic budgets. The fraction of baseflow contributed by tile drainage has rarely been reported. The authors of this study quantified baseflow discharge from three central Iowa drainage district tile mains using two different hydrograph separation methods and found that baseflow comprised approximately 60% of the annual flow for a 5-year period (2009–2013). The results of this study provide methods to better quantify hydrologic pathways throughout tiled landscapes.
van Meerveld, H. J. I., J. W. Kirchner, M. J. P. Vis, R. S. Assendelft and J. Seibert (2019). "Expansion and contraction of the flowing stream network alter hillslope flowpath lengths and the shape of the travel time distribution." *Hydrology and Earth System Sciences* 23(11): 4825-4834	"Flowing stream networks dynamically extend and retract, both seasonally and in response to precipitation events. These network dynamics can dramatically alter the drainage density and thus the length of subsurface flow pathways to flowing streams. We mapped flowing stream networks in a small Swiss headwater catchment during different wetness conditions and estimated their effects on the distribution of travel times to the catchment outlet. For each point in the catchment, we determined the subsurface transport distance to the flowing stream based on the surface topography and determined the surface transport distance along the flowing stream to the outlet. We combined the distributions of these travel distances with assumed surface and subsurface flow velocities to estimate the distribution of travel times to the outlet. These calculations show that the extension and retraction of the stream network can substantially change the mean travel time and the shape of the travel time distribution. During wet conditions with a fully extended flowing stream network, the travel time distribution was strongly skewed to short travel times, but as the network retracted during dry conditions, the distribution of the travel times became more uniform. Stream network dynamics are widely ignored in catchment models, but our results show that they need to be taken into account when modeling solute transport and interpreting travel time distributions."

Reference	Plain Text Summary
Wilkinson, M. E. and J. C. Bathurst (2018). “A multi-scale nested experiment for understanding flood wave generation across four orders of magnitude of catchment area.” *Nordic Hydrology* 49(3): 597-615	Current understanding of flood response is deficient concerning the variation of flood generation as a function at different spatial scales as a result of spatial and temporal variations in storm rainfall. This study investigates flood response to spatially variable rainfall through a multi-scale nested experiment. Hydrological data from an extensive network in the Eden catchment, UK, were collected for a range of flood events over varying scales from 1.1 km^2 to 2,286 km^2. Peak specific discharge for winter events appears to remain constant for areas up to 20-30 km^2, corresponding to upland headwater catchments. The flood response to the convective storms depends on the location of the rainfall, and the downstream rates of change of runoff and peak discharge can vary significantly from the winter storm relationships. Particularly for large synoptic storms, average scaling laws for peak discharge have been quantified (exponents ranging between 0.75 and 0.86), illustrating the non-linear nature of the cross-scale variations.

Floodplain Wetlands and Open Waters

Reference	Plain Text Summary
Thom, R. M., S. A. Breithaupt, H. L. Diefenderfer, A. B. Borde, G. C. Roegner, G. E. Johnson and D. L. Woodruff (2018). “Storm-driven particulate organic matter flux connects a tidal tributary floodplain wetland, mainstem river, and estuary.” *Ecological Applications* 28(6): 1420-1434	The authors used a multi-model approach to simulate organic matter transport from a recently connected and restored tidal emergent marsh in the Grays River tributary to the Columbia River estuary. They found that “restored floodplain wetlands can contribute significant amounts of organic matter to the estuarine ecosystem and thereby contribute to the restoration of historical trophic structure.”
Yang, W., Y. Liu, C. Ou and S. Gabor (2016). “Examining water quality effects of riparian wetland loss and restoration scenarios in a southern ontario watershed.” *Journal of Environmental Management* 174: 26	“The purpose of the study [was] to develop [watershed-scale] wetland modelling to examine water quality effects of riparian wetland loss and restoration scenarios in the 323-km Black River watershed in southern Ontario, Canada.” The model was applied to examine various riparian wetland loss scenarios on sediment and nutrient loads to the river network. The model outputs suggest that as riparian wetland loss increases, environmental functional losses increase at an accelerated rate. For example, sediment, total nitrogen, and total phosphorous loads to the river increased between by 2-, 3-, and 9-fold, respectively, with 100% riparian wetland loss, compared to current conditions. “The results further demonstrate the importance of targeting priority areas for stopping riparian wetland loss and initiating riparian wetland restoration based on scientific understanding of watershed wetland effects.”
Pyron, M., L. Etchison and J. Backus (2014). “Fish Assemblages of Floodplain Lakes in the Ohio River Basin.” *Northeastern Naturalist* 21(3): 419-430	The authors sampled and examined fish assemblages in 41 floodplain lakes [wetlands] in the Ohio River Basin (summer 2012). Their results demonstrated “that floodplain lakes in the Ohio River basin contain high species richness and are important habitats to conserve because they have the potential to act as source pools for river fish populations.”

Mengistu, S. G., H. E. Golden, C. R. Lane, J. R. Christensen, M. L. Wine, E. D'Amico, A. Prues, S. G. Leibowitz, J. E. Compton, M. H. Weber and R. A. Hill (2020). "Wetland Flowpaths Mediate Nitrogen and Phosphorus Concentrations across the Upper Mississippi River Basin." *Journal of the American Water Resources Association:* 1-18	The authors developed a large, novel set of spatial variables characterizing hydrological connectivity from wetlands (floodplain and non-floodplain) to streams across the ~0.5 million km^2 Upper Mississippi River Basin. They found that wetland connectivity variables provided insights into "processes governing how wetlands influence watershed-scale TN and TP concentrations". For example, they demonstrated that wetland connectivity variables describing how water transport slows along the flowpath from the wetland to the stream (e.g., in flowpaths with high soil porosity, which slows water via infiltration into the soils) were statistically related to lower total nitrogen and total phosphorus concentrations. This means that it is not just the wetlands, but the flowpaths/connectivity between wetlands and streams, that control their water quality effects on downstream surface waters.
Jensen, A. K. and W. I. Ford (2019). "Quantifying nitrate dynamics of a confluence floodplain wetland in a disturbed Appalachia watershed: High-resolution sensing and modeling." *Transactions of the ASABE* 62(6): 1545-1565	The authors coupled high-resolution water quality data and simulation modeling to assess what physical (hydrologic, hydraulic) or biogeochemical processes affect nitrate cycling in a confluence floodplain wetland along the Ohio River (June 2017-June 2018). Despite the wetland comprising only 0.42% of the overall watershed drainage area, 2.6% to 58.5% of the annual nitrate loads entering the wetland were removed by it. Longer water storage times in the wetlands and less frequent connectivity with the river allowed nitrate removal to occur at higher rates. The findings therefore "demonstrate the significance of [wetland] connectivity [and disconnectivity] on watershed nitrate loadings to floodplain wetland soils".
Hansen, A., C. L. Dolph, E. f. Foufoula-Georgiou and J. C. Finlay (2018). "Contribution of wetlands to nitrate removal at the watershed scale." *Nature Geoscience* 11(2): 127	The authors evaluate how existing wetlands (floodplain and non-floodplain) across the landscape of the Minnesota River Basin affect in-stream nitrate concentrations. They found that "under moderate-high streamflow, wetlands are five times more efficient per unit area at reducing riverine nitrate concentration than the most effective land-based nitrogen mitigation strategies, which include cover crops and land retirement". Their results suggest that "wetland restorations that account for the effects of spatial position in stream networks could provide a much greater benefit to water quality then previously assumed."
Fossey, M., A. N. Rousseau and S. Savary (2016). "Assessment of the impact of spatio-temporal attributes of wetlands on stream flows using a hydrological modelling framework: a theoretical case study of a watershed under temperate climatic conditions." *Hydrological Processes* 30: 1768-1781	The authors applied a hydrological model to assess how floodplain and non-floodplain wetlands affect streamflow in the Becancour River watershed of the St Lawrence Lowlands, Quebec, Canada. Their model simulations suggested that the more often floodplain wetlands are connected to the main stem channel, the greater their effects on moderating high flows and providing baseflow support. They suggest that wetland effects on streamflow depends on the "combined effect of wetland and landscape attributes".
Daneshvar, F., A. P. Nejadhashemi, U. Adhikari, B. Elahi, M. Abouali, M. R. Herman, E. Martinez-Martinez, T. J. Calappi and B. G. Rohn (2017). "Evaluating the significance of wetland restoration scenarios on phosphorus removal." *Journal of Environmental Management* 192: 184-196	The authors used a calibrated Soil and Water Assessment Tool (SWAT) model to assess what areas of the Saginaw River Watershed, Michigan, had the highest potential for successful (floodplain and non-floodplain) wetland restoration related to decreasing downstream phosphorous loads. They found that "wetlands located in headwaters and downstream had significantly higher phosphorus reduction than the ones located in the middle of the watershed. More specifically,

	wetlands implemented at distances ranging from 200 to 250 km and 50-100 km from the outlet had the highest impact on phosphorus reduction at the subwatershed and watershed levels, respectively".
Blanchette, M., A. N. Rousseau, É. Foulon, S. Savary and M. Poulin (2019). "What would have been the impacts of wetlands on low flow support and high flow attenuation under steady state land cover conditions?" *Journal of Environmental Management* 234: 448-457	The authors use a physically based hydrological model to quantify how land cover change, particularly for wetlands both inside and outside floodplains, affect streamflow in the St. Charles River, Quebec, Canada. They found that with 15% loss of wetlands in the watershed area, baseflow decreased and peak (or flood) flows increased. Their results suggested that "the loss of wetland areas generally leads to a loss of hydrological services and highlighted the need for wetland conservation programs and restoration actions."
Bellmore, R. A., J. E. Compton, J. R. Brooks, E. W. Fox, R. A. Hill, D. J. Sobota, D. J. Thornbrugh and M. H. Weber (2018). "Nitrogen inputs drive nitrogen concentrations in U.S. streams and rivers during summer low flow conditions." *Science of the Total Environment* 639: 1349-1359	The authors examined how in-stream nitrogen (N) concentrations are related to N inputs to watersheds (e.g., atmospheric deposition, synthetic fertilizer), land cover characteristics (e.g., wetland presence), and stream network characteristics across the United States. They found that (floodplain and non-floodplain) wetlands mediated. i.e., lowered, N concentrations in streams with watersheds draining areas of high agricultural N inputs across the US.
Carlson, A. K., M. J. Fincel, C. M. Longhenry and B. D. S. Graeb (2016). "Effects of historic flooding on fishes and aquatic habitats in a Missouri River delta." *Journal of Freshwater Ecology* 31(2): 271-288	Fish assemblages were studied pre and post flood in the Missouri River, Lewis and Clark delta in SD and NE. Findings suggest that backwater habitats in the delta provided refuge from floodwaters during the disturbance. Maintaining habitat connectivity in deltas during and after floods is particularly important for fisheries conservation.
Tetzlaff, D., C. Birkel, J. Dick, J. Geris and C. Soulsby (2014). "Storage dynamics in hydropedological units control hillslope connectivity, runoff generation, and the evolution of catchment transit time distributions." *Water Resources Research* 50(2): 969-985	In a montane catchment in NE Scotland, storage dynamics and isotopic analysis of riparian peatlands showed that water stored in the peats were typically >80% of flow, including base flow and storm flow. The riparian areas were a key zone, acting as a regulator of stream water composition and transit time.
Rudolph, J. C., C. A. Arendt, A. G. Hounshell, H. W. Paerl and C. L. Osburn (2020). "Use of Geospatial, Hydrologic, and Geochemical Modeling to Determine the Influence of Wetland-Derived Organic Matter in Coastal Waters in Response to Extreme Weather Events." *Frontiers in Marine Science* 7	Using a flood model, the contribution of Organic Matter (OM) from wetlands from a recent hurricane was quantified in Neuse River Estuary-Pamlico Sound (NRE-PS), in eastern North Carolina. The hurricane created a pulse of OM, with wetland contributing 48% and 18% of annual DOC loads to the NRE and PS respectively. The study highlights the importance of rare large events on the transport of materials within the connected riverine-estuarine system.
Bourgault, M. A., M. Larocque and M. Roy (2014). "Simulation of aquifer-peatland-river interactions under climate change." *Nordic Hydrology* 45(3): 425-440	In a peatland complex within Quebec Canada, a ground water (GW) model was used to investigate the role of the peatlands in supporting river baseflows. The model estimated that on average 77% of the annual river base flow originates from the peatland. Future climate scenarios both indicated reductions to the peat from the surrounding GW and then from the peat to the river.
Vanderhoof, M. K., H. E. Distler, M. W. Lang and L. C. Alexander (2018). "The influence of data characteristics on detecting wetland/stream surface-water connections in	Remote sensing techniques indicated springtime connections of wetlands and streams in a Delmarva Peninsula river. Using Lidar, Landsat and Worldview imagery, between 12-60% of wetlands

the Delmarva Peninsula, Maryland and Delaware." *Wetlands Ecology and Management* 26: 63-86	connected to streams, indicating that 50-94% of the watershed contributed direct surface water runoff to stream flows.
Manfrin, A., M. Bunzel-Drüke, A. W. Lorenz, A. Maire, M. Scharf, O. Zimball and S. Stoll (2020). "The effect of lateral connectedness on the taxonomic and functional structure of fish communities in a lowland river floodplain." *Science of the Total Environment* 719: 137169	Using an 18-year data set of fish abundance, researchers in Germany compared fish communities in main channels and floodplain habitats. While the overall diversity and relative abundance of species decreased from the main channel to more isolated floodplain wetlands, the floodplain waterbodies showed distinct assemblages with different life histories and feeding strategies. This highlights the importance of including the complete spectrum of connected floodplains in conservation.
Gordon, B. A., O. Dorothy and C. F. Lenhart (2020). "Nutrient Retention in Ecologically Functional Floodplains: A Review." *Water* 12(10)	In a review of North American and European literature, the authors quantify the removal of nitrogen (N) and phosphorus (P) within floodplains. The review found that floodplains remove an average of 200 kg-N/ha/yr of nitrate and 21 kg-P/ha/yr of total or particulate P and floodplain wetlands are most effective when located within river systems with higher nutrient loads.
Atkinson, C. L., B. C. van Ee, Y. Lu and W. Zhong (2019). "Wetland floodplain flux: temporal and spatial availability of organic matter and dissolved nutrients in an unmodified river." *Biogeochemistry* 142(3): 395-411	Within an unregulated, low gradient river in Alabama, extensive floodplains including the Sipsey Swamp were found to exert strong controls of organic materials and nutrients. Over two years at 10 sites, nutrients declined through the floodplains while the same floodplains supplied large amounts of organic material downstream. This research highlights the importance of floodplain complexes on the transport of organics and nutrients.
Abrial, E., L. A. Espinola, A. n. Rabuffetti, M. F. Eurich, A. R. Paira, M. C. M. Blettler and M. L. Amsler (2019). "Variability of hydrological connectivity and fish dynamics in a wide subtropical-temperate floodplain." *River Research and Applications* 35(9): 1520-1529	Researchers analyzed fish abundance and richness within a large floodplain system in the Parana River of Brazil over seven years. Fish dispersal, abundance and migration patterns during the different wet and dry seasons could largely be explained by the variation in connectivity of the floodplain habitats. The study demonstrates the importance of dynamic connection and isolation of floodplains on the makeup of the fish community.
Martens, K. D. and P. J. Connolly (2014). "Juvenile Anadromous Salmonid Production in Upper Columbia River Side Channels with Different Levels of Hydrological Connection." *Transactions of the American Fisheries Society* 143(3): 757-767	Young salmon use side or off channel habitat that can connect and disconnect from the main river channel. This study looked at seasonally and continually connected side channels on the Upper Columbia river and measured salmon survival. Seasonally disconnected side channels resulted in improved survival for juvenile salmon during periods of disconnection. Upon reconnection with the main channel, the previous cohort would rejoin the main population while new young of year salmon would move into the side channels.
De Giudici, G., D. Medas, R. Cidu, P. Lattanzi, F. Podda, F. Frau, J. C. l. Dick, D. Tetzlaff and C. Soulsby (2018). "Role of riparian wetlands and hydrological connectivity in the dynamics of stream thermal regimes." *Nordic Hydrology* 49(3): 634-647	Riparian wetlands were analyzed for their important in determining stream temperatures. The authors found that in periods of high river and riparian wetland connectivity, the coupled saturation and connectivity decreased the relative importance of the riparian wetland for temperature regulation. Conversely, dry periods with less river and riparian floodplain hydrologic connectivity were found to be important periods of distinctions between river water and riparian wetland temperatures (e.g., lower temperature waters were coming from the riparian wetland to the riverine system).

Battauz, Y. S., S. B. Jose de Paggi and J. C. Paggi (2017). "Macrophytes as dispersal vectors of zooplankton resting stages in a subtropical riverine floodplain." *Aquatic Ecology* 51(2): 191-201	Aquatic plants located in floodplain open waters were analyzed as potential sources for zooplankton dispersal into the riverine food web. Six plant species from Brazilian floodplain lakes (at least three of which occur in North American open waters) were analyzed as sources of passive zooplankton dispersal. The roots and submerged parts of the plants were found to host 70 different zooplankton taxa in resting stage (i.e., awaiting the proper environmental cues to emerge). The authors concluded that aquatic plants in floodplain open waters are important downstream dispersers of zooplankton, which are important base components of riverine food webs.
Vanderhoof, M. K., J. R. Christensen and L. C. Alexander (2016). "Patterns and drivers for wetland connections in the Prairie Pothole Region, United States." *Wetlands Ecology and Management* 25(3): 1-23	A remote sensing study in the Prairie Pothole Region of the US noted that precipitation-based expansion of surface waters connected wetlands and stream networks across a wide range, averaging from 90-1400 m, depending on the ecoregion studied. Most of the wetland to stream connections occurred first through consolidation, where clusters of wetlands connected to each other, followed by the stream connection which occurred most frequently through a riparian wetland.
Rees, G. N., R. A. Cook, N. S. P. Ning, P. J. McInerney, R. T. Petrie and D. L. Nielsen (2020). "Managed floodplain inundation maintains ecological function in lowland rivers." *Science of the Total Environment* 727: 138469	An inundated floodplain riparian zone was shown to be highly connected to the river food web, with substantively higher dissolved organic carbon, seston carbon, nutrients (nitrogen), and chlorophyll levels downstream of where the flood waters reentered the river. Isotopic analyses demonstrated that floodplain-derived carbon was incorporated into the riverine food webs and was measurably found for up to four months following the flood peak.
Macdonald, D. M. J., A. J. Dixon and D. C. Gooddy (2018). "Water and nitrate exchange between a managed river and peri-urban floodplain aquifer: Quantification and management implications." *Ecological Engineering* 123: 226-237	A study in the United Kingdom measured river water with high nitrate levels, which was noted to move into the riparian floodplain and recharge the local aquifer during overbank floods. The authors reported substantial microbially mediated denitrification occurred in the shallow riparian groundwater table due to carbon availability, oxygen-free conditions, and high nitrate concentrations. The lowland floodplain studied was able to annual remove substantial amounts of nitrate, though this was estimated to be three orders of magnitude less than the annual flux within the river. The floodplain nitrate reduction was noted to be locally important (e.g., for local drinking water supplies sourced from the river's alluvial aquifer).
Gillespie, J. L., G. B. Noe, C. R. Hupp, A. C. Gellis and E. R. Schenk (2018). "Floodplain Trapping and Cycling Compared to Streambank Erosion of Sediment and Nutrients in an Agricultural Watershed." *Water Resources Bulletin* 54(2 (Apr 2018)): 565	The authors analyzed sedimentation, nutrient loads, and mineralization of a floodplain in an agricultural watershed in the Valley and Ridge physiographic province of the US. All study reaches were areas of net sediment deposition (e.g., river-borne sediments were deposited), had high nitrogen (N) and phosphorus (P) deposited by the river, high mineralization of N and P, and high concentrations of N and P in the floodplain soils. They conclude that the net sediment and nutrient trapping functions of their study watershed floodplains (Smith Creek) benefit downgradient water quality.
Webb, J. R., I. R. Santos, B. Robson, B. e. Macdonald, L. Jeffrey and D. T. Maher (2017). "Constraining the annual groundwater contribution to the water	Groundwater dynamics of an extensively drained agricultural floodplain was analyzed using radon to create a water budget. Flooding in the riparian zone occurred only 12% of the study period but contributed 72-76% of the groundwater discharge (to the river

balance of an agricultural floodplain using radon: The importance of floods." *Water Resources Research* 53(1): 544-562	network). Annually, groundwater discharge contributed 30-80% of the total surface water discharged to the river system, which the authors propose is related to the high density of constructed drainage features (12.4 km per km^2) altering the hydrology of the floodplain.
Scott, D. T., R. F. Keim, B. L. Edwards, C. N. Jones and D. E. Kroes (2014). "Floodplain biogeochemical processing of floodwaters in the Atchafalaya River Basin during the Mississippi River flood of 2011." *Journal of Geophysical Research: Biogeosciences* 119(4): 537-546	The Atchafalaya River and floodplain was extensively flooded during the 2011 Lower Mississippi River flood event, with up to half of the water in the channel moving into the floodplain. The authors analyzed river water over the flood event and found that significant nitrate reduction (around 75%) occurred within the floodplain. The floodplain system was found to reduce total nitrate by 16.6% over the course of the flood event.
Quin, A. and G. Destouni (2018). "Large-scale comparison of flow-variability dampening by lakes and wetlands in the landscape." *Land Degradation & Development* 29(10): 3617-3627	A modeling study in Sweden used data from 82 catchments from 1984-2013 to investigate the floodwater attenuation capacity of floodplain wetlands and lakes. The storage function of lakes and floodplain wetlands lakes was responsible for decreasing the variability (e.g., "flashiness") of streamflow. Watersheds comprised of approximately 15% lakes and 0.5% floodplain wetlands decreased the streamflow variability to around 10-15%, compared to areas without lakes or floodplain wetlands, which had approximately 20-25% higher streamflow variabilities due to low landscape water storages.
Dwivedi, D., B. Arora, C. I. Steefel, B. Dafflon and R. Versteeg (2018). "Hot Spots and Hot Moments of Nitrogen in a Riparian Corridor." *Water Resources Research* 54(1): 205-222	Groundwater within the Colorado River riparian zone was modeled to typically flow towards the river, except during flood stages when oxygenated and nitrate-laden river water overtops the banks and then infiltrates downwards in the riparian area. Riparian area sediments differ in their nitrate removal capacity, and reduced zones along the river (or areas of low oxygen, as found in most wetland soils) were found to have approximately 70% greater nitrate removal capacity than non-reduced zones. However, the nitrate removal capacity of the reduced zones varied based on the oxygen content of the infiltrating water from 70% greater than non-reduced zones to ~5% greater than non-reduced zones.

Non-Floodplain Wetlands and Open Waters

Reference	Plain Text Summary
Vanderhoof, M. K., H. E. Distler, M. W. Lang and L. C. Alexander (2017). "The influence of data characteristics on detecting wetland/stream surface-water connections in the Delmarva Peninsula, Maryland and Delaware." *Wetlands Ecology and Management* 26: 63-86	A remote-sensing study in Maryland and Delaware found that streams and depressional wetlands were surface-water connected in spring 2015. The range reported in the large studied watershed, 12-60% of wetlands by count and 21-93% of wetlands by area, varied due to the spatial and temporal wetland and stream characteristics and the accuracy and resolution of the input remote-sensing datasets.
Park, J., D. Wang and M. Kumar (2020). "Spatial and temporal variations in the groundwater contributing areas of inland wetlands." *Hydrological Processes* 34(5)	Hydrologic connections between groundwater and wetlands were measured in a study in the southern US. The study noted that a) groundwater contributing areas to wetlands often have a different extent and shape than topographic contributing areas, and b) groundwater-fed wetlands in the study area were found to expand their groundwater contributing area (and received greater

	groundwater) during dry periods which could influence baseflow in downstream waters (depending on hydraulic gradients).
Wang, N., X. Zhang and X. Chu (2019). “New Model for Simulating Hydrologic Processes under Influence of Surface Depressions.” *Journal of Hydrologic Engineering* 24(5): https://doi.org/10.1061/(ASCE)HE.1943-5584.0001772	In a North Dakota study, a model was developed to assess the effects of depressions on rainfall-runoff processes and mechanisms of dynamic water release from depressions affecting down-gradient systems. The hydrologic model demonstrated that depressions captured and held back precipitation from down-gradient systems such that the majority of the study area did not contribute water directly to the stream system. This finding supports the hydrologic lag and sink functions of depressions (wetlands) in attenuating storm flows and maintaining baseflows.
Bugna, G. C., J. M. Grace and Y. P. Hsieh (2020). “Sensitivity of using stable water isotopic tracers to study the hydrology of isolated wetlands in North Florida.” *Journal of Hydrology* 580: 124321	In a North Florida water isotopic study of “isolated wetlands,” the authors found that so-called isolated wetlands stored and evaporated rainwater (thereby retaining water and performing hydrological lag and sink functions). A sinkhole (pond) was found to connect to both groundwater and precipitation. Wetlands and sinkholes were measurably important to quantifying and determining hydrological budgets for forested watersheds.
Lewis, D. B. and S. J. Feit (2015). “Connecting carbon and nitrogen storage in rural wetland soil to groundwater abstraction for urban water supply.” *Global Change Biology* 21(4): 1704-1714	Depressional wetlands were hydrologically affected by groundwater withdrawals for urban use (e.g., drinking water). Groundwater withdrawals diminished wetland hydroperiods, which in turn negatively affected carbon, nitrogen, and soil organic matter stocks in the wetlands (e.g., carbon sink functions of wetlands were diminished).
Shook, K., S. Papalexiou and J. W. Pomeroy (2021). “Quantifying the effects of Prairie depressional storage complexes on drainage basin connectivity.” *Journal of Hydrology* 593: 125846	In a Canadian hydrologic modeling study, Prairie Pothole depression water storage was found to control the fraction of the watershed that contributes flow to down-gradient stream systems. The effects of depressions varied: when there were few extant depressions, their size and location on the landscape was most important. In systems with greater depression abundance, depressions still controlled the relationship between water storage and the fraction of the watershed contributing surface flow down-gradient but the spatial location within the watershed decreased in importance.
Vasic, F., C. Paul, V. Strauss and K. Helming (2020). “Ecosystem Services of Kettle Holes in Agricultural Landscapes.” 10(9)	Kettle holes are glacially formed wetlands in Europe similar to the North American prairie potholes. A European literature review determined kettle hole wetlands provided important ecosystem services, including flood control and hydrological cycling, biogeochemical functions, and habitat. Agricultural activities around kettle hole wetlands were noted to potentially affect the provisioning of wetland ecosystem services.
Nasab, M. T. and X. Chu (2020). “Macro-HyProS: A new macro-scale hydrologic processes simulator for depression-dominated cold climate regions.” *Journal of Hydrology* 580: 124366	A hydrological modeling study of the Red River of the North (northern Great Plains) found that (wetland) depression-dominated areas controlled (or regulated) the connectivity of large areas of the basin via storage affecting surface-driven runoff. This was particularly important in the early spring months (i.e., during periods of rain-on-snow events, snowmelt, etc.).
Michelson, C., R. G. Clark and C. A. Morrissey (2018). “Agricultural land cover does not affect the diet of Tree Swallows in	Feeding habits of tree swallows, an insectivorous bird, were analyzed in a Canadian prairie landscape. Tree swallows were found to specialize in feeding on aquatic insects in wetland-dominated habitats (i.e., those insects emerging from wetlands). Agricultural land cover

wetland-dominated habitats." *The Condor* 120(4): 751-764	(e.g., grasslands, crops) within the study area did not affect tree swallow foraging success, though tree swallows were larger and in better condition in grasslands than cropped landscapes.
Martin, A. R., M. L. Soupir and A. L. Kaleita (2019). " Seasonal and intra-event nutrient levels in farmed Prairie Potholes of the Des Moines Lobe." *Transactions of the ASABE* 62(6): 1607-1617	Farmed wetlands (drained and under corn-soybean rotation) in the Des Moines Lobe of Iowa were found to reduce nitrate that entered into the wetland in 85% of the multi-day inundation events. Phosphorous was found to increase in the wetland water column over the inundation period (e.g., possibly through release from phosphorus sorbed onto soil particles), meaning that in addition to serving as nitrate removal areas, farmed wetlands were sources of total and soluble reactive phosphorus.
Shook, K., J. Pomeroy and G. van Der Kamp (2015). "The transformation of frequency distributions of winter precipitation to spring streamflow probabilities in cold regions; case studies from the Canadian Prairies." *Journal of Hydrology* 521: 395-409	Large-scale analyses of climate and basin processes contributing to streamflow in the Canadian Prairies were investigated. The authors found three major controls on streamflow, including a) the creation and distribution of the spring snowpack, b) the spring melt of the snowpack over frozen ground, and c) the subsequent filling and spilling of depressional (wetland) storage that connected fields, ponds, wetlands, and down-gradient lake systems.
Al Sayah, M. J., R. Nedjai, K. Kaffas, C. Abdallah and M. Khouri (2019). "Assessing the Impact of Man-Made Ponds on Soil Erosion and Sediment Transport in Limnological Basins." *Water* 11(12): 2526	Ponds, open-water systems in a French study, were analyzed in a modeling study to determine their effects on erosion and sediment transport at the watershed scale. The presence of ponds controlled sediment transport and erosion risk, with ~78% of the basin corresponding to no- or low-erosion risk zones and 22% noted as moderate to high-erosion risk. Without ponds, <2% of the basin was determined to be no- or low-erosion risk, while 98% was modeled as moderate to high erosion risk. Without ponded systems, the sediment pattern completely shifted to zones of higher sediment yields.
Kappas, I., G. Mura, D. Synefiaridou, F. Marrone, G. Alfonso, M. Alonso and T. J. Abatzopoulos (2017). "Molecular and morphological data suggest weak phylogeographic structure in the fairy shrimp Streptocephalus torvicornis (Branchiopoda, Anostraca)." *Hydrobiologia* 801(1): 21-32	A pan-European study analyzed the genetic structure of a fairy shrimp found in temporary ponds. Their results demonstrated there was unhindered gene flow and widespread connectivity between populations across the study area. One of five hypothesized reasons includes frequent dispersal by avian species throughout the range.
Wendt, A., C. A. Haas, T. Gorman and J. H. Roberts (2021). "Metapopulation genetics of endangered reticulated flatwoods salamanders (Ambystoma bishopi) in a dynamic and fragmented landscape." *Conservation Genetics*	Population dynamics of the reticulated flatwoods salamander, found in forested ponds and riparian zones in the southeastern U.S., were analyzed. Distance between ponds was found to be an important factor controlling metapopulation dynamics, with very low migration among ponds further than 400 m.
Yeo, I. Y., M. W. Lang, S. Lee, G. W. McCarty, A. M. Sadeghi, O. Yetemen and C. Huang (2019). "Mapping landscape-level hydrological connectivity of headwater wetlands to downstream waters: A geospatial modeling approach - Part 1." *Science of the Total Environment* 653: 1546-1556	A modeling study analyzed the hydrologic connectivity of so-called geographically isolated wetlands of the Mid-Atlantic region of the US. Wetland inundation and stream flows were well correlated, demonstrating a similar relationship. Wetlands with longer flooding duration were more strongly correlated with stream discharge than shorter-duration inundated wetlands. The authors conclude that the wetlands function in aggregate and that both the streams and the wetlands of their 300 km2 study area were connected via groundwater pathways.

Vanderhoof, M. K., J. R. Christensen and L. C. Alexander (2016). "Patterns and drivers for wetland connections in the Prairie Pothole Region, United States." *Wetlands Ecology and Management* 25(3): 1-23	A remote-sensing study (1990-2011) quantified surface-water connections between streams and wetlands across the US Prairie Pothole Region. They reported surface-water connections varied across ecoregions of the Prairie Pothole Region, averaging 90-1400 m. Connections were controlled by the arrangement and abundance of wetlands and surface-water expansion.
Neff, B. P. and D. O. Rosenberry (2017). "Groundwater Connectivity of Upland-Embedded Wetlands in the Prairie Pothole Region." *Wetlands* 38(1): 51-63	Local to regional groundwater connectivity between wetlands and other waters in the Prairie Pothole Region of North Dakota was modeled. Sand layers were found to facilitate wetland connectivity through groundwater, whereas water-table mounds were found to retard connectivity if completely surrounding the wetland or wetland complex. In the absence of restricting water-table mounds, connectivity was modeled to occur.
Golden, H. E., H. A. Sander, C. R. Lane, C. Zhao, K. Price, E. D'Amico and J. R. Christensen (2015). "Relative effects of geographically isolated wetlands on streamflow: a watershed-scale analysis." *Ecohydrology* 9(1): 21-38	A modeling study in North Carolina found that geographically isolated wetlands influenced streamflow. Increased water storage associated with increased geographically isolated wetland extent decreased streamflow. The distance of geographically isolated wetlands was positively associated with streamflow, affecting (or reflecting) the movement of water across the landscape.
Brooks, R. J., D. M. Mushet, M. Vanderhoof, S. G. Leibowitz, J. R. Christensen, B. P. Neff, D. Rosenberry, W. D. Rugh and L. C. Alexander (2018). "Estimating Wetland Connectivity to Streams in the Prairie Pothole Region: An Isotopic and Remote Sensing Approach." *Water Resources Research* 54(2): 955-977.	A water isotope study in a North Dakota watershed found that Prairie Pothole wetlands had high evaporation rates, and that groundwater typified winter precipitation-based recharge. However, the evaporative isotopic signal in the steam indicated that surficial flow from wetlands contributed to and connected to the stream network throughout the summer.
Ameli, A. A. and I. F. Creed (2019). "Does Wetland Location Matter When Managing Wetlands for Watershed-Scale Flood and Drought Resilience?" *Journal of the American Water Resources Association* 55(3): 529-542	A Canadian modeling study in the Prairie Pothole Region found that wetland loss affected streamflow, increasing peak flows from storm events that led to major down-gradient flooding in cities. Concurrently, wetland losses decreased base flow. Wetlands closer to the stream network were found to be disproportionately important to peak flow attenuation, while wetlands were found to be important controllers of baseflow regardless of their location vis-à-vis the stream network.
McKenna, O. P., S. R. Kucia, D. M. Mushet, M. J. Anteau and M. T. Wiltermuth (2019). "Synergistic Interaction of Climate and Land-Use Drivers Alter the Function of North American, Prairie-Pothole Wetlands." *Sustainability* 11(23): 6581	Twenty-five wetland basins were modeled over a 70-year period to ascertain the influence of both climate and land-use drivers on floods. During an extremely wet period (1993-2000), Prairie Pothole wetland drainage decreased watershed-scale water storage, resulting in 10 times the volume of water transiting towards local stream networks.
Bam, E., A. M. Ireson, G. Kamp and J. Hendry (2020). "Ephemeral Ponds: Are They the Dominant Source of Depression-Focused Groundwater Recharge?" *Water Resources Research* 56(3): e2019WR026640	Prairie wetland ponds within a Canadian study area are sources of recharge to confined groundwater aquifers providing water to farm and rural communities. An isotopic analysis found that permanently inundated wetland ponds were not the dominant groundwater recharge source. Ephemerally inundated wetlands were found to have identical isotopic signatures as the groundwater in aquifers. Ephemeral wetlands were the dominant source of groundwater recharge.

Ameli, A. and I. F. Creed (2019). “Groundwaters at Risk: Wetland Loss Changes Sources, Lengthens Pathways, and Decelerates Rejuvenation of Groundwater Resources.” *Journal of the American Water Resources Association* 55(2): 294-306	A modeling analysis of a Canadian study area explored the connections and effects of wetlands, and wetland losses, on local and regional waters. Wetland losses decreased contributing areas affecting baseflows of local surface waters. Modeled wetland losses increased the contributions to regional surface waters through subsurface hydrologic connections, which increased regional baseflows.
Sampath, P. V., H. Liao, Z. K. Curtis, P. J. Doran, M. E. Herbert, C. A. May and S. Li (2015). “Understanding the Groundwater Hydrology of a Geographically-Isolated Prairie Fen: Implications for Conservation.” *PLoS ONE* 10(10): e0140430	An analysis of a geographically isolated Michigan fen wetland determined the wetland was groundwater-fed by four sources: local recharge, regional recharge, a regional groundwater mound, and a nearby pond. The authors conclude a 3-dimensional groundwater ‘pipeline’ connects this fen to other fen cluster throughout southern Michigan, an interconnected and larger network of fens.
Marton, J. M., I. F. Creed, D. B. Lewis, C. R. Lane, N. B. Basu, M. J. Cohen and C. B. Craft (2015). “Geographically Isolated Wetlands are Important Biogeochemical Reactors on the Landscape.” *BioScience* 65(4): 408-418	The authors conducted a literature review of biogeochemical functions performed by geographically isolated wetlands. They found these wetlands provided biogeochemically mediated ecosystem services such as sediment and carbon retention, nutrient transformations, and water quality improvement that maintain the integrity of US waters.
Cohen, M. J., I. F. Creed, L. Alexander, N. B. Basu, A. J. K. Calhoun, C. Craft, E. D’Amico, E. Dekeyser, L. Fowler, H. E. Golden, J. W. Jawitz, P. Kalla, L. K. Kirkman, C. R. Lane, M. Lang, S. G. Leibowitz, D. B. Lewis, J. Marton, D. L. McLaughlin, D. M. Mushet, H. Raanan-Kiperwas, M. C. Rains, L. Smith and S. C. Walls (2016). “Do geographically isolated wetlands influence landscape functions?” *Proceedings of the National Academy of Sciences of the United States of America* 113(8): 1978-1986	Geographically isolated wetlands across the conterminous US were described as existing along a connectivity continuum. They were found to provide a disproportionately large fraction of wetland edges where many biogeochemical functions were enhanced. They also found that the slow (e.g., through groundwater) or episodic (e.g., through surface water) nature of wetland hydrologic connectivity to other waters provided the conditions for biogeochemical processing, sediment retention, and both biological and hydrological functioning.
Flint, S. A. and W. H. McDowell (2015). “Effects of headwater wetlands on dissolved nitrogen and dissolved organic carbon concentrations in a suburban New Hampshire watershed.” *Freshwater Science* 34(2): 456-471	Ten headwater wetlands, a possible type of non-floodplain wetland system, were analyzed in New Hampshire. The headwater wetlands were found to decrease nitrate and increase dissolved organic carbon and nitrogen concentrations, and to vary the seasonal values of total dissolved nitrogen. These functions would affect the downgradient system.
Denver, J. M., S. W. Ator, M. W. Lang, T. R. Fisher, A. B. Gustafson, R. Fox, J. W. Clune and G. W. McCarty (2014). “Nitrate fate and transport through current and former depressional wetlands in an agricultural landscape, Choptank Watershed, Maryland, United States.” *Journal of Soil and Water Conservation* 69(1): 1-16	Depressional wetlands in the Choptank River, a tributary to the Chesapeake Bay, were analyzed for biogeochemical processing. Natural wetlands had conditions conducive to nitrogen pollution removal for longer than farmed wetlands or restored wetlands but were generally groundwater-connected and were not exposed to nitrogen-laden waters; they were found to provide water to streams that diluted pollution concentrations. Farmed wetlands and restored wetlands that were exposed to nitrate pollution through groundwater removed substantial amounts of nitrate, but contributions to water quality improvement hinged on exposure to polluted waters.
Rajib, A., H. E. Golden, C. R. Lane and Q. Wu (2020). “Surface depression and wetland	In an Upper Mississippi River Basin study, 455,000 depressional wetlands and open waters were incorporated into a hydrologic model

water storage improves major river basin hydrologic predictions." *Water Resources Research* 56(7): e2019WR026561	and significantly affected and improved streamflow measures; these waters further improved the remotely sensed water yield across 70% of the study area. These results demonstrate the significant influence of wetlands and open waters on stream flow, and that wetlands and open waters affect landscape-scale hydrological conditions (e.g., rootzone wetness).
Schmadel, N. M., J. W. Harvey, G. E. Schwarz, R. B. Alexander, J. D. Gomez-Velez, D. Scott and S. W. Ator (2019). "Small Ponds in Headwater Catchments Are a Dominant Influence on Regional Nutrient and Sediment Budgets." *Geophysical Research Letters* 46(16): 9669-9677	Small ponds and impoundments across the Northeastern US were found to be important biogeochemical and physical sinks, retaining 34% of nitrogen, 69% of all phosphorus, and 12% of sediments in the study area. Their influence was dominant in headwater catchments, where they contained 54% of nitrogen, 85% of phosphorus, and 50% of sediments decreasing loads and thereby affecting downstream waters.
Nasab, M. T., V. Singh and X. Chu (2017). "SWAT Modeling for Depression-Dominated Areas: How Do Depressions Manipulate Hydrologic Modeling?" *Water* 9(1): w9010058	Hydrologic modeling in a large watershed in North Dakota found that depression (e.g., Prairie Potholes) storage exerted a gate-keeper effect on downstream flows, decreasing surface runoff contributing to stream flow during low-flow scenarios. Conversely, during high precipitation scenarios, depressions (hydrologic gatekeepers) increased surface runoff peak flows.
Green, D. I. S., S. M. McDeid and W. G. Crumpton (2019). "Runoff Storage Potential of Drained Upland Depressions on the Des Moines Lobe of Iowa." *JAWRA Journal of the American Water Resources Association* 55(3): 543-558	Drained depressions (possibly Prairie Pothole wetlands in farmed landscapes) in Iowa were found to store up to 903.5 million m3 of runoff. Runoff from a 1-yr, 24-hr event would likely exhaust this storage, while rainfall runoff from a 5-yr, 24-hr event would exceed the capacity of the drained depressional storage.
Thorslund, J., M. J. Cohen, J. W. Jawitz, G. Destouni, I. F. Creed, M. C. Rains, P. Badiou and J. Jarsjö (2018). "Solute evidence for hydrological connectivity of geographically isolated wetlands." *Land Degradation & Development* 29(11): 3954-3962	In an analysis across North America, geographically isolated wetlands were found to generate runoff at 1.2x the mean catchment rate which implies they are well-connected watershed-scale sources of water to down-gradient systems.
McKenna, O. P., D. M. Mushet, D. O. Rosenberry and J. W. LaBaugh (2017). "Evidence for a climate-induced ecohydrological state shift in wetland ecosystems of the southern Prairie Pothole Region." *Climatic Change* 145(3): 273-287	Changing precipitation patterning in the Prairie Pothole Region has resulted in an increased number of ponded wetlands and open waters, increases in runoff to wetlands altering wetland solute concentrations, tile drainage connecting wetlands to down-stream systems, and increases in stream flows.
Evenson, G. R., H. E. Golden, C. R. Lane, D. L. McLaughlin and E. D'Amico (2018). "Depressional Wetlands Affect Watershed Hydrological, Biogeochemical, and Ecological Functions." *Ecological Applications* 28(4): 953-966	In a North Dakota hydrologic modeling study, the influence of non-floodplain wetlands on down-gradient stream characteristics was analyzed. Small depressional wetlands (<3.0 ha) significantly affected inundation characteristics (inundated area, hydrologic residence time, and inundation heterogeneity). Larger non-floodplain wetlands were gatekeepers, controlling flows to the stream network. Scenarios of wetland loss based on distance (30-m and 450-m from streams) decreased inundated areas and inundation residence time (for biogeochemical processing). Depression wetlands also attenuated peak flows, decreasing the probability of downstream flooding.
Schofield, K. A., L. C. Alexander, C. E. Ridley, M. K. Vanderhoof, K. M. Fritz, B. C. Autrey, J. E. DeMeester, W. G. Kepner, C.	A review paper wherein freshwater streams, rivers, and wetlands were noted to form a 'freshwater ecosystem mosaic' that sustained aquatic life through connectivity and biotic linkages of organisms

R. Lane, S. G. Leibowitz and A. I. Pollard (2018). "Biota Connect Aquatic Habitats throughout Freshwater Ecosystem Mosaics." *Journal of the American Water Resources Association* 54(2): 372-399	within and among these components. The biotic connectivity of these aquatic systems was considered to be critical to the ecological integrity of freshwaters.
Ameli, A. A. and I. F. Creed (2017). "Quantifying hydrologic connectivity of wetlands to surface water systems." *Hydrol. Earth Syst. Sci.* 21: 1791-1808	In a modeled analysis in the North American Prairie Pothole Region, geographically isolated wetlands were found to have both "fast" surface-water connections and "slow" subsurface water connections to downgradient systems. Subsurface connections linked geographically isolated wetlands from throughout the watershed to the flowing water network, while surface water connections mainly emanated from large precipitation events and originated from wetlands closer to the stream network.
Mekonnen, B. A., K. A. Mazurek and G. Putz (2016). "Incorporating landscape depression heterogeneity into the Soil and Water Assessment Tool (SWAT) using a probability distribution." *Hydrological Processes* 30(13): 2373-2389	A hydrologic modeling study in the Canadian Prairie Pothole Region contrasted the effects of models with multiple small landscape (wetland) depressions versus a more typical and coarser modeling approach. Incorporating landscape depressions into the model improved streamflow estimates, suggesting that the hydrologic effects of depressions have an effect on down-gradient stream system characteristics.
Nitzsche, K. N., T. Kalettka, K. Premke, G. Lischeid, A. Gessler and Z. E. Kayler (2017). "Land-use and hydroperiod affect kettle hole sediment carbon and nitrogen biogeochemistry." *Science of The Total Environment* 574: 46-56	European kettle holes, like Prairie Potholes in North America, are wetland systems formed by past glaciation. An isotopic analysis of 51 kettle holes in Germany determined that in addition to processing organic matter from the surrounding area, kettle holes were coupled with shallow groundwater and were not closed hydrological systems but systems that connected with groundwater.
Golden, H. E., A. Rajib, C. R. Lane, J. R. Christensen, Q. Wu and S. Mengistu (2019). "Non-floodplain Wetlands Affect Watershed Nutrient Dynamics: A Critical Review." *Environmental Science & Technology* 53(13): 7203-7214	A review paper on the influence of non-floodplain wetlands on water quality at watershed scales. Includes analysis of how including non-floodplain wetlands in a Midwestern-US watershed-scale nutrient model markedly changes the predicted nutrient levels in down-gradient systems.
Evenson, G. R., H. E. Golden, C. R. Lane and E. D'Amico (2015). "Geographically isolated wetlands and watershed hydrology: A modified model analysis." *Journal of Hydrology* 529, Part 1: 240-256	In a hydrologic modeling study in a ~202 km2 North Carolina watershed, the authors directly analyzed the watershed-scale hydrologic effects of geographically isolated wetlands on stream characteristics. They found that geographically isolated wetlands: 1) seasonally affected stream baseflow, 2) decreased or attenuated storm peak flows, and 3) quantifiably affected the water balance (or the movement of water through various parts of the water cycle) at the watershed scale.

Legal Definition of "Traditional Navigable Waters"

This document is known as Appendix D when attached to the U.S. Army Corps of Engineers Jurisdictional Determination Form Instructional Guidebook. No changes have been made. This document was issued to provide guidance on determining whether a water is a "traditional navigable water" for purposes of the *Rapanos* Guidance, the Clean Water Act (CWA), and the agencies' CWA implementing regulations. The CWA definition of "traditional navigable waters" has not changed in recent rulemakings and the agencies have continued to use this document to provide guidance on determining whether a water is a "traditional navigable water." *See* "Clean Water Rule: Definition of 'Waters of the United States,'" 80 FR 37054, 37074 (June 29, 2015); Navigable Waters Protection Rule: Definition of "Waters of the United States." 85 FR 22250, 22281 (April 21, 2020).

Waters that Qualify as Waters of the United States Under Section (a)(1) of the Agencies' Regulations

The Environmental Protection Agency (EPA) and United States Army Corps of Engineers (Corps) "Clean Water Act Jurisdiction Following the U.S. Supreme Court's Decision in *Rapanos v. United States* and *Carabell v. United States*" guidance (*Rapanos* guidance) affirms that EPA and the Corps will continue to assert jurisdiction over "[a]ll waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide." 33 C.F.R. § 328.3(a)(1); 40 C.F.R. § 230.3(s)(1). The guidance also states that, for purposes of the guidance, these "(a)(1) waters" are the "traditional navigable waters." These (a)(1) waters include all of the "navigable waters of the United States," defined in 33 C.F.R. Part 329 and by numerous decisions of the federal courts, plus all other waters that are navigable-in-fact (e.g., the Great Salt Lake, UT and Lake Minnetonka, MN).

EPA and the Corps are providing this guidance on determining whether a water is a "traditional navigable water" for purposes of the Rapanos guidance, the Clean Water Act (CWA), and the agencies' CWA implementing regulations. This guidance is not intended to be used for any other purpose. To determine whether a water body constitutes an (a)(1) water under the regulations, relevant considerations include Corps regulations, prior determinations by the Corps and by the federal courts, and case law. Corps districts and EPA regions should determine whether a particular waterbody is a traditional navigable water based on application of those considerations to the specific facts in each case.

As noted above, the (a)(1) waters include, but are not limited to, the "navigable waters of the United States." A water body qualifies as a "navigable water of the United States" if it meets any of the tests set forth in 33 C.F.R. Part 329 (e.g., the water body is (a) subject to the ebb and flow of the tide, and/or (b) the water body is presently used, or has been used in the past, or may be susceptible for use (with or without reasonable improvements) to transport interstate or foreign commerce). The Corps districts have made determinations in the past regarding whether particular water bodies qualify as "navigable waters of the United States" for purposes of asserting jurisdiction under Sections 9 and 10 of the Rivers and Harbors Act of 1899 (33 USC Sections 401 and 403). Pursuant to 33 C.F.R. § 329.16, the Corps should maintain lists of final determinations of navigability for purposes of Corps jurisdiction under the Rivers and Harbors Act of 1899. While absence from the list should not be taken as an indication that the water is not navigable (329.16(b)), Corps districts and EPA regions should rely on any final Corps determination that a water body is a navigable water of the United States.

If the federal courts have determined that a water body is navigable-in-fact under federal law for any purpose, that water body qualifies as a "traditional navigable water" subject to CWA jurisdiction under 33 C.F.R. § 328.3(a)(1) and 40 C.F.R. § 230.3(s)(1). Corps districts and EPA regions should be guided by the relevant opinions of the federal courts in determining whether waterbodies are "currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce" (33 C.F.R. § 328.3(a)(1); 40 C.F.R. § 230.3(s)(1)) or "navigable-in-fact."

This definition of "navigable-in-fact" comes from a long line of cases originating with *The Daniel Ball*, 77 U.S. 557 (1870). The Supreme Court stated:

> Those rivers must be regarded as public navigable rivers in law which are navigable in fact. And they are navigable in fact when they are used, or are susceptible of being used, in their ordinary condition, as highways for commerce, over which trade and travel are or may be conducted in the customary modes of trade and travel on water.

The Daniel Ball, 77 U.S. at 563.

In *The Montello*, the Supreme Court clarified that "customary modes of trade and travel on water" encompasses more than just navigation by larger vessels:

> The capability of use by the public for purposes of transportation and commerce affords the true criterion of the navigability of a river, rather than the extent and manner of that use. If it be capable in its natural state of being used for purposes of commerce, no matter in what mode the commerce may be conducted, it is navigable in fact, and becomes in law a public river or highway.

The Montello, 87 U.S. 430, 441-42 (1874).

In that case, the Court held that early fur trading using canoes sufficiently showed that the Fox River was a navigable water of the United States. The Court was careful to note that the bare fact of a water's capacity for navigation alone is not sufficient; that capacity must be indicative of the water's being "generally and commonly useful to some purpose of trade or agriculture." Id. at 442.

In *Economy Light & Power*, the Supreme Court held that a waterway need not be continuously navigable; it is navigable even if it has "occasional natural obstructions or portages" and even if it is not navigable "at all seasons . . . or at all stages of the water." *Economy Light & Power Co. v. U.S.*, 256 U.S. 113, 122 (1921).

In *United States v. Holt State Bank*, 270 U.S. 49 (1926), the Supreme Court summarized the law on navigability as of 1926 as follows:

> The rule long since approved by this court in applying the Constitution and laws of the United States is that streams or lakes which are navigable in fact must be regarded as navigable in law; that they are navigable in fact when they are used, or are susceptible of being used, in their natural and ordinary condition, as highways for commerce, over which trade and travel are or may be conducted in the customary modes of trade and travel on water; and further that navigability 4 does not depend on the particular mode in which such use is or may be had - whether by steamboats, sailing vessels or flatboats- nor on an absence of occasional difficulties in navigation, but on the fact, if it be a fact, that the stream in its natural and ordinary condition affords a channel for useful commerce.

Holt State Bank, 270 U.S. at 56.

In *U. S. v. Utah*, 283 U.S. 64, (1931) and *U.S. v. Appalachian Elec. Power Co*, 311 U.S. 377 (1940), the Supreme Court held that so long as a water is susceptible to use as a highway of commerce, it is navigable-in-fact, even if the water has never been used for any commercial purpose. *U.S. v. Utah*, at 81-83 ("The question of that susceptibility in the ordinary condition of the rivers, rather than of the mere manner or extent of actual use, is the crucial question."); *U.S. v. Appalachian Elec. Power Co.*, 311 U.S. 377, 416 (1940) ("Nor is lack of commercial traffic a bar to a conclusion of navigability where personal or private use by boats demonstrates the availability of the stream for the simpler types of commercial navigation.").

In 1971, in *Utah v. United States*, 403 U.S. 9 (1971), the Supreme Court held that the Great Salt Lake, an intrastate water body, was navigable under federal law even though it "is not part of a navigable interstate or international commercial highway." *Id*. at 10. In doing so, the Supreme Court stated that the fact that the Lake was used for hauling of animals by ranchers rather than for the transportation of "water-borne freight" was an "irrelevant detail." *Id*. at 11. "The lake was used as a highway and that is the gist of the federal test." *Ibid*.[1]

In summary, when determining whether a water body qualifies as a "traditional navigable water" (i.e., an (a)(1) water), relevant considerations include whether a Corps District has determined that the water body is a navigable water of the United States pursuant to 33 C.F.R § 329.14, or the water body qualifies as a navigable water of the United States under any of the tests set forth in 33 C.F.R. § 329, or a federal court has determined that the water body is navigable-in-fact under federal law for any purpose, or the water body is "navigable-in-fact" under the standards that have been used by the federal courts.

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[1] Also of note are two decisions from the courts of appeals. In *FPL Energy Marine Hydro*, a case involving the Federal Power Act, the D.C. Circuit reiterated the fact that "actual use is not necessary for a navigability determination" and repeated earlier Supreme Court holdings that navigability and capacity of a water to carry commerce could be shown through "physical characteristics and experimentation." *FPL Energy Marine Hydro LLC v. FERC*, 287 F.3d 1151, 1157 (D.C. Cir. 2002). In that case, the D.C. Circuit upheld a FERC navigability determination that was based upon three experimental canoe trips taken specifically to demonstrate the river's navigability. Id. at 1158-59.

The 9th Circuit has also implemented the Supreme Court's holding that a water need only be susceptible to being used for waterborne commerce to be navigable-in-fact. *Alaska v. Ahtna, Inc.,* 891 F.2d 1404 (9th Cir. 1989). In *Ahtna*, the 9th Circuit held that current use of an Alaskan river for commercial recreational boating is sufficient evidence of the water's capacity to carry waterborne commerce at the time that Alaska became a state. *Id*. at 1405. It was found to be irrelevant whether or not the river was actually being navigated or being used for commerce at the time, because current navigation showed that the river always had the capacity to support such navigation. *Id*. at 1404.