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Indigenous Rights and Climate Change: The Influence of Climate Change on the Quantification of Reserved Instream Water Rights for American Indian Tribes

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INDIGENOUS RIGHTS AND CLIMATE CHANGE: THE INFLUENCE OF CLIMATE CHANGE ON THE QUANTIFICATION OF RESERVED INSTREAM WATER RIGHTS FOR AMERICAN INDIAN TRIBES

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"All models are wrong but some are useful."[1]

Abstract

The people indigenous to the Western portion of the lands now referred to as North America have relied on aquatic species for physical, cultural, and spiritual sustenance for millenia. Such indigenous peoples, referred to in the American legal system as Indian tribes, are entitled to water rights for fish habitat pursuant to the Winters Doctrine, which holds that the federal government impliedly reserved water rights for tribes when reservations were created. Recently, the methodology for quantifying these rights has been the Instream Flow Incremental Methodology (IFIM) and/or one of its major components, the Physical Habitat Simulation Model (PHABSIM). These models result in water right claims for fixed quantities of water, which—although not required by law—result in instream water rights that are decreed without any means for adjustment to account for changing conditions. Ultimately, climate change will likely alter the amount of water necessary to protect aquatic habitat, rendering obsolete any water right that is based on a fixed quantity. As climate change continues to worsen, we argue that quantifying reserved water rights for inflexible fixed quantities imposes an unreasonable burden on American Indian tribes. Instead, we suggest the application of a number of integrated technical and legal solutions to mitigate the uncertainty Indian tribes currently face from climate change as they seek to protect their rights, resources, and homelands.

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* © 2020 Dylan R. Hedden-Nicely. Associate Professor and Director, Native American Law Program, University of Idaho College of Law, 875 Perimeter Drive, MS 2321, Moscow, ID 83843. The author acknowledges that he lives and makes his living in the aboriginal homeland of the Nimi'ipuu (Nez Perce) and Schitsu'umsh (Coeur d'Alene) peoples and that the University of Idaho is situated within the boundaries of the Nez Perce Tribe's unceded 1855 Reservation. These Tribal Nations are distinct, sovereign, legal and political entities with their own powers of self-governance and self-determination. Honor the treaties; "[g]reat nations, like great men, should keep their word." F.P.C. v. Tuscarora Indian Nation, 362 U.S. 99, 142 (1960) (Black, J., dissenting).

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1 G.E.P. Box, *Robustness in the Strategy of Scientific Model Building*, *in* ROBUSTNESS IN STATISTICS 201, 202 (Rober L. Launer & Graham N Wilkinson eds., 1979).

I. RESERVED WATER RIGHTS FOR AMERICAN INDIAN TRIBES: INTRODUCTION & LEGAL BACKGROUND

Since time immemorial, the indigenous peoples that live in the area now known as the Northwestern United States have depended upon various species of fish for physical, cultural, and spiritual sustenance. Indeed, the historical record demonstrates that the continued right to hunt, fish, and gather was a central concern of such peoples—referred to in the American legal system as Indian tribes—throughout the region as they negotiated treaties and agreements with the United States government in the 1850s through 1880s.[2] Nearly without exception, however, these agreements lacked any express reservation of rights to water. The United States Supreme Court filled this gap in 1908 by announcing what has become known as the *Winters* Doctrine.[3] The Doctrine holds that, when tribes and the United States come to an agreement for the reservation of land for perpetual use by the tribe, they also, "by implication, reserve[] appurtenant water then unappropriated to the extent needed to accomplish the purpose of the reservation."[4]

Although *Winters* water rights were initially recognized only for irrigation purposes,[5] courts later recognized that tribes were likewise entitled to water rights necessary to maintain their rights to hunt, fish, gather, as well as engage in other subsistence, cultural, and spiritual activities.[6] These water rights are often

[2] *See*, *e.g.*, Treaty of Fort Bridger art. 4, July 3, 1868, 15 Stat. 673; Treaty with the Klamath, etc. art. 1, Oct. 14, 1864, 16 Stat. 707; Treaty of Hellgate, U.S.-Flathead Tribe, art. 3, July 16, 1855, 12 Stat. 975; Treaty of Olympia art. 3, July 1, 1855, 12 Stat. 971; Treaty with Indians in Middle Oregon art. 1, June 25, 1855, 12 Stat. 963; Nez Perce Treaty, U.S.-Nez Perce Tribe, art.3, June 11, 1855, 12 Stat. 957; Treaty with the Wallawalla, Cayuse, etc. art. 1, June 9, 1855, 12 Stat. 945; Treaty with the Yakima, U.S.-Yakima Tribe, art. 1, June 9, 1855, 12 Stat. 951; Treaty of Neah Bay, U.S.-Makah Tribe, art. 4, Jan. 31, 1855, 12 Stat. 939; Point No Point Treaty, U.S.-S'Kallam Tribe, art. 4, Jan. 26, 1855, 12 Stat. 933; Treaty of Point Elliot art. 2, Jan 22, 1855, 12 Stat. 1927; Treaty of Medicine Creek, U.S.-Nisqually Tribe, art. 3, Dec. 26, 1854, 10 Stat. 1132; *see also* United States v. Washington, 853 F.3d 946, 953–54 (9th Cir. 2017) (discussing a series of treaties known as the Stevens Treaties, which the United States entered into with various tribes in Northwest Washington in 1854 and 1855). The Executive Orders Creating the Coeur d'Alene, Colville, and Spokane Reservations have likewise all been interpreted to include on-reservation hunting and fishing rights. *See* United States v. Idaho, 95 F. Supp. 2d 1094, 1104 (D. Idaho 1998); Colville Confederated Tribes v. Walton, 647 F.2d 42, 48 (9th Cir. 1981); United States v. Anderson, 6 Indian L. Rep. F-129 (E.D. Wash. 1979).

[3] Winters v. United States, 207 U.S. 564 (1908); *see also* Cappaert v. United States, 426 U.S. 128, 138 (1976) (referring to the *Winters* Doctrine as the "reserved-water-rights doctrine" or the "implied-reservation-of-water-rights doctrine").

[4] *Cappaert*, 426 U.S. at 138.

[5] *Winters*, 207 U.S. at 566; *see also* Arizona v. California (*Arizona I*), 373 U.S. 546, 597 (1963) (applying *Winters* to irrigation rights on Indian land).

[6] *See*, *e.g.*, United States v. Adair, 723 F.2d 1394 (9th Cir. 1984); *Walton*, 647 F.2d at 48; Dep't of Ecology v. Yakima Reservation Irrigation Dist. (*In re* Surface Waters of the

maintained through the reservation of instream flows, defined as the amount of water flowing within a constrained stream channel over a particular period of time and, when considered in aggregate, constitutes the discharge associated with a particular stream.[7] For reserved water rights based on instream flow, the tribes' "entitlement consists of the right to prevent other [water users] from depleting the stream[']s waters below a protected level . . . ."[8]

The *Winters* Doctrine represents an important exception to the general rule that the states, not the federal government, enjoy plenary authority over the management of water resources within their boundaries.[9] In the West, states have developed a water rights doctrine known as prior appropriation.[10] Under prior appropriation, "one acquires a right to water by diverting it from its natural source and applying it to some beneficial use."[11] Traditionally, beneficial uses include water for irrigation, domestic, commercial, municipal, and industrial uses[12]—more recently, recognized uses have been expanded to include instream flows.[13] The cornerstone of prior appropriation is that those that were first in time are first in their water right: that is, "[i]n periods of shortage, priority among confirmed rights is determined according to the date of initial diversion."[14]

It is this bedrock principle of prioritizing older water rights that so often brings non-Indian and tribal water users into conflict. Tribal reserved water rights have a priority date "no later than the date on which a reservation was established . . . ."[15] Even earlier are water rights for traditional uses of water, which include water necessary for uses that predate the creation of the reservation—such as hunting, fishing, gathering, domestic, transportation, recreation, and cultural activities—and

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Yakima River Drainage Basin), 850 P.2d 1306 (Wash. 1993); *Anderson*, 6 Indian L. Rep. F-129.

7 NAT'L RESEARCH COUNCIL, THE SCIENCE OF INSTREAM FLOWS: A REVIEW OF THE TEXAS INSTREAM FLOW PROGRAM 139 (2005), https://www.nap.edu/read/11197/chapter/11 [https://perma.cc/G2CQ-5HFD]. Instream flows specifically do not include groundwater, hyporheic, or overland flows. *Id.*

8 *Adair*, 723 F.2d at 1411.

9 California Oregon Power Co. v. Beaver Portland Cement Co., 295 U.S. 142, 163–64 (1935); United States v. Rio Grande Dam & Irrigation Co., 174 U.S. 690, 703 (1899).

10 Colorado River Water Conservation Dist. v. United States, 424 U.S. 800, 805 (1976).

11 *Id.*

12 *See, e.g.*, MONT. CODE ANN. § 85-2-102(5)(a) (2019) ("'Beneficial use', unless otherwise provided, means . . . a use of water for the benefit of the appropriator, other persons, or the public, including but not limited to agricultural, stock water, domestic, fish and wildlife, industrial, irrigation, mining, municipal, power, and recreational uses").

13 *See, e.g.*, *id.* § 85-2-102(5)(c) (2019) ("a use of water by the department of fish, wildlife, and parks . . . for instream flow to protect, maintain, or enhance streamflows to benefit the fishery resource").

14 *Colorado River Water Conservation Dist.*, 424 U.S. at 805.

15 FELIX COHEN, COHEN'S HANDBOOK OF FEDERAL INDIAN LAW 1203 (Nell Jessup Newton et al. eds., 2012).

have a priority date of time immemorial.[16] Because of these early priority dates, tribal water rights invariably take precedence over junior non-Indian water rights and, as a result, "exercise of tribal [instream] water rights has the potential to disrupt non-Indian [out-of-stream] water uses."[17] Considerable litigation has been dedicated toward mitigating the uncertainty non-Indian water users face as a result of unquantified reserved water rights.[18] A number of early federal court decisions included open-ended decrees wherein the United States was authorized to use additional water consistent with the expanding needs of the tribes.[19]

However, this practice has largely fallen into disuse since the Supreme Court's 1963 decision in *Arizona v. California* (*Arizona I*).[20] There, the Court affirmed the decision of Special Master Simon Rifkind,[21] who opined that such open-ended decrees "place all junior water rights in jeopardy of the uncertain and the unknowable . . . ."[22] As a result, Master Rifkind found that the decree must "preserve the full extent of the water rights created by the United States and . . . establish water rights of fixed magnitude and priority so as to provide certainty for both the United States and non-Indian water users."[23]

Once decreed with a fixed quantity of water, the Supreme Court has held that tribes are precluded from reopening water rights decrees to provide Indian tribes with more water that is necessary for expanding needs.[24] In *Arizona II,* the Court

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[16] United States v. Adair, 723 F.2d 1394, 1414 (9th Cir. 1984).

[17] COHEN, *supra* note 15, at 1211.

[18] *See, e.g.*, Arizona v. California (*Arizona II*), 460 U.S. 605 (1983); Winters v. United States, 207 U.S. 564 (1908); Colville Confederated Tribes v. Walton, 752 F.2d 397, 399 (9th. Cir 1985); United States v. Adair, 723 F.2d 1394 (9th Cir. 1984); United States v. Anderson, 736 F.2d 1358, 1365–66 (9th Cir. 1984); Colville Confederated Tribes v. Walton, 647 F.2d 42, 49 (9th Cir. 1981); *Colorado River Water Conservation Dist.*, 424 U.S. at 800; Arizona v. California (*Arizona I*), 373 U.S. 546 (1963); United States v. Ahtanum Irrigation Dist., 236 F.2d 321 (9th Cir. 1956); Conrad Inv. Co. v. United States, 161 F. 829 (9th Cir. 1908); *In re* General Adjudication of All Rights to Use Water in Gila River Sys. & Source, 35 P.3d 68, 71–72 (Ariz. 2001); United States v. State, 448 P.3d 322, 330–31 (Idaho 2019); Dep't of Ecology v. Yakima Reservation Irrigation Dist. (*In re* Surface Waters of the Yakima River Drainage Basin), 850 P.2d 1306, 1308–10 (Wash. 1993); *In re* General Adjudication of All Rights to Use Water in the Big Horn River System, 753 P.2d 76, 84–85 (Wyo. 1988). *See generally* Dylan R. Hedden-Nicely, *The Historical Evolution of the Methodology for Quantifying Federal Reserved Instream Water Rights for American Indian Tribes*, 50 ENVTL. L. REV. 205 (2020) (chronicling numerous lawsuits to quantify reserved water rights and analyzing their adopted flow quantification methodologies).

[19] *See*, *e.g.*, *Conrad Inv. Co.*, 161 F. at 835.

[20] *Arizona I*, 373 U.S. 546.

[21] *Id.* at 600 ("We also agree with the Master's conclusion as to the quantity of water intended to be reserved . . . to satisfy the future as well as the present needs of the Indian Reservations . . . .").

[22] Report of the Special Master at 264, *Arizona I*, 373 U.S. 546 [hereinafter Rifkind Report].

[23] Rifkind Report, *supra* note 22, at 265.

[24] *Arizona II*, 460 U.S. at 619

acknowledged that "res judicata and collateral estoppel do not apply if a party moves the rendering court in the same proceeding to correct or modify its judgment," yet the Court concluded: "a fundamental precept of common law [water rights] adjudication is that an issue, once determined by a competent court, is conclusive."[25] The Court's refusal to modify a decree has extended to water rights omitted by mistake, as in *Arizona II*,[26] and even where it was alleged that the United States breached its trust responsibility by purposely failing to claim sufficient water rights on behalf of a tribe, as was the situation in *Nevada v. United States*.[27]

Importantly, Special Master Rifkind's report, as well as the Supreme Court's decisions in *Arizona II* and *Nevada v. United States*, all took place before the effect and magnitude of climate change were widely understood.[28] Although the Supreme Court's application of a fixed quantity of water for tribal reserved water rights provides certainty to non-Indian water users, it places Indian tribes in the precarious position of having one chance to quantify their water needs for all uses and all time—based upon imperfect information about current conditions. The risks associated with this approach are particularly acute for Indian tribes as climate change continues to progress, increasingly affecting global precipitation patterns, streamflow, and biological migration patterns and timing.[29]

The purpose of this Article is to explore the risks that climate change poses to quantifying fixed instream flows for reserved tribal water rights. For approximately the past forty years, the primary methodology employed for the quantification of reserved instream flow water rights has been some version of habitat capacity simulation modeling.[30] Most commonly, the Instream Flow Incremental Methodology (IFIM) and/or one of its major components, the Physical Habitat

[25] *Id*. In *Arizona II*, a number of tribes sought to intervene and assert new claims for water rights so-called "omitted lands," which were "irrigable lands . . . for which it was said that the United States failed to claim water rights in the earlier litigation . . . ." *Id*. at 612. The Tribes claimed these lands were "omitted" because the United States had not adequately represented the interests of the Tribes by diligently prosecuting the claims. *Id.* at 617. The Supreme Court rejected the Tribes' argument, finding "no merit in the Tribes' contention that the United States' representation of their interests was inadequate," *id.* at 627, and that "general principles of finality and repose" precluded the reopening of the decree. *Id*. at 619.

[26] *See id.* at 622 n.14.

[27] 463 U.S. 110, 119, 127–28 (1983).

[28] Climate change was predicted as early as the late 1800s, discussed in earnest in the 1950s, and widely acknowledged by 1988, when the Intergovernmental Panel on Climate Change was established. *See* Andrew Revkin, *Climate Change First Became News 30 Years Ago. Why Haven't We Fixed It?*, NAT'L GEOGRAPHIC (July 2018), https://www.nationalgeographic.com/magazine/2018/07/embark-essay-climate-change-pollution-revkin/#close [https://perma.cc/6N4H-QD9G].

[29] *See* CLIMATE CHANGE 2014 SYNTHESIS REPORT SUMMARY FOR POLICYMAKERS, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE [IPCC] 6 (2014), https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf [https://perma.cc/AV2R-87QJ]

[30] Hedden-Nicely, *supra* note 18, at 226.

Simulation Model (PHABSIM), have been used.[31] Although our comments apply to all models of systems affected by climate change, we focus primarily on PHABSIM's sensitivity to climate change because of its overwhelming prevalence in water rights adjudications involving Indian tribes.

We begin in Parts II and III with a brief primer on the biological and hydrological needs for fishes in general, and salmonids in particular. While non-salmonid fishes (e.g., lamprey, sturgeon, burbot) and non-fish aquatic species (e.g., freshwater mussels, beaver) are important and valuable from an ecological and cultural perspective,[32] salmonids have generally been most studied and tend to form the basis for most of the regulatory concerns, given their high degree of economic importance and legal protection.[33] We recognize that salmonid-centric models might not take a holistic approach that the preservation of first foods—those foods upon which tribal people have relied upon since time immemorial[34]—and their ecosystems require. The focus of this Article, however, is descriptive in nature, basing its analysis on what has historically been studied in these cases.

In Part IV we then move into a brief explanation of PHABSIM parameters and how they are used to quantify reserved instream flow water rights. From there, we examine in Part V how climate change may affect the primary input parameters for the PHABSIM models, as well as a discussion in Part VI of those parameters that are often left out of the reserved water right quantification methodology (e.g., temperature). The goal of that examination is to demonstrate that climate change will alter the amount of water necessary to protect aquatic habitat, rendering inadequate any water right claim that is based on static climate assumptions. We close in Parts VII and VIII with both technical and legal suggestions that would mitigate some of the uncertainty Indian tribes currently face from climate change as they seek to protect their rights, resources, and homelands.

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[31] *See id.* at 233–47 (chronicling the use of IFIM/PHABSIM to quanitfy flow in adjudications involving Indian tribes' reserved water rights, from its first use to becoming the "accepted methodology").

[32] *See*, *e.g.*, United States v. Washington, 157 F.3d 630, 642–43 (9th Cir. 1998) (noting the historical importance of shellfish to Northwest tribes); United States v. Adair, 723 F.2d 1394, 1409 n. 14 (9th Cir. 1984) (noting the variety of plants and animals traditionally important to the Klamath Tribes); *see also* KOOTENAI TRIBE OF IDAHO, KOOTENAI RIVER HABITAT RESTORATION PROJECT MASTER PLAN 1–2 (2009) (noting the traditional importance of "Kootenai River white sturgeon, burbot (*Lota lota*), kokanee (*Oncorhynchus nerka*), redband trout (*Oncorhynchus mykiss garideini*), westslope cutthroat trout (*O. clarki lewisii*) and bull trout (*Salvelinus confluentus*) as well as local wildlife" to the Kootenai Tribe); Adam Wicks-Arshack et al., *An Ecological, Cultural, and Legal Review of Pacific Lamprey in the Columbia River Basin*, 54 IDAHO L. REV. 45, 66–72 (2018) (discussing the importance of Pacific lamprey to Northwest tribes).

[33] Wicks-Arshack et al., *supra* note 32, at 49 ("Pacific salmon have received substantial regulatory attention and conservation actions exceeding a billion dollars in costs . . . .").

[34] *See, e.g.*, *First Foods & Life Cycles*, CONFEDERATED TRIBES OF THE UMATILLA INDIAN RESERVATION, https://ctuir.org/history-culture/first-foods [https://perma.cc/B2E2-R8M2] (last visited Apr. 9, 2020).

II. THE BIOLOGICAL AND HYDROLOGICAL NEEDS FOR FISH HABITAT

Individual fish species tend to predictably occupy relatively well-defined areas within particular ecosystems, which are referred to as that species' habitat.[35] Habitat includes physical, chemical, and biological dimensions that constrain where fishes live and how successful they are.[36] Habitat quality measures the appropriateness of a given habitat to support the growth and sustenance of a fish population according to those three parameters.[37] Consequently, "good habitat" can be formally conceptualized as areas that support individual and population growth.[38]

One common method of assessing habitat quality evaluates the amount or qualities of available resources that are selected for and used by a species.[39] Researchers tend to focus on resources and attributes associated with food, cover, and physical environmental conditions supportive to the organism.[40] The density of preferred resources is often indicative of habitat quality.[41] In this Part, we briefly review habitat requirements of Pacific salmonids, focusing on the attributes included in PHABSIM analyses, while also highlighting important habitat features that are not included in PHABSIM.

Salmonids are a group of soft-finned bony fishes that include grayling, whitefish, trout, and salmon.[42] Some salmonids exhibit anadromy, a life history that involves hatching in fresh water, migrating to a marine system where individuals grow and mature, then returning to fresh water for spawning.[43] Pacific salmonids

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[35] *See* PHILIP RONI ET AL., NAT'L OCEANIC & ATMOSPHERIC ADMIN., Tech. Memo. NMFS-NWFSC-127, FISH-HABITAT RELATIONSHIPS & THE EFFECTIVENESS OF HABITAT RESTORATION 3 (2014), https://www.nwfsc.noaa.gov/assets/25/7422_08122014_141405_FishHabRelationshipsTM127WebFinal.pdf [https://perma.cc/TPP4-ZRWZ] (describing the criticality of habitat quantity and quality parameters to the survival of juvenile salmonids).

[36] *Id.*

[37] *Id.*

[38] Matthew D. Johnson, *Measuring Habitat Quality: A Review*, 109 THE CONDOR 489, 498 (2007).

[39] *See generally* Douglas H. Johnson, *The Comparison of Usage & Availability Measurements for Evaluating Resource Preference*, 61 ECOLOGY 65 (1980).

[40] *Id.*; Dana L. Thomas & Eric J. Taylor, *Study Designs & Tests for Comparing Resource Use and Availability II*, 70 J. WILDLIFE MGMT. 324 (2006).

[41] David L. Garshelis, *Delusions in Habitat Evaluation: Measuring Use, Selection, & Importance*, *in* RESEARCH TECHNIQUES IN ANIMAL ECOLOGY (2000); Hawthorne L. Beyer et al., *The Interpretation of Habitat Preference Metrics Under Use-Availability Designs*, 365 PHIL. TRANSACTIONS ROYAL SOC'Y OF LONDON B: BIOLOGICAL SCI. 2245 (2010).

[42] *See* GENE S. HELFMAN ET AL., THE DIVERSITY OF FISHES: BIOLOGY, EVOLUTION, & ECOLOGY 277–79 (2d ed. 2009).

[43] *See* ROBERT J. BEHNKE, TROUT AND SALMON OF NORTH AMERICA 18 (George Scott ed., 2002).

(*Oncorhynchus* species) generally occupy perennial,[44] low-gradient,[45] well-oxygenated,[46] clean, cold, and connected streams and lakes.[47] Biologic processes, including growth, reproduction, behavior, and stress, are strongly influenced by environmental temperature.[48] Given the importance of temperature for fish physiology, water temperature strongly regulates the performance and distribution of fish populations.[49] As water temperatures increase above species-specific optimal levels, the metabolic effects associated with thermal stress become increasingly life-threatening and include reduced growth rates and elevated mortality.[50]

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[44] *See generally* D. A. Boughton et al., *Spatial Patterning of Habitat for* Oncorhynchus mykiss *in a System of Intermittent and Perennial Streams*, 18 ECOLOGY OF FRESHWATER FISH 92 (2009) (describing perennial as flowing year-round, not ephemeral, seasonal, or intermittent).

[45] *See generally* JORDAN ROSENFELD, B.C. MINISTRY OF FORESTS, Fisheries Mgmt. Rep. 113, FRESHWATER HABITAT REQUIREMENTS OF ANADROMOUS CUTTHROAT TROUT AND IMPLICATIONS FOR FORESTRY IMPACTS 18 (2000), https://www.for.gov.bc.ca/hfd/library/documents/bib89314.pdf [https://perma.cc/A3JF-U4XP] (describing low gradient as exhibiting a shallow (<5%) longitudinal pitch associated with the streambed).

[46] C. Dale Becker & Duane A. Neitzel, *Assessment of Intergravel Conditions Influencing Egg and Alevin Survival During Salmonid Redd Dewatering*, 12 ENVTL. BIOLOGY OF FISHES 41 (1985). Oxygenation refers to the concentration of dissolved O_2 (DO) in water, where high water quality is marked bu values approaching 100% DO saturation. KEN D. BOVEE, U.S. FISH & WILDLIFE SERV., Instream Flow Information Paper No. 12, A GUIDE TO STREAM HABITAT ANALYSIS USING THE INSTREAM FLOW INCREMENTAL METHODOLOGY 12, 29 (1982) [hereinafter BOVEE, A GUIDE TO STREAM HABITAT ANALYSIS].

[47] *See generally* ROSENFELD, *supra* note 45; THOMAS P. QUINN, THE BEHAVIOR & ECOLOGY OF PACIFIC SALMON & TROUT (2005); Boughton et al., *supra* note 44, at 92; D. Shallin Busch et al., *Landscape-Level Model to Predict Spawning Habitat for Lower Columbia River Fall Chinook Salmon (*Oncorhynchus Tshawytscha*)*, 29 RIVER RES. & APPLICATIONS 297 (2011), https://www.fs.fed.us/pnw/pubs/journals/pnw_2013_busch001.pdf [https://perma.cc/KBE6-N9T7]; Sally J. Petre & Scott A. Bonar, *Determination of Habitat Requirements for Apache Trout*, 146 TRANSACTIONS OF THE AM. FISHERIES SOC'Y 1 (2017).

[48] *See* Jonathan B. Armstrong et al., *Adaptive Capacity at the Northern Front: Sockeye Salmon Behaviourally Thermoregulate During Novel Exposure to Warm Temperatures*, 4 CONSERVATION PHYSIOLOGY 7 (2016); V. V. Zdanovich et al., *Specific Features of Growth and Energetics of Juvenile Rainbow Trout* Parasalmo *(*Oncorhynchus*)* mykiss *at Constant Temperature and Its Short-Time Periodic Deviations into the Upper Suboptimal Zone*, 51 J. ICHTHYOLOGY 528, 530–31 (2011).

[49] *See* Daniel J. Isaak et al., *The Cold-Water Climate Shield*: *Delineating Refugia for Preserving Salmonid Fishes Through the 21st Century*, 21 GLOBAL CHANGE BIOLOGY 2540, 2546–47 (2015) [hereinafter Isaak et al., *The Cold-Water Climate Shield*].

[50] *See* Jeffrey R. Baldock et al., *Juvenile Coho Salmon Track a Seasonally Shifting Thermal Mosaic Across a River Floodplain*, 61 FRESHWATER BIOLOGY 1454, 1459–61 (2016); Matthew L. Keefer et al., *Thermal Exposure of Adult Chinook Salmon in the Willamette River Basin*, 48 J. THERMAL BIOLOGY 11, 14 (2015); Eoin J. O'Gorman et al.,

Habitat quality for particular species is often evaluated at the watershed level.[51] A watershed is the bounded geographic region in which all precipitation ultimately drains to a single outlet.[52] Watersheds thus represent an area encircled by connected ridges and drained by a network of streams tributary to a single river or lake.[53] The hydrologic characteristics of a watershed describe how water moves through the drainage and at what quantity.[54] After falling to the ground as precipitation, water travels via conveyance (including both overland flow and infiltration to groundwater aquifers), accumulation, evaporation, and plant transpiration.[55] Conveyance varies seasonally, which impacts flow within stream channels and associated off-channel habitats (e.g., backwaters, sloughs, seasonally inundated floodplains).[56] Thus, any fluctuations in flow can significantly impact groups of organisms that have evolved within the context of relatively predictable runoff patterns.[57]

The relationship between flow and salmonid population dynamics has been well-characterized in many river systems: sustained flow in the stream channel is necessary during certain important life-history events, including spawning, embryo incubation, juvenile rearing, and migration.[58] Thus, both mean annual runoff,[59] as

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Temperature Effects on Fish Production Across a Natural Thermal Gradient, 22 GLOBAL CHANGE BIOLOGY 3206, 3212–15 (2016).

[51] *See* James M. Omernik & Robert G. Bailey, *Distinguishing Between Watersheds and Ecoregions*, 33 J. AM. Water RESOURCES ASS'N 935, 944–45 (1997).

[52] *Id.* at 937.

[53] *Id.*

[54] *See* Timothy J. Beechie et al., *Process-Based Principles for Restoring River Ecosystems*, 60 BIOSCIENCE 209, 211 (2010).

[55] *See* KEITH J. BEVEN, RAINFALL-RUNOFF MODELLING 129 fig.5.3 (2d ed. 2012).

[56] *Id.* at 7–9.

[57] *See* Stuart E. Bunn & Angela H. Arthington, *Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity*, 30 ENVTL. MGMT. 492, 493–94 (2002); Katrina McGuigan et al., *Adaptation of Rainbow Fish to Lake and Stream Habitats*, 57 EVOLUTION 104, 111–15 (2003).

[58] *See* GUY NORMAN ET AL., WASH. DEP'T OF FISHERIES, THE EFFECT OF RIVER FLOW ON ABUNDANCE OF PRE-SMOLT FALL CHINOOK SALMON IN THE NORTH FORK LEWIS RIVER BELOW MERWIN DAM, 1978–80 AND 1983–85 2–3 (1987); D. Brent Lister & C. E. Walker, *The Effect of Flow Control on Fresh-Water Survival of Chum, Coho, and Chinook Salmon in the Big Qualicum River*, 37 CAN. FISH CULTURIST 3, 14, 17 (1966); Dennis L. Scarnecchia, *Effects of Streamflow and Upwelling on Yield of Wild Coho Salmon (*Oncorhynchus kisutch*) in Oregon*, 38 CAN. J. FISHERIES & AQUATIC SCI. 471, 473 (1981); W. P. Wickett, *Review of Certain Environmental Factors Affecting the Production of Pink and Chum Salmon*, 15 J. FISHERIES RES. BOARD. CAN. 1103, 1112–16 (1958); William A. Smoker, Effects of Streamflow on Silver Salmon Production in Western Washington 58–59 (1955) (unpublished Ph.D. dissertation, University of Washington) (on file with the Utah Law Review).

[59] Smoker, *supra* note 58, at 58–59.

well as runoff during certain times of the year,[60] influence Pacific salmonid abundance and productivity.

Flow interacts with channel geometry to determine in-channel water depth and velocity, both of which are important characteristics for all freshwater life stages of salmonids.[61] Adult salmonids and other migratory species require sufficiently deep water during spawning seasons. Sufficient depth is required both to access reaches (sections of the river) for spawning during upstream migrations and to excavate redds (nests) in locations that minimize the possibility of perching (dewatering) of redds and associated desiccating (drying) of deposited eggs.[62] Many riverine fish species, including Pacific salmonids, synchronize their reproductive activities with local hydrology to optimize egg and larval rearing conditions, particularly relating to flow.[63] For example, Chinook and coho salmon tend to spawn in fall, after the initiation of early fall rainy season, while steelhead tend to spawn in late winter and spring, moving up during seasonal freshets associated with snowmelt in many systems.[64] These fishes thus deposit eggs at a time when stream discharge is sufficient to prevent redd perching and egg desiccation, but not so extreme as to cause substrate scouring that could demolish a redd and cause pre-hatch egg

[60] Sean C. Mitchell & Richard A. Cunjak, *Stream Flow, Salmon and Beaver Dams: Roles in the Structuring of Stream Fish Communities Within an Anadromous Salmon Dominated Stream*, 76 J. ANIMAL ECOLOGY 1062, 1063 (2007).

[61] *See* Hal A. Beecher et al., *Evaluation of Depth and Velocity Preferences of Juvenile Coho Salmon in Washington Streams*, 22 NORTH AM. J. FISHERIES MGMT. 785, 792 (2002); Hal A. Beecher et al., *Predicting Microdistributions of Steelhead (*Oncorhynchus mykiss*) Parr from Depth and Velocity Preference Criteria: Test of an Assumption of the Instream Flow Incremental Methodology*, 50 CAN. J. FISHERIES & AQUATIC SCI. 2380, 2384 (1993).

[62] *See* C.H. SWIFT, III, U.S. GEOLOGICAL SURV., PREFERRED STREAM DISCHARGES FOR SALMON SPAWNING AND REARING IN WASHINGTON 10 (1979); Clifford J. Burner, *Characteristics of Spawning Nests of Columbia River Salmon*, 61 FISHERY BULL. 97, 101 (1951); Ian R. Waite & Roger A. Barnhart, *Habitat Criteria for Rearing Steelhead: A Comparison of Site-Specific and Standard Curves for Use in the Instream Flow Incremental Methodology*, 12 NORTH AM. J. FISHERIES MANAGEMENT 40, 42–44 (1992). *See generally* E.R. KEELEY & P.A. SLANEY, B.C. MINISTRY OF FORESTS, B.C. MINISTRY OF ENVIRONMENT, LANDS AND PARKS, Watershed Restoration Project Report No. 4, QUANTITATIVE MEASURES OF REARING AND SPAWNING HABITAT CHARACTERISTICS FOR STREAM-DWELLING SALMONIDS: GUIDELINES FOR HABITAT RESTORATION (1996) (describing the spawning characteristics of salmonid fishes in streams); Julie L. Hall & Robert C. Wissmar, *Habitat Factors Affecting Sockeye Salmon Redd Site Selection in Off-Channel Ponds of a River Floodplain*, 133 TRANSACTIONS AM. FISHERIES SOC'Y 1480, 1488 (2004).

[63] *See* Timothy Beechie et al., *Hydrologic Regime and the Conservation of Salmon Life History Diversity*, 130 BIOLOGICAL CONSERVATION 560, 566–68 (2006); Alison J. King et al., *Using Abiotic Drivers of Fish Spawning to Inform Environmental Flow Management*, 53 J. APPLIED ECOLOGY 34, 38–40 (2016).

[64] *See generally* QUINN, *supra* note 47 (detailing the life-cycle of Pacific Salmon and Trout); BEHNKE, *supra* note 43, at 25–31 (detailing the life-cycle of Chinook Salmon).

mortality.[65] After hatching and emerging from gravel, juvenile salmonids are highly susceptible to predation by terrestrial predators and birds—a risk that they minimize by occupying sites with sufficient cover.[66] Flow velocity regulates adult access to spawning reaches and influences feeding dynamics, stream position, emigration timing, and other behaviors for juveniles.[67] Sufficient velocities mobilize aquatic insects and other invertebrates, which provide a food source for juvenile fish,[68] while excess velocities can block passage or prematurely flush juveniles out of headwater tributaries.[69]

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[65] *See* A. C. Cooper, THE EFFECT OF TRANSPORTED STREAM SEDIMENTS ON THE SURVIVAL OF SOCKEYE AND PINK SALMON EGGS AND ALEVIN, INT'L PACIFIC SALMON FISHERIES COMM'N 4–5 (1965); Becker & Neitzel, *supra* note 46, at 33; King et al., *supra* note 63, at 34; Thomas P. Quinn & N. Phil Peterson, *The Influence of Habitat Complexity and Fish Size on Over-Winter Survival and Growth of Individually Marked Juvenile Coho Salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington*, 53 CAN. J. FISHERIES & AQUATIC SCI. 1555, 1559 (1996).

[66] *See* Quinn & Peterson, *supra* note 65, at 1560; PHIL RONI, RESPONSES OF FISHES AND SALAMANDERS TO INSTREAM RESTORATION EFFORTS IN WESTERN OREGON AND WASHINGTON 96–98 (2001); J.D. Armstrong et al., *Habitat Requirements of Atlantic Salmon and Brown Trout in Rivers and Streams*, 62 FISHERIES RES. 143, 146, 153 (2003).

[67] *See* KEELEY & SLANEY, *supra* note 62, at 3, 5; Kurt D. Fausch, *Profitable Stream Positions for Salmonids: Relating Specific Growth Rate to Net Energy Gain*, 62 CAN. J. ZOOLOGY 441, 444 (1984); Charles R. Weaver, *Influence of Water Velocity upon Orientation and Performance of Adult Migrating Salmonids*, 63 FISHERY BULL. 97, 104–07, 112 (1963). *See generally* Peter B. Moyle & Donald M. Baltz, *Microhabitat Use by an Assemblage of California Stream Fishes: Developing Criteria for Instream Flow Determinations*, 114 TRANSACTIONS AM. FISHERIES SOC'Y 695 (1985) (noting that recommendations for instream flows should be based on microhabitat use data collected on site together with habitat availability data).

[68] *See* Erik Donofrio et al., *Velocity and Dominance Affect Prey Capture and Microhabitat Selection in Juvenile Chinook (*Oncorhynchus tshawytscha*)*, 101 ENVTL. BIOLOGY FISHES 609, 616–17 (2018); Fausch, *supra* note 67, at 441; Jordan S. Rosenfeld et al., *Food Abundance and Fish Density Alters Habitat Selection, Growth, and Habitat Suitability Curves for Juvenile Coho Salmon (*Oncorhynchus kisutch*)*, 62 CAN. J. FISHERIES & AQUATIC SCI. 1691, 1696–98 (2005); Jordan S. Rosenfeld & Ron Ptolemy, *Modelling Available Habitat Versus Available Energy Flux: Do PHABSIM Applications that Neglect Prey Abundance Underestimate Optimal Flows for Juvenile Salmonids?*, 69 CAN. J. FISHERIES & AQUATIC SCI. 1920, 1926–29 (2012); John J. Piccolo et al., *Water Velocity Influences Prey Detection and Capture by Drift-Feeding Juvenile Coho Salmon (*Oncorhynchus kisutch*) and Steelhead (*Oncorhynchus mykiss Irideus*)*, 65 CAN. J. FISHERIES & AQUATIC SCI. 266, 269–70 (2008).

[69] *See* J. Mitchel Lorenz & John H. Eiler, *Spawning Habitat and Redd Characteristics of Sockeye Salmon in the Glacial Taku River, British Columbia and Alaska*, 118 TRANSACTIONS AM. FISHERIES SOC'Y 495, 499 (1989); Timothy D. Mussen et al., *Assessing Juvenile Chinook Salmon Behavior and Entrainment Risk Near Unscreened Water Diversions: Large Flume Simulations*, 142 TRANSACTIONS AM. FISHERIES SOC'Y 130, 136–38 (2012); C.S. Shirvell, *Ability of PHABSIM to Predict Chinook Salmon Spawning Habitat*, 3 REGULATED RIVERS: RES. & MGMNT. 277, 285, 287 (1989); D. Tetzlaff et al., *Variability*

Another important habitat attribute for salmonids is the availability of appropriately sized substrate (sediment and other material composing the streambed) for spawning and embryo rearing.[70] Adult salmonids deposit eggs and milt (sperm) into redds excavated by the female, and the embryos (fertilized eggs) subsequently develop therein.[71] Ideal salmonid spawning substrate is appropriately-sized clean gravel with a minimum of fine sediment.[72] This type of substrate optimizes embryo development by promoting gas and waste exchange and preventing red entombment (suffocation by overlain fine sediment).[73]

However, it is important to recognize that, beyond depth, velocity, and substrate, additional habitat characteristics also regulate the distribution of salmonids and other fishes. For example, modern concepts of stream ecology no longer recognize a hard distinction at the stream's wetted edge.[74] Instead, it is generally understood that the transitional and terrestrial corridor abutting streambeds, known as the riparian zone, is critical for the maintenance of stream habitat.[75] Within small headwater streams, riparian habitats adjacent to the stream channel interact with the stream itself, regulating temperature, chemistry, and

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in Stream Discharge and Temperature: A Preliminary Assessment of the Implications for Juvenile and Spawning Atlantic Salmon, 9 HYDROLOGY & EARTH SYS. SCI. 193, 198, 203–04 (2005). *See generally* Glenn F. Čada et al., *Effects of Water Velocity on the Survival of Downstream Migrating Juvenile Salmon and Steelhead: A Review with Emphasis on the Columbia River Basin*, 5 REV. FISHERIES SCI. 131 (1997) (providing a literature review and analysis of flow studies in Columbia River tributaries; concluding that increased flow improves juvenile survival).

[70] FREDRICK B. LOTSPEICH & FRED H. EVEREST, U.S. FOREST SERV., A NEW METHOD FOR REPORTING AND INTERPRETING TEXTURAL COMPOSITION OF SPAWNING GRAVEL 2 (1981).

[71] QUINN, *supra* note 47, at 3.

[72] *Id*. at 9–10.

[73] *See* LOTSPEICH & EVEREST, *supra* note 70, at 9–10; Burner, *supra* note 62, at 97; William J. McNeil, *Effect of the Spawning Bed Environment on Reproduction of Pink and Chum Salmon*, 65 FISHERY BULL. 495, 500, 519–20 (1965); Paul D. Tappel & Ted C. Bjornn, *A New Method of Relating Size of Spawning Gravel to Salmonid Embryo Survival*, 3 NORTH AM. J. FISHERIES MGMT. 123, 127, 129, 130 (1983). *See generally* G. M. Kondolf, *Assessing Salmonid Spawning Gravel Quality*, 129 TRANSACTIONS AM. FISHERIES SOC'Y 262 (2000) (discussing the impact of salmonid spawning gravels on salmonid development).

[74] Magnus McCaffery & Lisa Eby, *Beaver Activity Increases Aquatic Subsidies to Terrestrial Consumers*, 61(4) FRESHWATER BIOLOGY 518, 524–27 (2016); Joseph E. Merz & Peter B. Moyle, *Salmon, Wildlife, and Wine: Marine-Derived Nutrients in Human-Dominated Ecosystems of Central California*, 16(3) ECOLOGICAL APPLICATIONS 999, 1003–06; Shigeru Nakano et al., *Terrestrial-Aquatic Linkages: Riparian Arthropod Inputs Alter* Crophic *Cascades in a Stream Food Web*, 80(7) ECOLOGICAL SOC'Y AM. 2435, 2439–40 (1999).

[75] *See* Nakano et al., *supra* note 74; Shigeru Nakano & Masashi Murakami, *Reciprocal Subsidies: Dynamic Interdependence Between Terrestrial and Aquatic Food Webs*, 98 PROCEEDINGS OF THE NAT'L ACAD. SCI. 166, 167–9 (2001).

delivery of terrestrial food sources to the aquatic environment.[76] As a result, habitat quality within these smaller streams depends largely upon riparian communities that include diverse woody plant and invertebrate species.[77]

III. THE BIOLOGICAL AND HYDROLOGICAL IMPACTS OF CHANGING CLIMATE ON STREAMS IN THE NORTHWESTERN UNITED STATES

Climate change, at times referred to as "global warming" or "climate disruption,"[78] is the change of "long-term averages and variations in weather as measured over a period of several decades."[79] The greenhouse effect, the primary mechanism causing climate change, has long been understood in the scientific community.[80] The Earth is heated by incoming solar radiation, which is partially absorbed by gases in the Earth's atmosphere (mainly carbon dioxide and methane).[81] However, the Earth likewise radiates energy, which is partially absorbed by carbon dioxide, water vapor, and other so-called "greenhouse gases" that exist in the Earth's atmosphere.[82] Some of this energy is then re-radiated back to the Earth, which causes additional warming on the Earth's surface.[83] The interrelationship of these phenomena historically moderated the Earth's temperature, which allowed human beings to evolve and survive.[84] Anthropogenic climate change, on the other hand,

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[76] *See* Eric K. W. Chan et al., *Arthropod 'Rain' into Tropical Streams: The Importance of Intact Riparian Forest and Influences on Fish Diets*, 59 MARINE & FRESHWATER RES. 653, 658–59 (2008); C. D. Raines & L. E. Miranda, *Role of Riparian Shade on the Fish Assemblage of a Reservoir Littoral*, 99 ENVTL. BIOLOGY FISHES 753, 756, 758 (2016).

[77] *See* J. Ryan Bellmore et al., *Incorporating Food Web Dynamics into Ecological Restoration: A Modeling Approach for River Ecosystems*, 27 ECOLOGICAL APPLICATIONS 814, 816, 823–27 (2017); Cristina da Silva Gonçalves et al., *Trophic Structure of Coastal Freshwater Stream Fishes from an Atlantic Rainforest: Evidence of the Importance of Protected and Forest-Covered Areas to Fish Diet*, 101 ENVTL. BIOLOGY OF FISHES 933, 940 (2018); Fran Sheldon et al., *Identifying the Spatial Scale of Land Use that Most Strongly Influences Overall River Ecosystem Health Score*, 22 ECOLOGICAL APPLICATIONS 2188, 2193, 2195–96 (2012).

[78] Jeff McMahon, *Forget Global Warming and Climate Change, Call It 'Climate Disruption,'* FORBES (Mar. 12, 2015), https://www.forbes.com/sites/jeffmcmahon/2015/03/12/forget-global-warming-and-climate-change-call-it-climate-disruption/#172ab16c50e2 [https://perma.cc/P7D3-A5QK].

[79] U.S. GLOBAL CHANGE RESEARCH PROGRAM, CLIMATE CHANGE IMPACTS IN THE UNITED STATES: THE THIRD NATIONAL CLIMATE ASSESSMENT 22 (Jerry M. Melillo et al. eds., 2014).

[80] *See generally* THE INFLUENCE OF CLIMATE CHANGE AND CLIMATE VARIABILITY ON THE HYDROLOGIC REGIME AND WATER RESOURCES, INT'L ASSOC. OF HYDROLOGICAL SCI., IAHS Pub. No. 168 (S.I. Solomon et al. eds., 1987) (publishing proceedings from symposium on climate change in Vancouver, British Columbia, Canada).

[81] U.S. GLOBAL CHANGE RESEARCH PROGRAM, *supra* note 79, at 737.

[82] *Id.*

[83] *Id.*

[84] *Id.*

results from disruption of the Earth's energy balance that "can only be explained by the effects of human influences, especially the emissions from burning fossil fuels (coal, oil, and natural gas) and from deforestation."[85] Although changes in the average global climate is a naturally occurring phenomenon, the rate and severity at which climate change has been occurring in the last half-century is not natural.[86] "Multiple lines of independent evidence confirm that human activities are the primary cause of global warming of the past 50 years."[87]

Unequivocal evidence of global climate change has been reported in the scientific literature for decades,[88] including early observations regarding the potential biological ramifications for Pacific salmonids and other fishes.[89] The most obvious, measurable, and pervasive impact has been the widespread warming of air, ground, and water. The years 2016 and 2017 have together been the hottest years on record within the contiguous United States,[90] while 2018 was recorded as the fourth hottest year on record worldwide.[91] Regionally, multi-decadal records of river water temperatures from 391 sites across the Northwest United States reveal substantial water temperature increases that generally parallel increases in air temperature.[92]

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[85] *Id.* at 23.

[86] *Id.* at 7.

[87] *Id.*

[88] *See generally* Nebojša Nakiçenovic et al., SPECIAL REPORT ON EMISSIONS SCENARIOS, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (2000) (describing how the world's climate will change in the coming century); Stephen R. Carpenter et al., *Global Change and Freshwater Ecosystems*, 23 ANN. REV. OF ECOLOGY & SYSTEMATICS 119 (1992) (explaining then-current and future effects of global warming); John P. McCarty, *Ecological Consequences of Recent Climate Change*, 15 CONSERVATION BIOLOGY 320 (2001) (describing the ecological consequences of climate change and how climate change is a major conservation threat).

[89] R. J. Beamish et al., *Recent Declines in the Recreational Catch of Coho Salmon (*Oncorhynchus Kisutch*) in the Strait of Georgia Are Related to Climate*, 56 CAN. J. FISHERIES & AQUATIC SCI. 506, 508–11 (1999); John G. Eaton & Robert M. Scheller, *Effects of Climate Warming on Fish Thermal Habitat in Streams of the United States*, 41 LIMNOLOGY AND OCEANOGRAPHY 1109, 1112–15 (1996); R. J. Beamish et al., *Recent Declines in the Recreational Catch of Coho Salmon (*Oncorhynchus Kisutch*) in the Strait of Georgia Are Related to Climate*, 56 CAN. J. FISH. & AQUAT. SCI. 506, 508–511 (1999); Marc Mangel, *Climate Change and Salmonid Life History Variation*, 41 DEEP-SEA RESEARCH II 75, 82–84 (1994).

[90] Jessica Blunden et al., *State of the Climate in 2017*, 99 BULL. AM. METEOROLOGICAL SOC'Y 1, 1–4 (2018).

[91] *2018 was 4th Hottest Year on Record for the Globe*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. (Feb. 6, 2019), https://www.noaa.gov/news/2018-was-4th-hottest-year-on-record-for-globe [https://perma.cc/NTN9-69GH].

[92] Daniel J. Isaak et al., *Global Warming of Salmon and Trout Rivers in the Northwestern U.S.: Road to Ruin or Path Through Purgatory?*, 147 TRANSACTIONS OF THE AM. FISHERIES SOC'Y 566, 566–68 (2018) [hereinafter Isaak et al., *Global Warming of Salmon and Trout Rivers in the Northwestern U.S.*].

The hydrological impacts of climate change have been difficult to predict with precision because they are complex in character and spatial distribution. However, some clear trends have emerged. One consistent climate model projection across the Pacific West region of the United States—which includes California, Oregon, Washington, and Idaho—is a shift from snow-dominated to rain-dominated precipitation.[93] Increasing rates of rain-on-snow events (i.e., rainstorms occurring when and where the ground is covered with snow) will likely result in an increase in flash floods and urban floods.[94] Throughout the Pacific West and elsewhere, a large-scale precipitation phase shift is predicted to occur in many watersheds during the next eighty years.[95]

Less dramatic but equally detrimental are decreasing mean annual streamflows in northwestern streams. Although annual precipitation rates have remained close to normal in the Northwestern United States,[96] the snow-rain shift has caused an overall decline in mountain snowpack.[97] As a result, along with the increased incidence of rain-on-snow driven floods, spring snowmelt has been observed to occur up to 30 days earlier over the past 50 years.[98] Consequently, summertime streamflows for many streams and rivers draining the mountainous Western United States have declined.[99] In the Central-Rocky Mountains (including portions of Idaho, Wyoming, and Montana), 89% of 65 sites included in a recent study exhibited substantial reductions in stream discharge, with a median reduction of approximately 20%.[100] Also, low-flow occurrences are increasing in both frequency and severity as conditions become increasingly drier.[101] The intersection of these factors will likely result in dramatic decreases in overall summertime streamflow, which will have

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[93] U.S. GLOBAL CHANGE RESEARCH PROGRAM, *supra* note 79, at 465–66, 489–90.

[94] *Id.* at 490.

[95] Bjørn Petter Kaltenborn et al., HIGH MOUNTAIN GLACIERS AND CLIMATE CHANGE: CHALLENGES TO HUMAN LIVELIHOODS AND ADAPTATION, U.N. ENVT. PROGRAMME 20–21 (2010); U.S. GLOBAL CHANGE RESEARCH PROGRAM, *supra* note 79, at 465, 490, 508, 768; Alan F. Hamlet et al., *An Overview of the Columbia Basin Climate Change Scenarios Project: Approach, Methods, and Summary of Key Results*, 51 ATMOSPHERE-OCEAN 392, 404 (2013); Ingrid M. Tohver et al., *Impacts of 21st Century Climate Change on Hydrologic Extremes in the Pacific Northwest Region of North America*, 50 J. AM. WATER RESOURCES ASS'N 1461, 1465 (2014); Huan Wu et al., *Projected Climate Change Impacts on the Hydrology and Temperature of Pacific Northwest Rivers*, 48 WATER RESOURCES RES. 1, 19–21 (2012).

[96] U.S. GLOBAL CHANGE RESEARCH PROGRAM, *supra* note 79, at 489.

[97] Philip W. Mote et al., *Declining Mountain Snowpack in Western North America*, 86 BULL AM. METEOROLOGICAL SOC'Y 39, 42, 44 (2005).

[98] U.S. GLOBAL CHANGE RESEARCH PROGRAM, *supra* note 79, at 489.

[99] *Id.*

[100] J.C. Leppi et al., *Impacts of Climate Change on August Stream Discharge in the Central-Rocky Mountains*, 112 CLIMATE CHANGE 997, 1002–03 (2012).

[101] C.H. Luce & Z.A. Holden, *Declining Annual Streamflow Distributions in the Pacific Northwest United States, 1948–2006*, 36 GEOPHYSICAL RES. LETTERS L16401, 2–3 (2009).

significant technical—as well as political—ramifications regarding the allocation of water resources.

Climate change will also create increasingly challenging thermal stream environments for Pacific salmonids as stream temperatures increase.[102] While it appears that most salmonid habitat will be suitable for the next two to four decades, some areas will become uninhabitably warm.[103] Effects may include fish population or species range shifts, altered migration timing, and impacts to both individual growth and population abundance.[104] For example, regional warming of 1–3 °C would reduce the spatial extent of thermally suitable sockeye salmon habitat by nearly one third, forcing populations to shift upstream.[105] Model predictions and real-world observations of shifts in population range limits both support these forecasted effects.[106] Regionally, warming trends could "advance the timing of marine entry by weeks or more" for populations of anadromous salmon in Washington.[107] Further, modeling and empirical results indicate decreases in abundance and shifts in size distribution as a result of increasing water temperatures for cold water inland fishes worldwide,[108] and specifically in the Inland Northwest.[109]

Taken together, the evidence indicates that these predicted—and in some cases already occurring—climatological shifts could disrupt populations of salmonids that have adapted over eons to certain temperature and instream flow patterns. Moreover, climate effects ripple beyond individual fish, affecting fish populations and, ultimately, entire aquatic communities. In recent decades, fish populations and aquatic ecosystem community dynamics have shifted—and are predicted to continue to shift—towards conditions that favor invasion by non-native species.[110] For

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[102] Isaak et al., *Global Warming of Salmon and Trout Rivers in the Northwestern U.S.*, *supra* note 92, at 566.

[103] *Id.* at 573–74.

[104] *Id.* at 567.

[105] *Id.* at 581.

[106] James E. Whitney et al., *Forecasted Range Shifts of Arid-Land Fishes in Response to Climate Change*, 27 REVIEWS IN FISH BIOLOGY & FISHERIES 463, 471, 473 (2017); Timothy C. Bonebrake et al., *Managing Consequences of Climate-Driven Species Redistribution Requires Integration of Ecology, Conservation and Social Science*, 93 BIOLOGICAL REV. 284, 287–88, 291 (2018).

[107] Joshua Weinheimer et al., *Monitoring Climate Impacts: Survival and Migration Timing of Summer Chum Salmon in Salmon Creek, Washington*, 146 TRANSACTIONS AM. FISHERIES SOC'Y 983, 983 (2017).

[108] Bonnie J.E. Myers et al., *Global Synthesis of the Documented and Projected Effects of Climate Change on Inland Fishes*, 27 REVIEWS IN FISH BIOLOGY & FISHERIES 339, 344–53 (2017).

[109] Knut Marius Myrvold & Brian Patrick Kennedy, *Increasing Water Temperatures Exacerbate the Potential for Density Dependence in Juvenile Steelhead*, 75 CAN. J. FISHERIES & AQUATIC SCI. 897, 902–03 (2018).

[110] *See generally* Philip E. Hulme, *Climate Change and Biological Invasions: Evidence, Expectations, and Response Options*, 92 BIOLOGICAL REVIEWS 1297 (2017) (providing a

example, throughout the American West, climate change has already forced range contractions for important salmonids,[111] and non-native species are rapidly occupying these newly vacated ecological niches.[112] The combined impacts from these changes could be severe for culturally and economically important fish populations; populations that tribal and non-tribal peoples alike rely on for subsistence.[113] Globally, the effects of climate change are predicted to impact food security, particularly for peoples who depend on inland fisheries.[114] This group includes Native American tribes harvesting Pacific salmonids from the freshwater drainages throughout the Northwest United States.[115]

comprehensive assessment of how climate change will shape the invasive processes of alien plants, animals, and pathogens in Great Britain's terrestrial, freshwater, and marine environments); Erin L. McCann et al., *Corresponding Long-Term Shifts in Stream Temperature and Invasive Fish Migration*, 75 CAN. J. FISHERIES & AQUATIC SCI. 772 (2018) (finding a correllation betewen long-term increases in stream temperatures and shifts in migration timing of an invasive fish in the Laurentian Great Lakes); Marco Milazzo et al., *Climate Change Exacerbates Interspecific Interactions in Sympatric Coastal Fishes*, 82 J. ANIMAL ECOLOGY 468 (2013 (concluding that warming of the Mediterranean Sea will lead to increased relative dominance of a warm-water fish species, which will lead cool-water fish to relocate to less-desirable habitat).

[111] Isaak et al., *The Cold-Water Climate Shield*, *supra* note 49, at 2541.

[112] *See* JOHN WINKOWSKI, ERIC WALTHER & MARA ZIMMERMAN, SUMMER RIVERSCAPE PATTERNS OF FISH, HABITAT, AND TEMPERATURE IN SUB BASINS OF THE CHEHALIS RIVER, 2013–2016 32–38 (Fish Sci. Division, Wash. Dep't Fish & Wildlife 2018), https://wdfw.wa.gov/sites/default/files/publications/01999/wdfw01999.pdf [https://perma.cc/YC99-83Q8].

[113] *See, e.g.*, *First Foods & Life Cycles*, *supra* note 34 ("Until the early 1900s, the culture of the Cayuse, Umatilla and Walla Walla Indians was based on a yearly cycle of travel from hunting camps to fishing spots to celebration and trading camps and so on.").

[114] *See generally* Craig P. Paukert et al., *Designing a Global Assessment of Climate Change on Inland Fishes and Fisheries: Knowns and Needs*, 27 REVIEWS IN FISH BIOLOGY & FISHERIES 393 (2017) (reporting recommendations made by an expert panel representing seven countries about how to bring assessments of climate change effects on inland fishes up to par with the more extensive studies of marine environments).

[115] *See supra* note 2 for a list of treaties recognizing the historic importance of salmonids to tribes throughout the region; *see also* Washington v. Washington State Commercial Passenger Fishing Vessel Assn., 443 U.S. 658, 661–62 (1979) (rehashing history of treaties signed by Northwestern tribes in 1854–55 in which their land was exchanged for "protection of their 'right of taking fish, at all usual and accustomed grounds and stations'" (quoting Treaty of Medicine Creek, U.S.-Nisqually Tribe, art. 3, Dec. 26, 1854, 10 Stat. 1132, 1133); United States v. Washington, 853 F.3d 946, 954 (9th Cir. 2017) (In describing the Stevens Treaties of 1854–55, the court recognized that "[i]n exchange for their land, the tribes were guaranteed a right to off-reservation fishing, in a clause that used essentially identical language in each treaty."); Colville Confederated Tribes v. Walton, 647 F.2d 42, 48 (9th Cir. 1981) (finding "an implied reservation of water from No Name Creek for the development and maintenance of replacement fishing grounds"); United States & Coeur d'Alene Tribe v. Idaho, 95 F. Supp. 2d 1094, 1099–1100 (D. Idaho 1998) (recognizing Coeur d'Alene Tribe's historical dependency on local fisheries); United States v. Anderson, 591 F. Supp. 1, 7–8

IV. THE QUANTIFICATION OF INSTREAM FLOW RESERVED WATER RIGHTS

Since the U.S. Supreme Court's affirmance of Special Master Rifkind's report in *Arizona I*,[116] the general approach by courts has been to abandon open-ended decrees in favor of the application of a fixed quantity of water for each water right reserved by an Indian tribe.[117] Although the methodology for determining these reserved minimum flow water rights has evolved, recent cases have employed the incremental flow methodology (IFIM), a major component of which is the Physical Habitat Simulation Model (PHABSIM).[118] IFIM is a flexible approach that analyzes discharge and channel geometry to define the range of physical habitat conditions available to a species for a given flow.[119] IFIM analysis is capable of quantitatively estimating habitat features at both a macro-scale (streamflow, water quality, and temperature), and micro-scale (hydraulic and structural features that make up the actual living space of fishes).[120] However, the parameters included in a reserved instream flow claim are primarily limited to those required for PHABSIM: velocity, depth, and substrate.[121] The goal of the PHABSIM analysis is to determine—on a

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(E.D. Wash. 1982) (finding maintenance of creek was for purpose of reservation); United States v. Washington, 384 F. Supp 312, 331–32 (W.D. Wash. 1974) (reviewing nature of treaty rights generally and distinguishing "*right*" of tribal members to fish from other state citizens' "*privilege*" to fish (emphasis in original)); Sohappy v. Smith, 302 F.Supp. 899, 906 (D. Oregon 1969) ("From the earliest known times, up to and beyond the time of the treaties, the Indians comprising each of the intervenor tribes were primarily a fishing, hunting and gathering people dependent almost entirely upon the natural animal and vegetative resources of the region for their subsistence and culture."); State v. Coffee, 556 P.2d 1185, 1189 (Idaho 1976) (extending the rights reserved under the Treaty of Hellgate to the Kootenai Tribe of Idaho); State v. McConville, 139 P.2d 485, 486–87 (Idaho 1943) (confirming right of indigenous man to fish without a state-issued fishing license).

[116] Arizona v. California, 373 U.S. 546 (1963); *see* discussion of *Arizona I* in Part I, *supra*.

[117] *Compare* Conrad Inv. Co. v. United States, 161 F. 829, 835 (9th Cir. 1908) *with* Special Master Report Concerning Reserved Water Right Claims By and On Behalf of the Tribes of the Wind River Indian Reservation, Wyoming, *In re* General Adjudication of All Rights to Use Water in the Big Horn River System and All Other Sources, State of Wyoming, Civ. No. 4993 (Wyo. Dist Ct., 5th Dist. Dec. 15, 1982) [hereinafter *Big Horn* Special Master Report] *and* Colville Confederated Tribes v. Walton, 460 F. Supp. 1320, 1329 (E.D. Wash. 1978) *and* Amended Order on Motions for Ruling on Legal Issues, *In re* Determination of the Relative Rights of the Waters of the Klamath River, a Tributary of the Pacific Ocean, Case No. 285, (Or. Office of Admin. Hearings for the Water Res. Dep't Feb. 13, 2007) [hereinafter *2007 Klamath Instream Flow Proposed Order*].

[118] *See* Hedden-Nicely, *supra* note 18, at 243–55.

[119] For a comprehensive explanation of the IFIM/PHABSIM methodology, as applied in reserved water rights adjudications, see Dylan R. Hedden-Nicely, *Law and Science Series No. 1: The Contemporary Methodology for Claiming Reserved Instream Flow Water Rights to Support Aquatic Habitat*, 50 ENVTL L. REV. (forthcoming 2020).

[120] BOVEE, A GUIDE TO STREAM HABITAT ANALYSIS, *supra* note 46, at v.

[121] *See*, *e.g.*, *id.* at 171.

reach-by-reach and month-by-month basis—the flow that maximizes habitat suitability across these three parameters for a target life stage and species of fish.[122] Velocity, depth, and substrate are related to habitat quantity and quality through the following equation:

$$WUA(Q) = \int_A f(v, d, ci)\, dA \qquad [1]$$

In the above equation, *WUA(Q)* represents the weighted usable area (WUA) at flow Q, which is summed over individual cells within the area, across incremental changes in flow. WUA can be thought of as the quantity, expressed as spatial area, of physical habitat that is present within the channel when streamflow equals *Q,* for a given cell within the study transect. The terms represented by *f(v)*, *f(d)*, and *f(ci)* are functional relationships that weight habitat quality for target species (frequently salmonids) based on velocity, depth, and an index of channel substrate, respectively. These functional relationships are derived from empirically determined habitat suitability curves—such as the curve displayed in **Figure 1**—relating stream conditions to fish usage. *A* is the cell surface area, and *d* indicates that the integral is summed over changes in surface area across a range of incremental changes in flow.[123]

The relationship between weighted usable area (WUA) and PHABSIM's three underlying parameters—stream depth, velocity, and substrate—can be conceptualized through the example portrayed in **Figure 1**. First, the cross-section of a particular stream reach is broken into "a large number of rectangular or trapezoidal cells . . . [e]ach [of which] is considered to have a unique combination of depth, velocity, [and] substrate . . . at any particular discharge."[124] Second, significant data are collected at each cross-section over several years and, based upon those data, PHABSIM modeling software estimates unique habitat

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[122] The target species are selected in consultation with the tribes and are usually those species that are native to the stream, were traditionally harvested by the tribe, and either continue to exist or have a reasonable likelihood of reintroduction to the watershed. Transcript of Record at VII-13-VII-17, *In re* Determination of the Relative Rights of the Waters of the Klamath River, a Tributary of the Pacific Ocean, Case No. 277 (Or. Office of Admin. Hearings for the Water Res. Dep't Dec. 1, 2011) [hereinafter D. Riser Aff., *Klamath River Adjud*]. Lifestage is prioritized based upon the resiliency of each lifestage to changes from optimal conditions, which generally results in spawning is the highest priority lifestage, followed by adult, juvenile, and fry (in order of descending priority). *Id.* at VII-35. Additionally, the highest lifestage prioritization for the month following a spawning event is the incubation stage, which corresponds to 2/3 of the previous month's spawning flow. *Id.* at VII-33–VII-35, VII-37.

[123] R. T. MILHOUS ET AL., U.S. FISH & WILDLIFE SERV., Instream Flow Information Paper No. 26, PHYSICAL HABITAT SIMULATION SYSTEM REFERENCE MANUAL: VERSION II, at I.9 (1989).

[124] KEN D. BOVEE, U.S. FISH & WILDLIFE SERV., Instream Flow Information Paper No. 21, DEVELOPMENT AND EVALUATION OF HABITAT SUITABILITY CRITERIA FOR USE IN THE INSTREAM FLOW INCREMENTAL METHODOLOGY 3 (1986) [hereinafter BOVEE, HABITAT SUITABILITY CRITERIA].

suitability—from zero (completely unsuitable) to one (most suitable)—across a range of flows for depth, velocity, and substrate.[125] Third, the composite suitability is found in each cell for the particular flow by multiplying the habitat suitability for the three parameters.[126] This composite suitability is the final weighing value, which is then multiplied by the surface area of the cell in order to arrive at weighted useable area.[127] This process is iterated across a range of flows within each study area and each life stage of the target species, developing a relationship between total habitat as function of discharge for each life stage.[128] The flow ultimately claimed for the water right corresponds to the highest weighted usable area for the priority life stage (i.e., the life stage that currently limits overall population productivity) of the priority species present in the study area.[129]

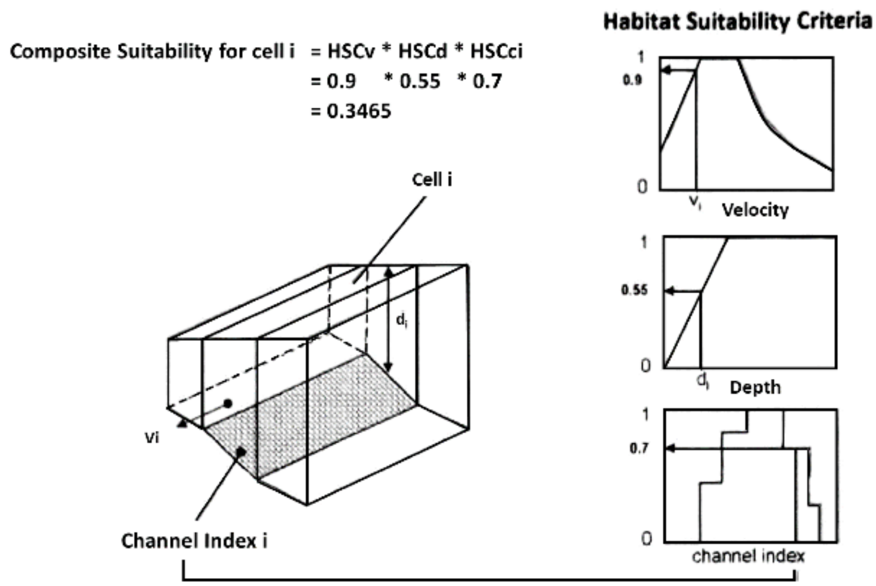

Figure 1: Example of a cell within a stream along with representative habitat suitability criteria.[130]

[125] D. Riser Aff., *Klamath River Adjud*, *supra* note 122, at VII-2–VII-3, VII-4 fig.VII-2.

[126] *Id*. at VII-4 fig.VII-2.

[127] *Id*. at VII-3.

[128] *Id*.

[129] *Id.* at VII-60. Priority species usually include fishes traditionally important to the tribe, an ESA-listed species, and/or an otherwise legally protected species. *Id.* at VI-1.

[130] *Id.* at VII-4 fig.VII-2.

As the methodology explained above demonstrates, a basic assumption underlying PHABSIM is that the flow that optimizes stream habitat today will continue to be the flow that optimizes stream habitat in the future. Indeed, PHABSIM's rigid use of data regarding past conditions, with no mechanism for accounting for future changes, assumes the fiction that stream depth, velocity, and substrate will remain the same moving into the future. That fundamental assumption is becoming increasingly untenable due to the sensitivity of the three core model parameters to climate change.

V. HOW CLIMATE CHANGE AFFECTS THE PHABSIM PARAMETERS—DEPTH, VELOCITY, SUBSTRATE

Courts have long understood the "uncertainty inherent in the computer modeling of the complex biological system of . . . rivers."[131] Although uncertainty exists regardless of the particular model that is used, we focus here on PHABSIM due to its overwhelming use in water rights adjudications.[132] The Washington Supreme Court has recognized that the use of PHABSIM results in "conservative" underestimates "of the flows that would best protect the fishery."[133] Although

[131] Dep't. of Ecology v. Public Util. Dist. No. 1 of Jefferson Cty., 849 P.2d 646, 658 (Wash. 1993), *aff'd,* 511 U.S. 700 (1994).

[132] D. Riser Aff., *Klamath River Adjud*, *supra* note 122, at VII-1 ("IFIM/PHABSIM . . . is the most widely recognized method in North America . . . and . . . the most appropriate method for evaluating incremental changes in habitat with flow."); Hedden-Nicely, *supra* note 18, at 230–42; *see also Ecology v. PUD No. 1*, 849 P.2d at 858–59; Transcript of Record Vol. 71 at 6346–60, *In re* General Adjudication of All Rights to Use Water in the Big Horn River System and All Other Sources, Civ. No. 4993, (Wyo. Dist Ct., 5th Dist. May 10, 1983) (describing the Instream Flow Incremental Methodology used by experts in the *Big Horn* adjudication); Affidavit of Dell Simmons at 7, Dep't of Ecology v. Acquavella, No. 77-2-01484-5 (Wash. Super. Ct., Yakima Cty. Nov. 29, 1990) [hereinafter D. Simmons Aff., *Acquavella (In re Yakima Basin Adjudication)*] ("All the analysis used to define habitat versus flow relationships in the Yakima River System used the Physical Habitat Simulation System . . . ."), *aff'd sub nom.*, Dept' of Ecology v. Yakima Reservation Irrigation Dist., 850 P.2d 1406 (Wash. 1993); *compare* Order Modifying the Minimum Flow Provisions of this Court's Memorandum Decision of July 23, 1979 at 2–4, United States v. Anderson, No. 3643 (E.D. Wash. Dec. 9, 1988) [hereinafter *Anderson* Modification Order] (modifying the instream flow water right reserved by the Spokane Tribe and United States in Chamokane Creek, Washington, from 20 cfs to 24 or 27 cfs, depending on priority), *with* MICHAEL R. BARBER ET AL., PREDICTING THE EFFECT OF REDUCED STREAMFLOW ON RAINBOW TROUT, BROWN TROUT, AND SCULPIN POPULATIONS IN CHAMOKANE CREEK USING INSTREAM FLOW INCREMENTAL METHODOLOGY (IFIM) 1–8, 105 (1988) (criticizing the original 1979 *Anderson* court's adjudicated flow of 20 cfs as insufficient to protect the fishery, and advocating instead for a miniumum flow of 27.7 cfs based on an IFIM analysis).

[133] *Ecology v. PUD No. 1*, 849 P.2d at 659. The Washington Supreme Court listed some of the "other important flow-related habitat variables" that PHABSIM leaves out of the analysis, "including (1) predation, (2) competition and territoriality, (3) sedimentation and

prescient for 1993, the Washington Supreme Court's observations become even more grave as the effects of anthropgenic climate change transpire. As discussed above in Part IV, the primary assumption that underpins the PHABSIM method's output is that streams, and therefore, habitat suitability, remain constant through time. Further, data used in the PHABSIM methodology include static observations of stream depth, velocity, and substrate for a given streamflow.[134] However, stream channel geometry is not constant. Instead, stream morphology is controlled by watershed hydrology and sediment loading,[135] which are highly dynamic and sensitive to climate change:

> [p]otential consequences of climate change for river processes include changes to the magnitude of flood flows; modification of river channel dimensions and form; changes to bank stability, bank erosion rates, and channel migration; modification of in-channel erosion and deposition; on-set of long term aggradation or degradation of river channels; changes to intensity and frequency of overbank flooding and ice-jams; and changes to the stability of valley sides.[136]

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its effect on eggs and food supplies, (4) the adequacy of flows to prevent eggs from dehydrating, and (5) the creation of barriers to migration." *Id.* at 658.

[134] *See supra* Part IV.

[135] P. ASHMORE & M. CHURCH, GEOLOGICAL SURVEY OF CANADA, Bull. 555, THE IMPACT OF CLIMATE CHANGE ON RIVERS AND RIVER PROCESSES IN CANADA 5 (2001).

[136] *Id.*

Scenario	Imposed Changes			Resulting Changes							
	Q	**Q_{bm}**	**Q_W**	**w**	**d**	**S**	**D**	**F**	**L**	**P**	**M**
1	+	+	+	+	+	±	±	±	+	?	±
2	+	+	-	+	+	±	±	+	+	-	-
3	+	-	-	+	+	-	+	-/+	+	+	-
4	-	+	+	-	-	+	-	-/+	-	-	+
5	-	-	+	-	-	-/+	-	±	-	?	+
6	-	-	-	-	±	-	±	±	-	+	-

Abbreviations:
Q, mean annual discharge; **Q_{bm}**, ratio of bed material load to discharge; **Q_W**, ratio of wash load to discharge; **w**, mean channel width; **d**, mean channel depth; **S**, mean channel gradient; **D**, bed material particle size; **F**, ratio of width to depth; **L**, meander wavelength; **P**, sinuosity; **M**, fine sediment content of bed and bank material

Note:
1. '+' means an increase and '-' means decrease;
2. Long term and short term changes are separated by a '/'
3. '±' means that the stream may change in either direction
4. '?' means no reasonable prediction may be made.

Table 1: Potential changes in stream morphology resulting from changes in discharge and sediment supply.[137]

Table 1 demonstrates the variability in stream morphology that could result from climate change. This underscores the primary thrust of the concern presented in this Article: although local impacts will be variable, confidence is high that stream habitat suitability will become increasingly uncertain as climate change progresses. In general, climate change is predicted to cause decreased summer low flows in the Northwestern United States, while increasing the incidence of flood events at the same time.[138] Both of these changes will result in altered stream sediment dynamics, impacting the core parameters of a PHABSIM evaluation: depth, velocity, and sediment composition.[139] For demonstrative purposes, in this Part we discuss how the predicted effects of climate change will likely affect PHABSIM output, thereby altering the amount of water necessary to provide a suitable habitat for fish.

Although PHABSIM assumes that channel depth will remain constant through time, changes to stream hydrology as a result of climate change are widely expected

[137] *Id.* at 18. This table is based on concepts originating with STANLEY A. SCHUMM, THE FLUVIAL SYSTEM (1977). The table was modified from R. Kellerhals & M. Church, *The Morphology of Large Rivers: Characterization and Management*, *in* PROCEEDINGS OF THE INTERNATIONAL LARGE RIVER SYMPOSIUM (LARS), Canadian Special Publication of Fisheries and Aquatic Sciences No. 106, at 43–44 (Douglas P. Dodge ed. 1989).

[138] *See supra* Part III.

[139] *Id.*

to result in changes to stream morphology. For example, an overall decrease in streamflow, as predicted in the Northwestern United States, will likely cause stream reaches to generally accumulate sediment along the bed (i.e., aggrade).[140] Aggradation will, in turn, cause reductions of both channel width and depth.[141] Changes in depth resulting from flood events are more variable and localized; in some reaches, flooding would likely cause stream aggradation while other reaches would degrade.[142]

The habitat suitability curves depicted in **Figure 1** demonstrate that changes to channel depth have a corresponding effect on overall habitat suitability. Generally, reducing depth for a fixed quantity of water often results in an overall decrease in habitat quality because available habitat in the stream reach will decrease.[143] Although the impact will be different depending on the study species and the characteristics of a given stream reach, the overall result is that the changes to channel depth caused by climate change will invariably change the amount of water necessary to adequately protect stream habitat.

PHABSIM likewise assumes that the substrate of a stream channel remains static through time and space. However, as stream hydrology changes with climate change, so too will stream morphology and substrate particle size.[144] The most dramatic example of this occurs as a result of abrupt changes to stream morphology resulting from floods.[145] Although salmonid substrate preferences are site-specific and tend to reflect tradeoffs between optimizing spawner redd excavation, embryo survival, and juvenile cover,[146] the "channel index" habitat suitability curve depicted in **Figure 1** provides an example of how changes to channel substrate have a corresponding effect on overall habitat suitability. More generally, increases in bed material particle size from coarse gravels to cobbles and boulders tend to reduce habitat suitability for spawning salmonids.[147] In contrast, a decrease from boulder or cobble to gravels would improve habitat suitability for spawning and rearing salmonids, but as bed material becomes increasingly fine (i.e., approaching high concentrations of sand and silt), consequences would be negative for spawning habitat of Pacific salmonids.[148] Regardless of whether the channel substrate becomes

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[140] BOVEE, A GUIDE TO STREAM HABITAT ANALYSIS, *supra* note 46, at 8.

[141] *Id.*; *see supra* Table 1, Scenarios 4–6; *see also supra* note 137 and accompanying text.

[142] *See supra* Table 1, Scenarios 1–3; *see also supra* note 137 and accompanying text.

[143] *See supra* Figure 1.

[144] *See supra* Table 1, Column D.

[145] G. Mathias Kondolf, *Profile: Hungry Water: Effects of Dams and Gravel Mining on River Channels*, 21 ENVTL. MGMT. 533, 545–47 (1997) [hereinafter Kondolf, *Profile: Hungry Water*].

[146] Joseph Merz et al., *Balancing Competing Life Stage Requirements in Salmon Habitat Rehabilitation: Between a Rock and a Hard Place*, 27 RESTORATION ECOLOGY 611, 668–69 (2019).

[147] Kondolf, *supra note* 73, at 265.

[148] *See generally* WILLIAM J. MCNEIL & WARREN H. AHNELL, U.S. FISH & WILDLIFE SERV., Special Scientific Report – Fisheries No. 469, SUCCESS OF PINK SALMON SPAWNING

progressively more or less coarse, modifications to substrate particle size will cause a change in overall habitat suitability, thereby rendering the originally awarded water right quantity less meaningful.

Finally, PHABSIM relies upon the assumption that stream velocity will remain static for a given flow. However, as with stream depth and substrate, climate change is likely to cause stream velocity to become increasingly unstable and variable. Stream velocity is driven by a number of factors, including channel area, roughness, and slope—all of which are highly sensitive to changes in hydrology caused by climate change.[149] For example, channel width and depth may decrease as climate change results in decreasing overall streamflows.[150] At the same time, decreasing overall stream channel area or increased flooding within constrained or degrading channels will result in increasing stream velocity.[151] Climate change is likewise expected to cause channel slope in many streams to increase while simultaneously decreasing bed material particle size, which would also cause increases in velocity.[152]

Increasing stream velocity delivers more power at the streambed, resulting in greater shear stress and altered channel shape (i.e., geometry), primarily manifesting as streambed downcutting (i.e., degradation), which will cause stream velocity to eventually become stable in a new regime.[153] However, it is unlikely that the new relationship between velocity and flow—which depends primarily on channel geometry—will be identical to conditions when the PHABSIM analysis was initially conducted. **Figure 1** once again demonstrates that variability of stream velocity causes inconsistent influences on overall stream habitat suitability. In the case

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RELATIVE TO SIZE OF SPAWNING BED MATERIALS (1964); D.W. REISER & T.C. BJORNN, U.S. FOREST SERV., General Tech. Report No. PNW-96, INFLUENCE OF FOREST AND RANGELAND MANAGEMENT ON ANADROMOUS FISH HABITAT IN WESTERN NORTH AMERICA: HABITAT REQUIREMENTS OF ANADROMOUS SALMONIDS (1979); M.R. Crouse et al., *Effects of Fine Sediments on Growth of Juvenile Coho Salmon in Laboratory Streams*, 110 TRANSACTIONS OF THE AM. FISHERIES SOC'Y 281 (1981); Kondolf, *supra* note 73; D.A. Sear, *Fine Sediment Infiltration into Gravel Spawning Beds Within a Regulated River Experiencing Floods: Ecological Implications for Salmonids*, 8 REGULATED RIVERS: RES. & MGMT. 373 (1993).

149 Velocity can be approximated through Manning's equation:

$$Q = VA = A\left(\frac{1}{n}\right)R^{\frac{2}{3}}\sqrt{S}$$

where Q is discharge; V is velocity; A is stream cross-sectional area; n is Manning's roughness coefficient; R is hydraulic radius; and S is slope. R. H. MCCUEN, HYDROLOGIC ANALYSIS AND DESIGN 144 (3d ed. 2005).

150 *See* Table 1, Scenarios 4, 5.

151 L.B. LEOPOLD, A VIEW OF THE RIVER 23 (1994).

152 Kondolf, *Profile: Hungry Water*, *supra* note 145, at 545–47.

153 *See generally* Mikel Calle et al., *Channel Dynamics and Geomorphic Resilience in an Ephemeral Mediterranean River Affected by Gravel Mining*, 285 GEOMORPHOLOGY 333 (2017).

exemplified in **Figure 1**, small increases in velocity would improve habitat suitability for the stream reach. However, as velocity continues to increase, habitat suitability would plateau and eventually degrade significantly. Although the impact on habitat suitability from changes in stream velocity will be different in every stream, it is reasonable to conclude that climate change will generally cause changes in velocity for a given reach of moving water.

Ultimately, it is presently impossible to predict precisely how climate change may influence stream velocity, depth, and substrate. However, this uncertainty underscores the primary concern presented in this Article: as the climate changes, the morphology of many streams will inevitably but unpredictably change as well, resulting in changes in the amount of water necessary to adequately protect stream habitat. PHABSIM and similar static analyses cannot account for these dynamics.

VI. PROBLEMS ASSOCIATED WITH MODEL OMISSION OF TEMPERATURE

In addition to issues related to how climate change may affect stream depth, velocity, and substrate, PHABSIM fails to incorporate other factors sensitive to climate change that influence stream habitat.[154] At least one court has recognized that omission of these other "important flow-related habitat variables" causes uncertainty in model output and likely results in "conservative . . . estimation of the flows that would best protect the fishery . . . ."[155] As discussed above, the most obvious of these effects is warming air and stream temperatures.[156] Currently, PHABSIM, which essentially analyzes a temporally static cross-section or snapshot of stream conditions, cannot account for the variability of parameters attributable to climate change.

A primary problem with PHABSIM-based evaluations of impacts on fish that are predicted to result from water withdrawals stems from the model's omission of temperature variables. Given the accelerated climactic warming across the Pacific West and the influences of temperature on fish performance and distribution, any model that omits temperature is problematic for two reasons. First, this leads to inaccurate prediction of abundance, which is one of the most critical model outputs.[157] Optimizing the amount of suitable habitat using a modeling scheme that

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[154] *See* Dep't. of Ecology v. Public Util. Dist. No. 1 of Jefferson Cty., 849 P.2d 646, 658–59 (Wash. 1993), *aff'd,* 511 U.S. 700 (1994).

[155] 849 P.2d at 658.

[156] *See supra* Part III.

[157] *See* Allen L. Conder & Thomas C. Annear, *Test of Weighted Usable Area Estimates Derived from a PHABSIM Model for Instream Flow Studies on Trout Streams*, 7 NORTH AM. J. FISHERIES MGMT. 339, 349 (1987); Deborah J. Walks, Discharge and its Consequences to Physical Habitat and Trout Populations in the Deschutes River of Central Oregon 2–5 (Mar. 11, 1997) (unpublished M.A. thesis, Oregon State University) (on file with the Utah Law Review). *See generally* D. Scott & C. S. Shirvell, *A Critique of the Instream Flow Incremental Methodology and Observations on Flow Determination in New Zealand*, *in* REGULATED STREAMS: ADVANCES IN ECOLOGY 27–43 (John F. Craig & J. Bryan Kemper

is based on velocity, depth, and substrate, but omits temperature, leaves out a critical environmental variable that strongly constrains salmonid distributions.[158] As a result, these predictions of fish habitat quality are tempered by relatively low confidence. Practitioners have tended to circumvent PHABSIM's omission of temperature effects by either conducting a more comprehensive IFIM analysis,[159] conducting a standalone temperature study or evaluation,[160] or reworking aspects of PHABSIM output into a larger evaluation.[161] Taken together, these trends suggest a second problem with PHABSIM's omission of temperature: even if current fish abundance is accurately predicted by whatever methodology is selected, the omission of temperature would mean that model output is increasingly inaccurate under future warming as the environment shifts to become (generally) less hospitable for salmonids.

We suggest that this is a problem of emergent ineptitude, recognizing that the omission of temperature in PHABSIM results not from practitioner malice or ignorance, but rather a lack of process oversight by any single regulatory agency, as individuals interpret and apply elements of PHABSIM to the idiosyncratic challenges they face.[162] Importantly, IFIM—of which PHABSIM was initially a component—*is capable* of evaluating temperature.[163] However, when IFIM is parsed and only the parameters for a PHABSIM analysis are included, as frequently occurs, the temperature evaluation is omitted in the process. Thus, as stressed here

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eds. 1987) (presenting several assumptions made by IFIM/PHABSIM and why they are not always met).

[158] *See generally* D. J. Isaak et al., *Effects of Climate Change and Wildfire on Stream Temperatures and Salmonid Thermal Habitat in a Mountain River Network*, 20 ECOLOGICAL APPLICATIONS 1350 (2010); D.J. Isaak et al., *Climate Change Effects on Stream and River Temperatures Across the Northwest U.S. from 1980–2009 and Implications for Salmonid Fishes*, 113 CLIMATIC CHANGE 499 (2012).

[159] Luis Filipe Gomes Lopes et al., *Hydrodynamics and Water Quality Modelling in a Regulated River Segment: Application on the Instream Flow Definition*, 173 ECOLOGICAL MODELLING 197, 206 (2004).

[160] TERRY MARET ET AL., U.S. GEOLOGICAL SURV., Scientific Investigations Report No. 2005-5212, INSTREAM FLOW CHARACTERIZATION OF UPPER SALMON RIVER BASIN STREAMS, CENTRAL IDAHO, 2004, at 26–31 (2005). *See generally* Christoph Hauer et al., *The Impact of Discharge Change on Physical Instream Habitats and Its Response to River Morphology*, 116 CLIMATIC CHANGE 827 (2013) (investigating the "climate-induced discharge on fish habitats" in the Grosse Mühl River).

[161] Weiwei Yao et al., *Modeling of River Velocity, Temperature, Bed Deformation and Its Effects on Rainbow Trout (*Oncorhynchus mykiss*) Habitat in Lees Ferry, Colorado River*, 8 INT'L J. ENVTL. RES. 887 (2014) (quantifying the available habitat for Rainbow Trout in Lees Ferry, Colorado River).

[162] *See* ATUL GAWANDE, THE CHECKLIST MANIFESTO: HOW TO GET THINGS RIGHT, 1–13 (2009).

[163] BOVEE, A GUIDE TO STREAM HABITAT ANALYSIS, *supra* note 46, at 13.

and elsewhere, the problem is not PHABSIM per se, but rather the inappropriate application of PHABSIM as a standalone tool.[164]

VII. INTEGRATED LEGAL AND TECHNICAL ADAPTATIONS TO IMPROVE QUANTIFICATION OF RESERVED INSTREAM WATER RIGHTS IN A CLIMATE CHANGE ERA

As famously attributed to Dr. George Box, "all models are wrong but some are useful."[165] There is no question that the PHABSIM methodology forms a useful model for determining flows necessary to protect fish habitat. Indeed, despite its shortcomings, PHABSIM has long been recognized as a practical and powerful tool for practitioners tasked with estimating streamflow needs for fish, based upon imperfect and often insufficient data.[166] Our concern lies not with the use of PHABSIM in particular as a model to quantify the flow of reserved instream water rights, but rather the use of any model based solely upon past data as a standalone tool in the era of anthropogenic climate change. Such an approach fails to consider "the uncertainty inherent in the . . . modeling of the complex biological system of the river," which likely results in a "*conservative* . . . estimation of the flows that [underestimates what is necessary to] best protect the fishery . . . ."[167] As a result, models such as PHABSIM are best used as part of a suite of both technical and non-technical approaches to protect aquatic species and "preserve the full extent of the water rights" reserved by American Indian tribes.[168]

Numerous technical improvements to PHABSIM have been proposed, validated, and reviewed.[169] For decades, researchers, managers, regulators, and

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[164] *See generally* H. A. Beecher, *Comment 1: Why It Is Time to Put PHABSIM Out to Pasture*, 42 FISHERIES 508 (2017); D. W. Reiser & P. J. Hilgert, *A Practitioner's Perspective on the Continuing Technical Merits of PHABSIM*, 43 FISHERIES 278 (2018) (defending the continued use of PHABSIM for instream flow assessments); C. B. Stalnaker et al., *Comment 2: Don't Throw Out the Baby (PHABSIM) with the Bathwater: Bringing Scientific Credibility to Use of Hydraulic Habitat Models, Specifically PHABSIM*, 42 FISHERIES 510 (2017).

[165] Box, *supra* note 1, at 202.

[166] Reiser & Hilgert, *supra* note 164, at 279; Stalnaker et al., *supra* note 164, at 510.

[167] Dep't of Ecology v. Public Util. Dist. No. 1 of Jefferson Cty., 849 P.2d 646, 658–59 (Wash. 1993) (emphasis added), *aff'd,* 511 U.S. 700 (1994).

[168] *Rifkind Report*, *supra* note 22, at 265. We note that other commenters have made similar arguments in the separate but related field of modeling aquatic environs for aquatic species pursuant to the United States Endangered Species Act. *See generally* M. M. McClure et al., *Incorporating Climate Science in Applications of the U.S. Endangered Species Act for Aquatic Species*, 27 CONSERVATION BIOLOGY 1222, 1230–31 (2013).

[169] *See generally* T. Linnansaari et al., CAN. DEP'T OF FISHERIES & OCEANS, REVIEW OF APPROACHES AND METHODS TO ASSESS ENVIRONMENTAL FLOWS ACROSS CANADA AND INTERNATIONALLY, Research Doc. No 2012/039 (2012); M. J. Dunbar et al., *Hydraulic-Habitat Modelling for Setting Environmental River Flow Needs for Salmonids*, 19 FISHERIES MGMT AND ECOLOGY 500 (2012); Volker Huckstorf et al., *Environmental Flow*

adjudicators have attempted to predict how a proposed change to instream flow will affect fish habitat, and ultimately fish populations.[170] Evaluating instream habitat needs for salmonids,[171] and determining relative densities of salmonids within fully occupied habitats[172] have received considerable attention.[173] As these approaches develop and their estimates become more refined and precise, we can expect to see

Methodologies to Protect Fisheries Resources in Human-Modified Large Lowland Rivers, 24 RIVER RES. AND APPLICATIONS 519 (2008); K. J. Murchie et al., *Fish Response to Modified Flow Regimes in Regulated Rivers: Research Methods, Effects and Opportunities*, 24 RIVER RES. AND APPLICATIONS 197 (2008); Yves Souchon & Herve Capra, *Aquatic Habitat Modelling: Biological Validations of IFIM/PHABSIM Methodology and New Perspectives*, 14 HYDROÉCOLOGIE APPLIQUÉE 9 (2004).

[170] *See* TOM ANNEAR ET AL., INSTREAM FLOW COUNCIL, INTERNATIONAL INSTREAM FLOW PROGRAM INITIATIVE: STATUS REPORT OF STATE AND PROVINCIAL FISH AND WILDLIFE AGENCY INSTREAM FLOW ACTIVITIES AND STRATEGIES FOR THE FUTURE, at v, 1–6 (2009); Brian Richter et al., *How Much Water Does a River Need?*, 37 FRESHWATER BIOLOGY 231, 231 (1997).

[171] *See* Burner, *supra* note 62, at 97; Fausch, *supra* note 67, at 441; Moyle & Baltz, *supra* note 67, at 695; Waite & Barnhart, *supra* note 62, at 40. *See generally* THOMAS E. MCMAHON, U.S. FISH & WILDLIFE SERV., FWS/OBS-82/10.49, HABITAT SUITABILITY INDEX MODELS: COHO SALMON 3–8 (1983); ROBERT F. RALEIGH ET AL., U.S. FISH & WILDLIFE SERV., Biological Report 82(10.122), HABITAT SUITABILITY INDEX MODELS AND INSTREAM FLOW SUITABILITY CURVES: CHINOOK SALMON (1986); T. C. Bjornn & D. W. Reiser, *Habitat Requirements of Salmonids in Streams*, *in* INFLUENCES OF FOREST AND RANGELAND MANAGEMENT ON SALMONID FISHES AND THEIR HABITATS 83 (W. R. Meehan ed., 1991); Christopher A. Frissell et al., *A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context*, 10 ENVTL. MGMT. 199 (1986); David G. Hankin & Gordon H. Reeves, *Estimating Total Fish Abundance and Total Habitat Area in Small Streams Based on Visual Estimation Methods*, 45 CAN. J. FISHERIES & AQUATIC SCI. 834 (1988); Charles P. Hawkins et al., *A Hierarchical Approach to Classifying Stream Habitat Features*, 18 FISHERIES 3 (1993); Charles P. Hawkins et al., *Density of Fish and Salamanders in Relation to Riparian Canopy and Physical Habitat in Streams of the Northwestern United States*, 40 CAN. J. FISHERIES & AQUATIC SCI. 1173 (1983); N. J. Milner et al., *Habitat Evaluation as a Fisheries Management Tool*, 27 J. FISH BIOLOGY 85 (1985).

[172] *See* RONI ET AL., *supra* note 35, at 3. *See generally* Stephen Bennett et al., *Progress and Challenges of Testing the Effectiveness of Stream Restoration in the Pacific Northwest Using Intensively Monitored Watersheds*, 41 FISHERIES 92 (2016); Jordan Rosenfeld et al., *Developing Bioenergetic-Based Habitat Suitability Curves for Instream Flow Models*, 36 NORTH AM. J. FISHERIES MGMT. 1205 (2016); Nichole K. Sather et al., *Shallow Tidal Freshwater Habitats of the Columbia River: Spatial and Temporal Variability of Fish Communities and Density, Size, and Genetic Stock Composition of Juvenile Chinook Salmon*, 145 TRANSACTIONS AM. FISHERIES SOC'Y 734 (2016); C. Eric Wall et al., *Net Rate of Energy Intake Predicts Reach-level Steelhead (*Oncorhynchus mykiss*) Densities in Diverse Basins from a Large Monitoring Program*, 73 CAN. J. FISHERIES & AQUATIC SCI. 1081 (2016).

[173] However, it is worth noting that basic biologic properties (including life history trajectories and habitat needs) for other culturally and ecologically important aquatic species (e.g., lamprey, sturgeon, burbot, freshwater mussels, beaver, etc.) have received considerably less attention.

increasing reliance upon these massive compilations of data and metadata for evaluating the effects of habitat alteration on fish populations.[174]

One technical approach that offers particular promise to improve our understanding of stream channel morphology—and its influence on stream depth, velocity, and substrate—involves the pairing of 2D hydrodynamic models[175] with high-resolution spatial mapping of channel geometry[176] and underwater streambed topography (bathymetry).[177] Remote sensing technologies, such as Light Detection And Ranging (LiDAR) using water-penetrating green-band lasers[178] or drone-based aerial photogrammetry can be used to develop digital elevation models of stream channels providing high-resolution (grid cells of less than one meter) maps of stream bathymetry. Structure-from-motion (SFM) technologies that rely on dense clusters of overhead photographs to construct comprehensive photomosaics[179] of stream

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[174] *See generally* M. P. Beakes et al., *Evaluating Statistical Approaches to Quantifying Juvenile Chinook Salmon Habitat in a Regulated California River*, 30 RIVER RES. & APPLICATIONS 180 (2014); Michael Beakes & Tim Beechie, Nat'l Oceanic & Atmospheric Admin., A Geomorphic Approach to Quantifying Salmon Habitat Capacity: How this Works in the Wenatchee (2016) (PowerPoint presentation on file with author); Morgan Bond et al., Nat'l Oceanic & Atmospheric Admin., Estimating the Historical and Contemporary Rearing Capacity for Spring Chinook Above and Below Willamette Project Dams (2016) (PowerPoint presentation on file with author); Morgan Bond, Nat'l Oceanic & Atmospheric Admin., Estimating Spring Chinook Habitat Capacity in the Columbia River Basin (2016) (PowerPoint Presentation on file with author).

[175] 2D hydrodynamic models are spatially referenced mathematical models that relate water velocities along two dimensions (downstream and laterally within a stream channel) to magnitude of flow. *See generally* Gregory B. Pasternack et al., *Application of a 2D Hydrodynamic Model to Design of Reach-Scale Spawning Gravel Replenishment on the Mokelumne River, California*, 20 RIVER RES. APPLICATIONS 2, 205–225 (2004); Stanford A. Gibson & Gregory B. Pasternack, *Selecting Between One-Dimensional and Two-Dimensional Hydrodynamic Models for Ecohydraulic Analysis*, 32 RIVER RES. APPLICATIONS 6, 1365–1381 (2015).

[176] We recommend using mapping tools with a relatively high resolution—frequently on the order of grid cells measuring less than one meter—to map the shape of stream and river channels. *See generally* Joseph M. Wheaton et al., *Geomorphic Mapping and Taxonomy of Fluvial Landforms*, 248 GEOMORPHOLOGY 273 (2015).

[177] *See generally* Rohan Benjankar et al., *One-Dimensional and Two-Dimensional Hydrodynamic Modeling Derived Flow Properties: Impacts on Aquatic Habitat Quality Predictions*, 40 EARTH SURFACE PROCESSES & LANDFORMS 340 (2015); Gibson & Pasternack, *supra* note 175; Pasternack et al., *supra* note 175.

[178] *See generally* Robert C. Hilldale & David Raff, *Assessing the Ability of Airborne LiDAR to Map River Bathymetry*, 33 EARTH SURFACE PROCESSES & LANDFORMS 773 (2008); Jim A. McKean et al., *Geomorphic Controls on Salmon Nesting Patterns Described by a New, Narrow-Beam Terrestrial–Qquatic Lidar*, 6 FRONTIERS IN ECOLOGY & ENV'T 3, 125–30 (2008).

[179] A photomosaic is "a patchwork of overlapping aerial photographs that have been rectified and fit together so as to form a continuous survey of a territory." Paul K. Saint-

channels[180] can also be used. The result of such techniques has been termed "near-census" river science (to reflect that results associated with these techniques approach comprehensive rather than interpolative mapping).[181] Near-census river science is emerging as a solution of choice that avoids errors from estimating the topography between widely spaced cross-sections (interpolating),[182] as frequently occur with PHABSIM analyses. These high-resolution approaches improve hydraulic modeling precision, as the spatial scale over which estimation of topography diminishes.[183] As channel mapping datasets become more widespread, the utility of these approaches is likely to become more accepted.

The inclusion of a temperature parameter—particularly in streams and/or reaches subject to warming from climate change—will likewise improve the robustness of the instream flow water rights claimed to maintain fish populations. Quantifying reserved water rights based upon stream temperature is precedented, having been judicially decreed on at least two occasions.[184] However, the water rights decreed in those cases were based *solely* upon temperature.[185] That approach has lately been abandoned in favor of an IFIM/PHABSIM analysis.[186] While basing an instream flow water right solely upon temperature is problematic, integrating temperature into a model that includes other important habitat characteristics would likely result in a water right that is more resilient in the face of a changing climate. Importantly, the IFIM methodology is capable of incorporating water temperature

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Amour, *Applied Modernism: Military and Civilian Uses of the Aerial Photomosaic,* 28 THEORY, CULTURE & SOC'Y 241, 241 (2011).

[180] *See generally* L. Javernick et al., *Modeling the Topography of Shallow Braided Rivers Using Structure-from-Motion Photogrammetry*, 213 GEOMORPHOLOGY 166 (2014); M. J. Westoby et al., *'Structure-from-Motion' Photogrammetry: A Low-Cost, Effective Tool for Geoscience Applications*, 179 GEOMORPHOLOGY 300 (2012).

[181] Gregory B. Pasternack et al., *Near-Census River Science*, U.C. DAVIS, http://pasternack.ucdavis.edu/research/projects/near-census-river-science [https://perma.cc/GUZ3-MK9R] (last visited Mar. 30, 2020) [hereinafter Pasternack et al., *Near-Census River Science*].

[182] *See generally* IAN MADDOCK ET AL., ECOHYDRAULICS: AN INTEGRATED APPROACH (2013); GREGORY B. PASTERNACK, 2D MODELING AND ECOHYDRAULIC ANALYSIS (2011).

[183] *See* Pasternack et al., *Near-Census River Science*, *supra* note 181.

[184] United States v. Anderson, 6 Indian L. Rep. F-129, F-130 (E.D. Wash. 1979); Transcript of Record at 578–82, Colville Confederated Tribes v. Walton, No. C-3421 (E.D. Wash. Aug. 31, 1983) (discussing the relationship of temperature and flow and the importance of certain temperatures over other factors in sustaining fishery health), *rev'd on other grounds*, 752 F.2d 397 (9th Cir. 1984); Hedden-Nicely, *supra* note 18, at 212–24 (citing Colville Confederated Tribes v. Walton, 752 F.2d 397 (9th Cir. 1985) and United States v. Anderson, 736 F.2d 1358 (9th Cir. 1984)).

[185] The Court in *Anderson* eventually reopened the decree and modified the water right based upon an IFIM analysis. *See Anderson* Modification Order, *supra* note 132, at 2; BARBER ET AL., *supra* note 132, at app. A (1988).

[186] *See* BOVEE, HABITAT SUITABILITY CRITERIA, *supra* note 124, at 3.

as a parameter.[187] While data collection and analysis of temperature is often complex, the importance of temperature to stream habitat quality warrants its inclusion in water rights quantification modeling.

Notwithstanding the various technical approaches that would improve instream flow quantification methods, uncertainty associated with how climate change will influence stream habitat—and how to accurately model those changes—renders any solely technical suggestion inadequate. While many alternative technical approaches offer benefits and improvements, each carries its own shortcomings, and none fix the problems that emerge when water rights are quantified using past observations and static assumptions despite the reality of climate change. Resultantly, lasting solutions require the integration of meaningful technical, legal, and policy improvements. Specifically, assurance of adequate flows moving into an uncertain future requires a shift away from quantifying instream flow water rights for a particular quantity of water without any mechanism for adjustment to address changing conditions.

The most basic—but nonetheless effective—means for improving flow quantification is to provide a legal mechanism whereby a water rights decree may be modified should additional water become necessary to mitigate the impacts of climate change.[188] The ability to modify a decree according to changing conditions is nearly as old as the *Winters* Doctrine itself, with courts long recognizing that "the amount of water specified in the decree should be subject to modification, should the conditions on the reservation at any time require such modification."[189] Modifications could occur on an as-needed basis or after a set period of years—for example, every five or ten years. Adjustment would be predicated on estimates of the amount of water necessary to protect fish habitat based upon data collected in the interim between the adjustment date and the last date the instream flow quantity was set.[190]

Undoubtedly, modifications of reserved water right quantities have gone out of vogue since the U.S. Supreme Court abandoned the concept in *Arizona I*.[191] However, that decision dates from 1963, a time before climate change was well

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[187] BOVEE, A GUIDE TO STREAM HABITAT ANALYSIS, *supra* note 46, at 13.

[188] For a broader discussion of adaptive governance, see generally B. C. Chaffin et al., *A Decade of Adaptive Governance Scholarship: Synthesis and Future Directions*, 19 ECOLOGY & SOC'Y 56 (2014); B. A. Cosens et al., *The Adaptive Water Governance Project: Assessing Law, Resiliance and Governance in Regional Socio-Ecological Water Systems Facing a Changing Climate*, 51 IDAHO L. REV. 1 (2014).

[189] Conrad Inv. Co. v. United States, 161 F. 829, 835 (9th Cir. 1908).

[190] Although in a different context, adjustments of this nature have been employed in Idaho to adjust tribal reserved water rights to account for a lack of information regarding certain competing needs in the Blackfoot River. *See* 1990 Fort Hall Indian Water Rights Agreement, art. 7.18.x.d., July 10, 1990, *ratified by* Fort Hall Indian Water Rights Act of 1990, Pub. L. No. 101-602 § 6(c), 104 Stat. 3059, 3060 (1990).

[191] *See supra* discussion in Part I.

understood.[192] The paradigmatic shift in our understanding of the interrelationship between climate, hydrology, and reserved water rights warrants the reexamination of the Supreme Court's relatively recent insistence on decreeing tribal water rights for a fixed quantity of water. In any case, the Supreme Court has never precluded courts from providing for modifications of decrees. In fact, at least one federal court has explicitly asserted continuing jurisdiction to permit "the [Spokane] Tribe to apply for modification of the judgment on showing of a substantial change in circumstances, unanticipated in the Court's quantification herein, resulting in a need for water greater than the amount reserved for future needs."[193]

Although modifications to water rights decrees introduce uncertainty for non-tribal water right holders, the approach actually rebalances the risks so that uncertainty is shared more equally between tribal and non-tribal stakeholders. Currently, the cost of providing non-Indian water users with the certainty of knowing the exact quantity reserved by senior tribal entities is to force tribes into an uncertain future where they will not know if their water rights will be sufficient. This inequity is particularly acute given that climate change cannot be decoupled from colonialism, which "created both the economic conditions for anthropogenic climate change and the social conditions that limit indigenous resistance and resilience capacity."[194] Indeed, indigenous people "contribute little to greenhouse gas emissions,"[195] and in fact, are some of the world's staunchest protectors of our natural ecosystems.[196] Accordingly, the adjudication process should be recalibrated in such a way that it provides both groups with a reasonable level of certainty that their rights and interests will be protected moving into the future.[197]

A more robust yet technically complex solution would be to provide a mechanism to review minimum flows on an annual basis, given "current yearly

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[192] *See supra* note 28 and accompanying text.

[193] United States v. Anderson, 6 Indian L. Rep. F-129, F-131 (E.D. Wash. 1979).

[194] KATHRYN NORTON-SMITH ET AL., U.S. FOREST SERV., Gen. Technical Rep. PNW-GTR-944, CLIMATE CHANGE AND INDIGENOUS PEOPLES: A SYNTHESIS OF CURRENT IMPACTS AND EXPERIENCES 3 (2016).

[195] *Climate Change and Indigenous Peoples*, INDIGENOUS PEOPLES INDIGENOUS VOICES BACKGROUNDER (U.N. Permanent Forum on Indigenous Issues, New York, N.Y.), 2008, at 2, https://www.un.org/en/events/indigenousday/pdf/Backgrounder_ClimateChange_FINAL.pdf [https://perma.cc/2EP3-PDJG].

[196] *See generally* L. Etchart, *The Role of Indigenous Peoples in Combating Climate Change*, PALGRAVE COMMUNICATIONS (2017).

[197] Further, the decree in *Anderson*—the one modern instance where a reserved water rights decree has been subject to modification—has been reopened and modified once in the forty years since the decree was issued, changing the quantity reserved from 20 cfs to 27 cfs. *Anderson* Modification Order, *supra* note 132, at 1. Like *Anderson*, modifications in other instances would likely be rare, due to the amount of time and resources necessary to reopen a decree. The burden of proof would lie with the party seeking to change the decree, who would have to establish by a preponderance of the evidence (1) that a change in conditions necessitated a modification of the decree; and (2) the amount of additional water necessary as a result of that change. *See, e.g.*, FED. R. CIV. P. 60(b).

considerations and constraints . . . to provide maximum benefits to each of the water demands in the river system."[198] This approach has been successful in the Yakima River Basin, where the Yakima County Superior Court (a Washington state trial court) recognized that fish habitat relied on a number of "variables that may enter in the determination, on an annual basis," including "water quality, *climatic and temperature changes*, changes in substrate locations within the stream, etc."[199] Resultantly, the court found "[i]n view of ever-changing circumstances, it would be inappropriate for the Court to set specific, discrete quantifications . . . for all times and conditions."[200] Instead, the court decreed that flows necessary to maintain fish habitat should be set annually, taking into account the specific physical factors present that year.[201]

Under this approach, PHABSIM could remain the starting point, establishing the annual instream flow target that would establish a healthy and productive habitat in normal hydrological conditions.[202] From there, additional analysis would be necessary to establish lower and higher flow bounds. The lower bound—applied during drought years—would be set at a level that causes stress to fish but allows more water to be used for out-of-stream applications.[203] As this flow is not sustainable over multiple low-flow periods, a limit should be placed on the number of seasons that the lower flows can be applied. A low instream flow year should also be coupled with an optimum flow in the subsequent year, if possible, to provide an opportunity for affected fish populations to recover in more ideal habitat. Similar approaches, based on "turn-taking," where indicators vary yearly, have been

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[198] U.S. BUREAU OF RECLAMATION, INTERIM COMPREHENSIVE BASIN OPERATING PLAN FOR THE YAKIMA PROJECT WASHINGTON 5-1 (2002).

[199] Amendment to Memorandum Opinion Re: Motions for Partial Summary Judgment Dated May 22, 1990 at 58, Dep't of Ecology v. Acquavella, No. 77-2-01484-5 (Wash. Super. Ct., Yakima Cty. Oct. 22, 1990), [hereinafter *Acquavella*, Amended Memo. Opinion (Yakima River)] (emphasis added).

[200] *Id.* at 59.

[201] *Id.*

[202] IFIM was the starting point in the Yakima Adjudication. D. Simmons Aff., *Acquavella (In re Yakima Basin Adjudication)*, *supra* note 132, at 3–4; *see also* Hedden-Nicely, *supra* note 18, at 230–42.

[203] For instance, one regulation that could serve as a model is that of Washington state, which provides:

> Normal year flows must be maintained at all times unless a critical condition is declared by the director. The director, or his designee, may authorize, in consultation with the state departments of fisheries and wildlife, a reduction in instream flows during a critical condition period. At no time are diversions subject to this regulation permitted for any reason when flows fall below the following critical year flows, except where a declaration of overriding considerations of public interest is made by the director.

WASH. ADMIN. CODE § 173-507-020 (2018)

developed for California's highly managed and hydrologically over-allocated Central Valley.[204]

The approach proposed in the preceding paragraph requires the establishment of some entity to set the annual instream flow values. Although this is a role that could be left to the court issuing the decree, a more efficient and conciliatory approach is to establish an independent entity that determines the appropriate flows each year, given prevailing conditions. Entities performing a similar function already exist throughout the United States and have varying powers and duties. For example, because the primary water supplier in Washington's Yakima River Basin is the Yakima Federal Irrigation Project, the instream flows within the watershed are established each year by the Yakima Field Office of the U.S. Bureau of Reclamation.[205] That office determines instream flows in consultation from the System Operations Advisory Committee, which is composed of representatives from the U.S. Fish and Wildlife Service, The Yakama Nation, the Washington Department of Fish and Wildlife, and irrigation entities represented by the Yakima Basin Joint Board.[206]

Perhaps the most politically complex but comprehensive suggestion to date is currently being implemented at the Flathead Reservation in Montana.[207] There, pursuant to a negotiated compact between the Confederated Salish and Kootenai Tribes (CSKT), the State of Montana, and the United States, water management at the Flathead Reservation has been removed from the State and CSKT and has been delegated to the Water Management Board of the Flathead Indian Reservation ("Board"). The Board is "the exclusive regulatory body on the Reservation for the issuance of Appropriation rights and authorizations for Changes in Use of Appropriation Rights and Existing Uses, and for the administration and enforcement of all Appropriation Rights and Existing Uses."[208] The Board is composed of two members selected by the State of Montana, two members selected by the CSKT, and one member selected by the other four members.[209]

Unlike on the Yakama Reservation, the instream flow water rights at the Flathead Reservation are for particular quantities of water.[210] However, the CSKT's

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[204] *See generally* Clint A. D. Alexander et al., *Improving Multi-Objective Ecological Flow Management with Flexible Priorities and Turn-Taking: A Case Study from the Sacramento River and Sacramento–San Joaquin Delta*, 16 S.F. ESTUARY & WATERSHED SCI. Article 2 (2018).

[205] U.S. BUREAU OF RECLAMATION, *supra* note 198, at 5-34.

[206] *Id*. at 5-1.

[207] MONT. CODE ANN. § 85-20-1902 (2017).

[208] Proposed Water Rights Compact Entered into by The Confederated Salish and Kootenai Tribes, the State of Montana, and the United States of America [herineafter Flathead Water Compact], art. IV.I.1. (2015), *ratified by* 2015 Mont. Laws 294 (codified at MONT. CODE ANN. § 85-20-1901 (2019)). A bill has also been introduced to rarify the compact at the federal level. *See* Montana Water Rights Protection Act, S. 3019, 116th Cong. (2019).

[209] Flathead Water Compact, *supra* note 208, art. IV.I.2.

[210] *See id.* app. 10–12.

active role in water management on the Flathead Reservation provides greater certainty that it can take necessary measures to balance instream and consumptive water uses within the reservation. For example, the Board can take a more cautious approach to allocating new water rights and/or require more stringent water conservation measures to mitigate the potential that the water rights in a particular basin may become overallocated as a result of climate change. The experience at the Flathead Reservation also highlights the opportunities that settlement rather than litigation provide for all stakeholders in a water rights dispute.

Importantly, any combination of the specific approaches from the Spokane, Yakima, and Flathead Reservations could be employed to meet the unique characteristics of a given watershed. The approaches used on these three reservations could also be combined with other widely accepted management techniques to reduce or mitigate depletions caused by junior consumptive out-of-stream uses. Today, the primary legal mechanisms by which senior water rights owners may protect their interests are through traditional prior appropriation principles. The cornerstone of prior appropriation continues to be that those whose rights are first in time are first in right; that is, older water rights have priority over junior water rights.[211] At its core, the system is quite harsh; there is no requirement to impose water conservation measures when the water supply is insufficient for all users.[212] Consequently, the more junior water rights-holders often receive the brunt of the consequences in times of shortage. However, considerable attention has been dedicated to the development of technical and legal reforms to mitigate the harshness of prior appropriation and to help conserve water resources. Reforms that have been developed in recent decades include storage projects,[213] voluntary water marketing

[211] ANTHONY DAN TARLOCK & JASON ANTHONY ROBISON, LAW OF WATER RIGHTS AND RESOURCES § 5:32 (2019); *see also* COLO. REV. STAT. § 37-92-301 (2019); IDAHO CODE § 42-607 (2019); MONT. CODE ANN. § 85-2-406 (2019); NEV. REV. STAT. § 533.305 (2019); UTAH CODE ANN. § 73-5-3 (2019); WASH. REV. CODE § 90.03.010 (2019); WYO. STAT. ANN. § 41-3-101 (2019).

[212] TARLOCK & ROBISON, *supra* note 211, § 5:32.

[213] *Id.* § 5:39.

or water banks,[214] managed aquifer recharge,[215] conservation incentives,[216] water transfers to increase water use efficiency,[217] and habitat mitigation that does not require water use such as stream restoration efforts to stabilize and shade streams.[218]

For example, a decree could remain open as a worst-case-scenario, stopgap measure while also providing for the annual management by a technical working group of instream flows to address more mild fluctuations in water supply. The group tasked with determining those flows could also make recommendations on annual water banking and aquifer recharge rates, as well as conservation incentives. Water banks "are institutional mechanisms through which water rights holders can safely deposit unneeded rights into a regulated account, and people who need water can lease it from the account at a fair market-rate on a temporary basis."[219] In water-rich years, water could be banked in aquifers or reservoirs at a higher rate without interrupting necessary instream flows or consumptive water needs.[220] During times of drought, at least some of that banked water would be available to augment irrigation, thereby leaving additional water in the streams. The group could also recommend incentives for irrigators and other large water users to reduce their consumption. Over time, such a group would develop sufficient on-the-ground expertise to understand whether the instream water resource could be improved

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[214] *Id.* § 5:40.

[215] *See, e.g.*, KATJA LUXEM, AMERICAN GEOSCIENCES INST., Case Study 2017-002, MANAGED AQUIFER RECHARGE IN CALIFORNIA (2017); KATJA LUXEM, AMERICAN GEOSCIENCES INST., Case Study 2017-006, MANAGED AQUIFER RECHARGE: A TOOL TO REPLINISH AQUIFERS AND INCREASE UNDERGROUND WATER STORAGE (2017); Joel Casanova et al., *Managed Aquifer Recharge: An Overview of Issues and Options*, *in* INTEGRATED GROUNDWATER MANAGEMENT: CONCEPTS, APPROACHES AND CHALLENCES (Anthony J. Jakeman et al. eds., 2016); Peter Dillon & Muhammad Arshad, *Managed Aquifer Recharge in Integrated Water Resource Management*, *in* INTEGRATED GROUNDWATER MANAGEMENT: CONCEPTS, APPROACHES AND CHALLENGES (Anthony J. Jakeman et al. eds., 2016).

[216] *See generally* Craig Bell, *Promoting Conservation by Law: Water Conservation and Western State Initiatives*, 10 U. DENV. WATER L. REV. 313 (2007) (noting examples of various water conservation incentive programs throughout the West).

[217] TARLOCK & ROBISON, *supra* note 211, at §§ 5:74–86.

[218] *See, e.g.*, Nez Perce Tribe et al., Mediator's Term Sheet § II(B) (April 20, 2004), *ratified by* Consolidated Appropriateions Act of 2005, Pub. L. No. 108-447, tit. X, 118 Stat. 2809, 3431–41 (2004).

[219] Cedar Q. Cosner, *Water Banking: A Distribution Solution*, 34 NAT. RESOURCE & ENV'T 58, 58 (2019).

[220] In making this suggestion, the authors note that—although beyond the scope of this Article—there remains a strong water *quality* component to managed aquifer recharge that should be fully considered before proceeding to inject surface water into the ground. *See generally* Kelly L. Warner et al., *Interactions of Water Quality and Integrated Groundwater Management: Examples from the United States and Europe*, *in* INTEGRATED GROUNDWATER MANAGEMENT: CONCEPTS, APPROACHES AND CHALLENGES (Anthony J. Jakeman et al. eds., 2016)

through stream restoration, or whether water management in the basin would benefit from the purchase, retirement, and/or transfer of certain consumptive water rights.

The CSKT joint-management approach goes one step further by vesting in a single entity the authority not only to make annual recommendations but to comprehensively manage the water resource in the basin. Under this approach, the decision-making body would be a joint board consisting of state and tribal officials, which could go beyond planning on an annual basis and develop a long-term comprehensive management strategy—only one facet of which would be instream flows—that better positions all water users in times of shortage. That long term strategy could include any combination of traditional mitigation techniques that best suits the particular needs of the basin. For example, the joint board could employ the same combination of water banking, aquifer recharge, and conservation incentives mentioned above, but on a ten- or twenty-year time horizon.

Further, since such a joint board would be vested with management authority, it can do more than simply make recommendations to be adopted—or not—in a piecemeal fashion by state, tribal, and federal managers. Instead, the joint board would be the ones adopting and implementing policy. Rather than recommend that certain water rights be purchased or that a certain restoration project be undertaken, it can move forward and implement new policies and management decisions if it determines that they are consistent with the public interest.

Most importantly, the tribes would become active water managers, able to ensure the protection of the aquatic habitat that was expressly preserved by their ancestors.[221] That leadership role would allow Western tribes to move away from reliance on monolithic instream water rights that may not be necessary to protect instream habitat in every situation but could cause significant hardship to non-Indian water users. The combination of these approaches described above would result in a streamlined management process that is comprehensive, consistent, and fair. Adaptive and streamlined management protects not only tribal instream water rights but also the water rights of all users in the basin.

Undoubtedly, any approach that requires active management of instream flows and consumptive uses in a river basin will be time-consuming and expensive. The approach requires an intricate understanding of (1) the hydrology and the consumptive water requirements of the basin; (2) how climatic conditions will drive water availability on a seasonal basis; and (3) the appropriate decision-making process that best balances the consumptive water needs against instream flows. However, the flexibility created by such an approach could strike a more appropriate balance in many watersheds than current practices. Unlike the classic prior appropriation system—which requires junior users to cease using water entirely should minimum flows not be met—annual adjustment to the minimum flow could allow for more flexibility in any given year for junior non-Indian appropriators during times of drought. Likewise, providing an upper bound to the minimum flow, as well as an active role in the management of consumptive uses, would provide

[221] *See supra* Part I.

tribal water users with more certainty that instream flows will be sufficient to meet their needs in the long term.

VIII. CONCLUSION

Climate change is ongoing and has real and direct influences on stream hydrology, morphology, and biology. As a result, quantities of water that may currently sustain habitats for salmonid populations will likely become insufficient in the near future. Native American tribes in the Northwestern United States have reserved rights to take fish that are recognized and protected under federal law. Those fishing rights include the reserved right to sufficient quantities of water to ensure the continued existence of healthy fish populations that are of traditional, cultural, subsistence and/or economic importance to the tribes.

The most common methodology used to quantify reserved instream flow water rights is the IFIM/PHABSIM method. The IFIM methodology is a flexible approach that is capable of including a range of hydrological parameters—depth, velocity, substrate—as well as biological indicators such as water temperature and quality. However, in practice, most reserved water rights are quantified using only the basic PHABSIM parameters of depth, velocity, and substrate.

Stream depth, velocity, and substrate are highly sensitive to climate change. Further, the omission of important biological indicators predicted to be influenced by climate change, particularly temperature, leads to predictions of fish performance that will become increasingly inaccurate—to an unquantified degree—moving into the future. Strengthening the utility of PHABSIM by including temperature and other biologically relevant endpoints would help mitigate some of this uncertainty regarding predicting fish population performance. Although we focus here on PHABSIM's sensitivity to climate change, we stress that our observations are generally applicable to *any methodology* that purports to model complex climatologically driven systems based solely on current or past observations. Indeed, the high variability associated with how streams will react to climate change renders any wholly technical solutions that include static instream water rights inadequate and technically inappropriate.

Instead, reserved instream water rights should be decreed in a flexible manner that allows for adjustment should climate change render previously adequate water quantities insufficient. Many such solutions are already being implemented throughout the Northwestern United States and include provisions for reopening decrees to allow for more water if necessary, as well as annual adjustments to instream flows to account for prevailing climatic conditions. Ultimately, the only way to adequately ensure the protection of tribal rights and resources is for American Indian tribes to be placed on equal footing with states and the federal government by recognizing tribes as equal partners in water resource management throughout their territories.