Supplementary Materials 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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Supplementary Materials

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Supplementary Material A: Scientific Papers Selected for Forward-Citation Mapping

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 provided 553 papers relevant to the connectivity and effects of streams, floodplain wetlands and open waters, and non-floodplain wetlands and open waters for forward-citation mapping from within the Web of Science global citation database. Those 553 papers are listed below.

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Zimmer, M.A., K.E. Kaiser, J.R. Blaszczak, S.C. Zipper, J.C. Hammond, K.M. Fritz, K.H. Costigan, J. Hosen, S.E. Godsey, G.H. Allen, S. Kampf, R.M. Burrows, C.A. Krabbenhoft, W. Dodds, R. Hale, J.D. Olden, M. Shanafield, A.G. Delvecchia, A.S. Ward, M.C. Mims, T. Datry, M.T. Bogan, K.S. Boersma, M.H. Busch, C.N. Jones, A.J. Burgin, and D.C. Allen. 2020. "Zero or not? Causes and consequences of zero-flow stream gage readings." *Wiley Interdisciplinary Reviews. Water* n/a (n/a): e1436. http://dx.doi.org/10.1002/wat2.1436.

Zimmermann, B., A. Zimmermann, B.L. Turner, T. Francke, and H. Elsenbeer. 2014. "Connectivity of overland flow by drainage network expansion in a rain forest catchment." *Water Resources Research* 50 (2): 1457-1473. http://dx.doi.org/10.1002/2012WR012660.

Supplementary Material B: Papers Screened Early to Expediate Machine-Learning Model Building

In the SWIFT Active-Screener environment, model seed papers expedite the machine-learning process (Howard et al. 2020). These seed papers for each aquatic system were identified by the ORD subject matter experts from known scientific literature on the connectivity and effects of ephemeral, intermittent, and perennial streams, floodplain wetlands and open waters, and non-floodplain wetlands and open waters.

Ephemeral, Intermittent, and Perennial Streams: Seed Papers

Abbott, B. W., G. Gruau, J. P. Zarnetske, F. Moatar, L. Barbe, Z. Thomas, O. Fovet, T. Kolbe, S. Gu, A.-C. Pierson-Wickmann, P. Davy and G. Pinay (2018). "Unexpected spatial stability of water chemistry in headwater stream networks." *Ecology Letters* 21(2): 296-308.

Botter, G. and N. Durighetto (2020). "The Stream Length Duration Curve: A Tool for Characterizing the Time Variability of the Flowing Stream Length." *Water Resources Research* 56(8): e2020WR027282.

Boulton, A. J., R. J. Rolls, K. L. Jaeger and T. Datry (2017). Chapter 2.3 - Hydrological Connectivity in Intermittent Rivers and Ephemeral Streams. *Intermittent Rivers and Ephemeral Streams*. T. Datry, N. Bonada and A. Boulton, Academic Press: 79-108.

Covino, T. (2017). "Hydrologic connectivity as a framework for understanding biogeochemical flux through watersheds and along fluvial networks." *Geomorphology* 277: 133-144.

Datry, T., A. J. Boulton, N. Bonada, K. Fritz, C. Leigh, E. Sauquet, K. Tockner, B. Hugueny and C. N. Dahm (2018). "Flow intermittence and ecosystem services in rivers of the Anthropocene." *Journal of Applied Ecology* 55(1): 353-364.

Ebersole, J. L., P. J. Wigington, S. G. Leibowitz, R. L. Comeleo and J. V. Sickle (2015). "Predicting the occurrence of cold-water patches at intermittent and ephemeral tributary confluences with warm rivers." *Freshwater Science* 34(1): 111-124.

Fesenmyer, K. A., S. J. Wenger, D. S. Leigh and H. M. Neville (2021). "Large portion of USA streams lose protection with new interpretation of Clean Water Act." *Freshwater Science* 40(1): 252-258.

Fritz, K. M., G. J. Pond, B. R. Johnson and C. D. Barton (2019). "Coarse particulate organic matter dynamics in ephemeral tributaries of a Central Appalachian stream network." *Ecosphere* 10(3): e02654.

Gallo, E. L., K. A. Lohse, C. M. Ferlin, T. Meixner and P. D. Brooks (2014). "Physical and biological controls on trace gas fluxes in semi-arid urban ephemeral waterways." *Biogeochemistry* 121(1): 189-207.

Jasechko, S., J. W. Kirchner, J. M. Welker and J. J. McDonnell (2016). "Substantial proportion of global streamflow less than three months old." *Nature Geoscience* 9(2): 126-129.

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

McGuire, K. J., C. E. Torgersen, G. E. Likens, D. C. Buso, W. H. Lowe and S. W. Bailey (2014). “Network analysis reveals multiscale controls on streamwater chemistry.” *Proceedings of the National Academy of Sciences* 111(19): 7030.

Messager, M. L., B. Lehner, C. Cockburn, N. Lamouroux, H. Pella, T. Snelder, K. Tockner, T. Trautmann, C. Watt and T. Datry (2021). “Global prevalence of non-perennial rivers and streams.” *Nature* 594(7863): 391-397.

Moore, J. W., M. P. Beakes, H. K. Nesbitt, J. D. Yeakel, D. A. Patterson, L. A. Thompson, C. C. Phillis, D. C. Braun, C. Favaro, D. Scott, C. Carr-Harris and W. I. Atlas (2015). “Emergent stability in a large, free-flowing watershed.” *Ecology* 96(2): 340-347.

Perkin, J. S., K. B. Gido, J. A. Falke, K. D. Fausch, H. Crockett, E. R. Johnson and J. Sanderson (2017). “Groundwater declines are linked to changes in Great Plains stream fish assemblages.” *Proceedings of the National Academy of Sciences* 114(28): 7373–7378.

Pierdomenico, M., D. Casalbore and F. L. Chiocci (2019). “Massive benthic litter funnelled to deep sea by flash-flood generated hyperpycnal flows.” *Scientific Reports* 9(1): 5330.

Rice, S. P. (2017). “Tributary connectivity, confluence aggradation and network biodiversity.” *Geomorphology* 277: 6-16.

Rogosch, J. S. and J. D. Olden (2019). “Dynamic contributions of intermittent and perennial streams to fish beta diversity in dryland rivers.” *Journal of Biogeography* 46(10): 2311-2322.

Sutfin, N. A., E. E. Wohl and K. A. Dwire (2016). “Banking carbon: a review of organic carbon storage and physical factors influencing retention in floodplains and riparian ecosystems.” *Earth Surface Processes and Landforms* 41(1): 38-60.

Tonkin, J. D., F. Altermatt, D. S. Finn, J. Heino, J. D. Olden, S. U. Pauls and D. A. Lytle (2018). “The role of dispersal in river network metacommunities: Patterns, processes, and pathways.” *Freshwater Biology* 63(1): 141-163.

Floodplain Wetlands and Open Waters: Seed Papers

Amezcua, F., J. Rajnohova, F. Flores-De-Santiago, F. Flores-Verdugo and F. Amezcua-Linares (2019). “The Effect of Hydrological Connectivity on Fish Assemblages in a Floodplain System from the South-East Gulf of California, Mexico.” *Frontiers in Marine Science* 6.

Biehler, A., G. Chaillou, T. Buffin-Belanger and P. Baudron (2020). “Hydrological connectivity in the aquifer-river continuum: Impact of river stages on the geochemistry of groundwater floodplains.” *Journal of Hydrology* 590.

Chanut, P. C. M., T. Datry, C. Gabbud and C. T. Robinson (2019). “Direct and indirect effects of flood regime on macroinvertebrate assemblages in a floodplain riverscape.” *Ecohydrology* 12(5).

Czuba, J. A., S. R. David, D. A. Edmonds and A. S. Ward (2019). “Dynamics of Surface-Water Connectivity in a Low-Gradient Meandering River Floodplain.” *Water Resources Research* 55(3): 1849-1870.

D’Araujo Couto, T. B., J. Zuanon, J. D. Olden and G. Ferraz (2018). “Longitudinal variability in lateral hydrologic connectivity shapes fish occurrence in temporary floodplain ponds.” *Canadian Journal of Fisheries and Aquatic Sciences* 75(2): 319-328.

Fritz, K. M., K. A. Schofield, L. C. Alexander, M. G. McManus, H. E. Golden, C. R. Lane, W. G. Kepner, S. D. LeDuc, J. E. DeMeester and A. I. Pollard (2018). “Physical and Chemical Connectivity of Streams and Riparian Wetlands to Downstream Waters: A Synthesis.” *Journal of the American Water Resources Association* 54(2): 323-345.

Holgerson, M. A., A. Duarte, M. P. Hayes, M. J. Adams, J. A. Tyson, K. A. Douville and A. L. Strecker (2019). “Floodplains provide important amphibian habitat despite multiple ecological threats.” *Ecosphere* 10(9).

Kaase, C. T. and J. A. Kupfer (2016). “Sedimentation patterns across a Coastal Plain floodplain: The importance of hydrogeomorphic influences and cross-floodplain connectivity.” *Geomorphology* 269: 43-55.

Kreiling, R. M., L. A. Bartsch, P. M. Perner, E. J. Hlavacek and V. G. Christensen (2021). “Riparian Forest Cover Modulates Phosphorus Storage and Nitrogen Cycling in Agricultural Stream Sediments.” *Environmental Management* 68(2): 279-293.

Larsen, L. G., J. W. Harvey and M. M. Maglio (2015). “Mechanisms of nutrient retention and its relation to flow connectivity in river-floodplain corridors.” *Freshwater Science* 34(1): 187-205.

Larsen, S., U. Karaus, C. Claret, F. Sporka, L. Hamerlík and K. Tockner (2019). “Flooding and hydrologic connectivity modulate community assembly in a dynamic river-floodplain ecosystem.” *PLoS ONE* 14(4): e0213227.

McMillan, S. K. and G. B. Noe (2017). “Increasing floodplain connectivity through urban stream restoration increases nutrient and sediment retention.” *Ecological Engineering* 108: 284-295.

Natho, S., M. Tschikof, E. Bondar-Kunze and T. Hein (2020). “Modeling the Effect of Enhanced Lateral Connectivity on Nutrient Retention Capacity in Large River Floodplains: How Much Connected Floodplain Do We Need?” *Frontiers in Environmental Science* 8.

Noe, G. B., K. Boomer, J. L. Gillespie, C. R. Hupp, M. Martin-Alciati, K. Floro, E. R. Schenk, A. m. Jacobs and S. Strano (2019). “The effects of restored hydrologic connectivity on floodplain trapping vs. release of phosphorus, nitrogen, and sediment along the Pocomoke River, Maryland USA.” *Ecological Engineering* 138: 334-352.

Pongruktham, O. and C. Ochs (2015). “The rise and fall of the Lower Mississippi: effects of hydrologic connection on floodplain backwaters.” *Hydrobiologia* 742(1): 169-183.

Schilling, K. E., B. J. Haines, C. S. Jones and M. St Clair (2018). “Effectiveness of a newly reconstructed floodplain oxbow to reduce NO3-N loads from a spring flood.” *Journal of Environmental Management* 215: 385-393.

Stoffels, R. J., R. A. Rehwinkel, A. E. Price and W. F. Fagan (2016). “Dynamics of fish dispersal during river-floodplain connectivity and its implications for community assembly.” *Aquatic Sciences* 78(2): 355-365.

Stone, M. C., C. F. Byrne and R. R. Morrison (2017). “Evaluating the impacts of hydrologic and geomorphic alterations on floodplain connectivity.” *Ecohydrology* 10(5).

Sutfin, N. A., E. E. Wohl and K. A. Dwire (2016). “Banking carbon: a review of organic carbon storage and physical factors influencing retention in floodplains and riparian ecosystems.” *Earth Surface Processes and Landforms* 41(1): 38-60.

Wohl, E. and A. Pfeiffer (2018). “Organic carbon storage in floodplain soils of the US prairies.” *River Research and Applications* 34(5): 406-416.

Non-Floodplain Wetlands and Open Waters: Seed Papers

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.

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.

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.

Chandler, H. C., D. L. McLaughlin, T. A. Gorman, K. J. McGuire, J. B. Feaga and C. A. Haas (2017). “Drying Rates of Ephemeral Wetlands: Implications for Breeding Amphibians.” *Wetlands* 37(3): 545-557.

Cheng, F. Y. and N. B. Basu (2017). “Biogeochemical hotspots: Role of small water bodies in landscape nutrient processing.” *Water Resources Research* 53(6): 5038-5056.

Cheng, F. Y., K. J. Van Meter, D. K. Byrnes and N. B. Basu (2020). “Maximizing US nitrate removal through wetland protection and restoration.” *Nature* 588: 625-630.

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.

Creed, I. F., C. R. Lane, J. N. Serran, L. C. Alexander, N. B. Basu, A. J. K. Calhoun, J. R. Christensen, M. J. Cohen, C. Craft, E. D'Amico, E. DeKeyser, L. Fowler, H. E. Golden, J. W. Jawitz, P. Kalla, L. K. Kirkman, M. Lang, S. G. Leibowitz, D. B. Lewis, J. Marton, D. L. McLaughlin, H. Raanan-Kiperwas, M. C. Rains, K. C. Rains and L. Smith (2017). "Enhancing protection for vulnerable waters." *Nature Geoscience* 10: 809-815.

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.

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.

Lane, C. R., S. G. Leibowitz, B. C. Autrey, S. D. LeDuc and L. C. Alexander (2018). "Hydrological, Physical, and Chemical Functions and Connectivity of Non-Floodplain Wetlands to Downstream Waters: A Review." *JAWRA Journal of the American Water Resources Association* 54(2): 346-371.

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Supplementary Material C: Questions Answered from Each Included Scientific Paper's Abstract

After initially reading the abstract in the SWIFT Active-Screener environment and concluding to include the peer-reviewed paper, the subject-matter experts (three per aquatic system type: streams, floodplain wetlands and open waters, and non-floodplain wetlands and open waters) answered the following questions to the best of their ability based on the abstract content.

Ephemeral, Intermittent, and Perennial Streams

1. Stream type
    a. Ephemeral
    b. Intermittent
    c. Perennial
    d. Headwater
    e. Stream type not discernible
2. Connection/effect type
    a. Physical
    b. Chemical
    c. Biological
    d. Connection/effect type not discernible
3. Scale
    a. Reach (individual connections/effects)
    b. Watershed (cumulative connections/effects)
    c. Scale not discernible
4. Geographic/physiographic location
    a. US (or portions of the US)
    b. Non-US (or geographic/physiographic region not discernible)
5. Interacting effects
    a. Climate
    b. Land use
    c. Water use (e.g., drinking water, agricultural use, industrial, etc.)
    d. None
6. Specific topics
    a. Distance (headwaters affecting downstream waters)
    b. Ditched or impounded systems (i.e., human alterations)
    c. Flood/flooding
    d. Baseflow
    e. Groundwater recharge
    f. Human health
    g. None discernible
7. 2015 CR Major Conclusion: The scientific literature unequivocally demonstrates that streams, individually or cumulatively, exert a strong influence on the integrity of downstream waters. All tributaries, regardless of size or flow duration, are physically, chemically, and biologically connected to downstream waters and strongly influence their function.
    a. Supports findings
    b. Refutes findings

c. Cannot be discerned

8. General comment (e.g., important paper, paper hyperlink if abstract missing, etc.):

Floodplain Wetlands and Open Waters

1. Wetland [and open water] system type
    a. Floodplain (or riparian) system
    b. Riverine (i.e., within-channel)
    c. Multiple wetland types and/or spatial locations noted (e.g., floodplain, riverine, NFW, etc.)
    d. Wetland type not discernible
2. Connection/effect type
    a. Physical
    b. Chemical
    c. Biological
    d. Connection/effect type not discernible
3. Scale
    a. Individual (functions/connections/effects)
    b. Landscape-scale (connections/functions/effects…to something)
    c. Watershed (downstream and/or down-gradient cumulative connections/functions/effects)
    d. Scale not discernible
4. Geographic/physiographic location
    a. US (or portions of the US)
    b. Non-US (or geographic/physiographic region not discernible)
5. Interacting effects
    a. Climate
    b. Land use
    c. Water use (e.g., drinking water, agricultural use, industrial, etc.)
    d. None
6. Specific topics
    a. Distance (floodplain wetlands affecting downstream waters)
    b. Wetlands ditched, impounded, or behind levees/berms (i.e., human alterations)
    c. Farmed floodplain wetlands
    d. Flood/flooding
    e. Baseflow
    f. Groundwater recharge
    g. Human health
    h. None discernible
7. 2015 CR Major Conclusion: Wetlands and open waters in riparian areas and floodplains are physically, chemically, and biologically integrated with rivers via functions that improve downstream water quality. These systems buffer downstream waters from pollution and are essential components of river food webs.
    a. Supports findings
    b. Refutes findings
    c. Cannot be discerned
8. General comment (e.g., important paper, paper hyperlink if abstract missing, etc.):

Non-Floodplain Wetlands and Open Waters

1. Wetland type

    a. Paper explicitly about known non-floodplain type (e.g., GIW, NFW, upland-embedded wetland, vernal pools, woodland pond, etc.).
    b. Multiple wetland types and/or spatial locations noted (e.g., NFW, floodplain wetlands, streams, etc.)
    c. Wetland type not discernible
2. Connection/effect type
    a. Physical
    b. Chemical
    c. Biological
    d. Connection/effect type not discernible
3. Scale
    a. Individual (functions/effects)
    b. Landscape-scale (connections/functions/effects…to something)
    c. Watershed-scale (downstream and/or down-gradient cumulative connections/functions/effects)
    d. Scale not discernible
4. Geographic/physiographic location
    a. US (or portions of the US)
    b. Non-US (or geographic/physiographic region not discernible)
5. Interacting effects
    a. Climate
    b. Land use
    c. Water use (e.g., drinking water, agricultural use, industrial, etc.)
    d. None
6. Specific topics
    a. Distance (NFWs affecting downstream waters)
    b. Wetlands ditched, impounded, or behind levees/berms (i.e., human alterations)
    c. Flood/flooding
    d. Baseflow
    e. Groundwater recharge
    f. Human health
    g. None discernible
7. 2015 CR Major Conclusion: Wetlands and open waters located outside of riparian areas and floodplains, even when lacking surface water connections, provide numerous functions that could affect the integrity of downstream waters. Some benefits of these wetlands are due to their relative isolation rather than their connections.
    a. Supports findings
    b. Refutes findings
    c. Cannot be discerned
8. General comment (e.g., important paper, paper hyperlink if abstract missing, etc.):