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Assessing System Resilience and Ecosystem Services in Large River Basins: A Case Study of the Columbia River Basin

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ASSESSING SYSTEM RESILIENCE AND ECOSYSTEM SERVICES IN LARGE RIVER BASINS: A CASE STUDY OF THE COLUMBIA RIVER BASIN[1]

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1. This research is part of a synthesis project on Social-ecological System Resilience, Climate Change, & Adaptive Water Governance, co-chairs Cosens, B. and Gunderson, L., with the National Socio-Environmental Synthesis Center (SESYNC) under funding from the National Science Foundation DBI-1052875.

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I. INTRODUCTION

The economic life and the health of society depend on the services provided by large river basins. Throughout the world, widespread development and modification of river basins has resulted in highly stressed ecosystems and societal dependence on engineered services (i.e. the use of infrastructure such as dams and diversions to maximize certain uses of the river) that may be reaching their maximum capability in delivery.[2] These water-based social-ecological systems (SESs) are particularly vulnerable to climate change.[3] The complexity of river basins is reflected not only in the biophysical system and the provisioning of ecosystem services, but in societal interaction with these systems, particularly water governance.[4] In the face of change, water governance must become adaptive. Improvement in the capacity of these social-ecological systems to adapt through changes in governance begins with understanding the system-wide effects of past changes and the evolution of social interaction with the basin's ecological system. As part of the Adaptive Water Governance Project,[5] this article explores the resilience of the Columbia River Basin's social-ecological system to climate change. It begins with an overview of its theoretical background and methodology, and proceeds to a basin characterization. The article then presents a resilience assessment of the Basin following methods developed by Brian Walker and David Salt[6] and by the Resilience Alliance,[7] but modified to include ecosystem services concepts as a means to discuss system properties.[8] This study takes place in the face of a key window of opportunity[9] for change brought about by expiration of certain provisions of a treaty between

2. *See generally* BLANCA E. JIMÉNEZ CISNEROS ET AL., FINAL DRAFT OF CHAPTER 3: FRESHWATER RESOURCES IN CLIMATE CHANGE 2014: IMPACTS, ADAPTATION, AND VULNERABILITY 22 (Pavel Kabat & Zbigniew Kundzewicz eds., 2013), http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap3_FGDall.pdf.

3. *Id.*; Barbara Cosens et al., *Identifying Legal, Ecological and Governance Obstacles, and Opportunities for Adapting to Climate Change*, 6 SUSTAINABILITY 2338, 2345 (2014), http://www.mdpi.com/2071-1050/6/4/2338/pdf

4. Cosens et al. 2014, *supra* note 3, at 2346; Dave Huitema et al., *Adaptive Water Governance: Assessing the Institutional Prescriptions of Adaptive (Co-)Management from a Governance Perspective and Defining a Research Agenda*, 14 No. 1 ECOLOGY & SOC'Y Art. 26 (June 2009), *available at* http://www.earthsystemgovernance.org/sites/default/files/publications/files/Huitema-et-al_2009_Adaptive-water-governance.pdf.

5. Barbara Cosens & Lance Gunderson, *Social-ecological System Resilience, Climate Change, & Adaptive Water Governance*, SESYNC, http://www.sesync.org/project/water-people-ecosystems/adaptive-water-governance (last visited Nov. 4, 2014).

6. *See generally* BRIAN WALKER & DAVID SALT, RESILIENCE PRACTICE: BUILDING CAPACITY TO ABSORB DISTURBANCE AND MAINTAIN FUNCTION (2012).

7. *See generally* RESILIENCE ALLIANCE, ASSESSING RESILIENCE IN SOCIAL-ECOLOGICAL SYSTEMS: A WORKBOOK FOR SCIENTISTS (2007), http://www.resalliance.org/index.php/resilience_assessment.

8. John W. Day Jr. et al., *Ecology in Times of Scarcity*, 59 BIOSCI. 321 (2009), http://yosemite.epa.gov/sab/sabproduct.nsf/07D11497DA74AB79852575AD005950EA/$File/JDay+et+al+2009+Bio+Sci+Article+for+May+14-15+2009+INC+Mtg.pdf.

9. Per Olsson et al., *Shooting the Rapids: Navigating Transitions to Adaptive Governance of Social-Ecological Systems*, 11 No. 1 ECOLOGY & SOC'Y Art. 18 (Mar. 2013), *available at*, http://www.ecologyandsociety.org/vol11/iss1/art18/ (citing J. W. KINGDON, AGENDAS, ALTERNATIVES, AND PUBLIC POLICIES 4, 8 (1995), which describes a window of opportunity as a "critical moment in time between the two phases . . . [characterized by a moment when] three independently operating 'streams,' i.e., problems, solutions, and politics, come together at critical times . . .").

the United States and Canada,[10] and the review process both countries have begun.[11] Although focused on system-wide perturbation resulting from climate change as a thought experiment, this article will view that change in light of this current window of opportunity.

II. THEORETICAL BACKGROUND

In any effort to convey the results of an interdisciplinary project to audiences from multiple disciplines, it is worthwhile to step back and consider the assumptions underlying our approach. That is, why did we choose river basins to consider adaptive governance? What viewpoints and methods do ecologists and resilience scholars bring to the problem that will inform a legal analysis of river basin governance and vice versa, and what are the meanings of the important terminology? We begin with river basins.

A. Why River Basins?

The river basin is a system with clear geographic boundaries,[12] making it a definable unit of study. In an effort to inform governance of complex systems of closely integrated human and environment interaction (i.e. a social-ecological system) rivers are an archetype system. Rivers carry the water on which life and commerce depend. By its very nature, the network of rivers in a basin connects the parts of the system through which water flows. River networks span ecological zones ranging from high alpine to estuarine.[13] River networks run through multiple jurisdictions without regard for political or cultural differences.[14] Society relies on goods and services from river ecosystems (i.e. ecosystem services).[15] These river ecosystems are themselves reliant on processes within the ecosystem that are connected across many scales.[16] Finally, because climate change has direct effects on water supply and the corresponding riverine ecosystem, rivers are ground zero for the test of society's ability to adapt.[17]

Most river systems, and certainly all North American systems in the Adaptive Water Governance study, are highly engineered to enhance the provision of ser-

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10. Columbia River Basin: Cooperative Development of Water Resources, U.S.-Can., Jan. 17, 1961, 15 U.S.T. 1555.

11. *See* U.S. Army Corps of Eng'rs & Bonneville Power Admin., *Columbia River Treaty: 2014/2024 Review,* COLUMBIA RIVER TREATY, http://www.crt2014-2024review.gov/ (last visited Nov. 4, 2014).

12. *See, e.g.*, Hydrologic Unit Maps, U.S. GEOLOGICAL SURVEY, http://water.usgs.gov/GIS/huc.html (last visited Nov. 4, 2014).

13. Lee Benda et al., *The Network Dynamics Hypothesis: How Channel Networks Structure Riverine Habitats*, 54 BIOSCI. 413, 423 (2004), *available at* http://sites.nicholas.duke.edu/martindoyle/files/2013/01/Benda-et-al-2004-Bioscience-Session-5.pdf.

14. *See, e.g.*, OR. STATE U., *The Transboundary Freshwater Dispute Database*, C. EARTH, OCEAN & ATMOSPHERIC SCIS., http://www.transboundarywaters.orst.edu/database/ (last visited Nov. 4, 2014) (archiving agreements from 276 water basins that cross international boundaries).

15. Alexander K. Fremier et al., *Understanding Spatiotemporal Lags in Ecosystem Services to Improve Incentives*, 63 BIOSCI. 472, 472–73 (2013), *available at* http://www.bioversityinternational.org/uploads/tx_news/Understanding_spatiotemporal_lags_in_ecosystem_services_to_improve_incentives_1688_01.pdf .

16. *Id.*

17. *Id.* at 472.

vices considered central to society at the time of development—as described below for the dam building era on the Columbia River—yet this effort to optimize certain variables (e.g. hydropower production) [18] has rendered river systems vulnerable to disturbance that is outside the range of predicted change by reducing their room to adapt (i.e. reduced their resilience).[19] Exacerbating this reduction in resilience is the change in societal interests regarding the benefits of environmental protection since twentieth century development occurred. Changing values and growing recognition of the ecosystem services a river system provides have led stakeholders to seek solutions that enhance benefits ranging from hydropower, flood control, navigation, irrigation, to water quality, fisheries and recreation, while at the same time, improving ecosystem integrity.[20] The search for solutions is complicated by the intrinsic complexity of river systems with social and ecological drivers at multiple scales.[21] To capture this complexity, resilience theory provides a systems approach to aid in framing this search and ecosystem services provide a construct through which ecosystem function can be viewed in socially relevant terms.

B. Why Resilience?

Resilience as applied to ecological systems addresses the ability of the system to continue to provide, or return to a state in which it will provide, a full range of ecosystem services in the face of change.[22] Resilience is a term that describes a property of a complex systems such as an ecosystem: that rather than displaying a continuous range, complex systems organize into discrete stable states or regimes; that multiple alternative regimes are possible for any system (a regime being a particular structure and function of an ecological system);[23] that a regime exists within a certain degree of variability; that a perturbation may result in a regime shift (i.e.

18. William L. Graf, *Dam Nation: A Geographic Census of American Dams and Their Large-Scale Hydrologic Impacts*, 35(4) WATER RESOURCES RES. 1305 (1999), *available at* http://scholarcommons.sc.edu/cgi/viewcontent.cgi?article=1052&context=geog_facpub.

19. *See generally* BRIAN WALKER & DAVID SALT, RESILIENCE THINKING: SUSTAINING ECOSYSTEMS AND PEOPLE IN A CHANGING WORLD 141 (2006) [hereinafter WALKER & SALT II] (discussing generally the impact of management for optimization on ecological resilience); Barbara Cosens, *Transboundary River Governance in the Face of Uncertainty: Resilience Theory and the Columbia River Treaty*, 30 J. LAND RESOURCES & ENVTL. L. 229, 239 (2010) (discussing optimization in the context of river basin management); SIMON A. LEVIN, FRAGILE DOMINION: COMPLEXITY AND THE COMMONS (1999).

20. *See, e.g.*, *Columbia River Treaty: 2014/2024 Review*, *supra* note 11; U.S. ARMY CORPS OF ENG'RS & BONNEVILLE POWER ADMIN., U.S. ENTITY REGIONAL RECOMMENDATION FOR THE FUTURE OF THE COLUMBIA RIVER TREATY AFTER 2024 (2013), *available at* http://www.crt2014-2024review.gov/Files/Regional%20Recommendation%20Final,%2013%20DEC%202013.pdf. *See generally*, Giulio A. De Leo & Simon Levin, *The Multifaceted Aspects of Ecosystem Integrity,* 1 No. 1 Ecology & Soc'y Art. 3 (June 1997), *available at* http://www.ecologyandsociety.org/vol1/iss1/art3/vol1-iss1-3.pdf.

21. *See generally* Graeme S. Cumming, *The Resilience of Big River Basins,* 36 WATER INT'L 63 (2011).

22. *See, e.g.*, C.S. Holling, *Resilience and Stability of Ecological Systems*, 4 ANN. REV. ECOLOGY & SYSTEMATICS 1, 1–3 (1973); PANARCHY: UNDERSTANDING TRANSFORMATIONS IN HUMAN AND NATURAL SYSTEMS (Lance H. Gunderson & C.S. Holling eds., 2nd ed. 2002); Brian H. Walker et al., *Resilience, Adaptability and Transformability in Social–ecological Systems*, 9 No. 2 ECOLOGY & SOC'Y Art. 5 (, Dec. 2004) at art. 5, *available at* http://ecologyandsociety.org/vol9/iss2/art5; WALKER & SALT II, *supra* note 19.

23. Note, we also use the term regime shift in the context of social systems, and although collapse and transformation of social systems is documented, there is not (at least at this point) a clearly defined finite set of alternative states.

shift from one alternative state to another, such as lake eutrophication leading to cyanobacteria outbreaks); and that once a regime shift occurs, it is much more difficult to recover (or restore) the original structure and function.[24] Thus "resilience"—the quantum nature of ecological and social-ecological systems—is a property of the system, and allows us to approach complex systems from the viewpoint of their ability to continue to provide key functions and maintain supporting structure in the face of change.[25] It provides a framework for environmental management of non-stationary systems by focusing attention on achieving societal goals without simplification of the processes that support ecosystem function, and in fact, by supporting those processes rather than optimizing for a single output such as hydropower.[26] Resilience theory ties society's response to change in an ecological system to the complex feedbacks between the social and ecological system.[27]

Resilience in this context is value neutral.[28] The term resilience has been picked up by the development and disaster response literature to describe whether and how quickly a community may recover from a crisis.[29] Thus, it has become a normative term in which resilience (good) contrasts with vulnerability (bad). This is appropriate for understanding whether communities are prepared to respond to a disaster. But for long-term management of a social-ecological system, the value neutral definition used by ecologists[30] is a better fit. To illustrate the difference between the term resilience as it is used in the disaster response literature versus the literature of social-ecological systems, consider a community trapped in poverty. The disaster response literature would find the community to be vulnerable and therefore not resilient. Applying the ecology-based definition, the community is both resilient, due to the difficulty of moving it out of the poverty regime, and vulnerable. If the question we seek to answer is not how communities will respond to a single disaster, but how society can co-exist with a functioning ecosystem that provides the necessary services over the long term or adapt when it is inevitable that the system will transform to a new state, then the ecological resilience definition is appropriate. Using this lens, it is therefore imperative when discussing the resilience of a social-ecological system to ask *the resilience of what, to what*? This case study explores the resilience of the ecosystem services provided by the Columbia River Basin to climate change. Before turning to the study, we must explain our use of the concept of ecosystem services.

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24. *See generally* Holling, *supra* note 22, at 19–20; PANARCHY, *supra* note 22; Walker, *supra* note 22; WALKER & SALT II, *supra* note 19.

25. *See generally* Holling, *supra* note 22; Walker, *supra* note 22; WALKER & SALT II, *supra* note 19.

26. *See generally* Holling, *supra* note 22; Walker, *supra* note 22; WALKER & SALT II, *supra* note 19.

27. C.S. Holling & Lance H. Gunderson, *Resilience and Adaptive Cycles*, *in* PANARCHY: UNDERSTANDING TRANSFORMATIONS IN HUMAN AND NATURAL SYSTEMS 25 (Lance H. Gunderson & C.S. Holling eds., 2nd ed. 2002).

28. *See* Holling, *supra* note 22, at 8; Walker, *supra* note 22; WALKER & SALT II, *supra* note 19.

29. *See, e.g.*, FED. EMERGENCY MGMT. AGENCY, CRISIS RESPONSE AND DISASTER RESILIENCE 2030: FORGING STRATEGIC ACTION IN AN AGE OF UNCERTAINTY: PROGRESS REPORT HIGHLIGHTING THE 2010-2011 INSIGHTS OF THE STRATEGIC FORESIGHT INITIATIVE (2012), *available at* http://www.fema.gov/media-library-data/20130726-1816-25045-5167/sfi_report_13.jan.2012_final.docx.pdf.

30. *See* Holling, *supra* note 22; Walker, *supra* note 22; WALKER & SALT II, *supra* note 19.

C. Why Ecosystem Services?

Ecosystem services are the benefits humans get from ecosystems.[31] Thus they bridge the ecological and social system by describing a subset of ecosystem processes that have direct human and economic value. Humans depend upon ecosystem structures and processes to provide a range of vital services: some for the provisioning of water and food, others for regulating environmental extremes, such as floods, yet others for cultural value including spiritual and recreation, and finally others to more indirectly support water quality and nutrient cycling.[32] The term "ecosystem services" is generally used to refer to natural services, both biological (e.g. wild fisheries and pollination) and physical or spatial, such as naturally functioning floodplains, habitat connectivity for migration,[33] and flow regimes that allow for engineering of storage and production of hydropower.[34] However, in highly modified basins the definition is blurred between natural and engineered (Table 1).[35] For example, the seasonal flow regime in the Columbia River is impacted by watershed processes and can have significant impact on power generation;[36] here, the natural service of water capture and flow assists the provisioning of the engineered services of power production. The EPA terms this mixture of engineering and natural features "green" infrastructure, distinguishing it from entirely engineered "gray" infrastructure.[37] Dependence of the engineered service on the natural features leads many to include green infrastructure in the category of ecosystem services.[38] The ability to build gray infrastructure and rely on green infrastructure depends on the basin context, and both have specific implications for system resilience.[39] In our resilience assessment methodology described below, we include the full range of natural and engineered services to allow us to assess the tradeoffs that occurred as humans increasingly engineered the Columbia River and to guide our consideration of changes that may increase the range of adaptation options in the face of climate change.

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31. MILLENNIUM ECOSYSTEM ASSESSMENT, ECOSYSTEMS AND HUMAN WELL-BEING: A FRAMEWORK FOR ASSESSMENT 49 (2003), *available at* http://www.millenniumassessment.org/documents/document.300.aspx.pdf.

32. *See generally id.*

33. Alexander K. Fremier et al., *A Riparian Conservation Network to Build Ecological Resilience* (in prep).

34. *See generally* Day, *supra* note 8; MILLENNIUM ECOSYSTEM ASSESSMENT, *supra* note 31.

35. Jos Brils et al., *Ecosystem Services and River Basin Management, in* RISK-INFORMED MANAGEMENT OF EUROPEAN RIVER BASINS 265–94 (Jos Brils et al. eds., 2014).

36. USACE, BPA, and BC Hydro. 2010. *Columbia River Treaty 2014/2024 Review: Phase 1 Report. available at* http://www.crt2014-2024review.gov/.

37. U.S. EPA, GREEN INFRASTRUCTURE IMPLEMENTATION STRATEGY FOR THE TOWN OF FRANKLIN, MASSACHUSETTS: AN EVALUATION OF PROJECTS, PROGRAMS, AND POLICIES 1–2 (2014), *available at* http://water.epa.gov/infrastructure/greeninfrastructure/upload/Franklin_Report.pdf ("Green infrastructure is an approach that communities can choose to maintain healthy waters, provide multiple environmental benefits and support sustainable communities. Unlike single-purpose gray stormwater infrastructure, which uses pipes to dispose of rainwater, green infrastructure uses vegetation and soil to manage rainwater where it falls. By weaving natural processes into the built environment, green infrastructure provides not only stormwater management, but also flood mitigation, air quality management, and much more.").

38. See, e.g, *Ecosystem Services and Green Infrastructure*, URBAN GREENSPACES INST., http://www.urbangreenspaces.org/ecosystem (last visited Nov. 4, 2014).

39. *See* U.S. EPA, *supra* note 37, at 1-3.

	Properties	**Processes**
Natural Services		
Water flow regulation	Timing of flow and magnitude	Storage as snow, storage in floodplains, infiltration into soil
Water quality regulation	Cool, clean water	Soil infiltration, bank protection by riparian vegetation, in-stream filtration
Fisheries	Healthy stocks of wild anadromous and resident fish	Habitat for key life history stages, including appropriate water temperatures, water quality, and stream geomorphology and productivity.
Recreation	Scenic beauty, fishing, discovery	Natural, clean, and accessible places
	Properties	**Processes**
Combined Natural and Engineered Services		
Energy production	Dams	Power production is dependent on flow magnitude and timing; sediment flows to reservoirs
Transportation	Locks	Change in water levels to enable transport of goods upstream and down
Recreation	Reservoirs—boating, fishing, etc.	Reservoirs create places to recreate but also require clean waters
Hatcheries	Hatchery-raised fish released and transported within basin	Fish raised in hatcheries are released into streams to rear and out-migrate
Engineered Services		
Flood control	Dams, levees	Flood protection influence by water residence time in watershed
Crop production	Irrigation and fish farms	Water for food production depends on available water flows

TABLE 1. Ecosystem Services for the Columbia River Basin

Environmental degradation tends to reduce the rates of service provisioning while human infrastructure (dams, levees, etc.) masks the importance of natural ecosystem services and reduces the system's resilience.[40] For example, the replacement of flood control services provided by a wetland with a dam or levee reduces the vulnerability of the human population to flood, but also removes the water quality benefits provided by filtration of water through a wetland.[41] This indirect benefit of filtering is less likely to be noticed than the direct benefit of reduction in flood risk, but is nevertheless a loss of service to society. This tradeoff between engineered and natural ecosystem services means that it is crucial to strike a balance between maintaining natural services and human-engineered. Some ecosystem services are in the economic domain, and are likely to exhibit tight feedbacks to governance, meaning that decision makers are quickly aware of changes or problems within the system due to immediate impact and thus, have direct incentives to act, as is the case with floods.[42] Others are indirectly related to human needs and result from diffuse processes that cross jurisdictional boundaries and have proved difficult to govern effectively (e.g., water quality).[43] Further, ecosystems are temporally dynamic, as demonstrated by the seasonal, year-to-year, and decadal cycles in pest outbreaks, wild fire, and floods.[44] This dynamic and seemingly random system behavior results in weak feedbacks to governance, and reduces the likelihood that these processes will be effectively protected.[45] From this perspective, our analysis aims to integrate ecological and legal perspectives to inform a governance of dynamic and complex social-ecological systems.

For this analysis we focus on services at the basin scale, referencing the social-ecological drivers and processes above and below this scale of focus (Table 1). By integrating concepts of ecosystem services, we classify historical periods of basin development in terms of critical transitions in society's understanding and interest in different ecosystem processes and functions, allowing us to understand the relation between basin development and its social-ecological resilience. It is through the integration of resilience theory and ecosystem services that we examine the Columbia River Basin's recent history to help understand its complex social-ecological dynamics.

III. METHODOLOGY: RESILIENCE ASSESSMENT

40. Stephen R. Carpenter, et al., *Science for Managing Ecosystem Services: Beyond the Millennium Ecosystem Assessment*, 106 PROC. NAT'L ACAD. SCI. U.S. 1305, 1305–12 (2009), *available at* http://www.pnas.org/content/106/5/1305.full.

41. U.S. EPA, EPA 843-F-01-002C: FUNCTIONS AND VALUES OF WETLANDS (2001), *available at* http://water.epa.gov/type/wetlands/upload/2006_08_11_wetlands_fun_val.pdf.

42. The concept of "tight feedbacks" refers to the timing and directness of human detection of change in the ecosystem coupled with a perceived need to respond. *See, e.g.*, Kristine T. Nemec et al., *Assessing Resilience in Stressed Watersheds*, 19 No. 1 ECOLOGY & SOC'Y Art. 34 (2013), *available at* http://www.ecologyandsociety.org/vol19/iss1/art34/.

43. Kate A. Brauman et al., *The Nature and Value of Ecosystem Services: an Overview Highlighting Hydrologic Services,* 32 ANN. REV. ENV'T & RES. 67, 67–98 (2007), *available at* http://www.annualreviews.org/doi/pdf/10.1146/annurev.energy.32.031306.102758.

44. *See, e.g.*, TEMPORAL DYNAMICS AND ECOLOGICAL PROCESS (Colleen K. Kelly, et al. eds., 2013).

45. *See generally* Fremier et al., *supra* note 15.

A. Basin Characterization

Characterization of a river basin begins with a definition of the basin boundaries. We defined the Columbia River Basin hydrological basin as our unit of study using the US Geological Survey's National Hydrography Dataset (NHD+) (670,000 sq. km, Figure 2).[46] As defined, the Columbia River Basin includes large parts of Idaho, Washington, Oregon, the lower portion of British Columbia, Canada, a smaller portion of Montana, and much smaller areas in Wyoming, California, Nevada, and Utah. We did not include the smaller coastal ocean-draining watersheds, particularly the watersheds around Puget Sound, because they are not directly connected hydrologically to the large Columbia River Basin water resources system.

Although we define the Columbia River Basin boundaries hydrologically, recognizing the external (referred to as "cross-scale" in the resilience literature[47]) influences is important for assessing resilience. Such external influences occur at multiple scales, but for our purposes we chose the Columbia River Basin (CRB) as the unit of scale, and look to coarser and finer scales to describe drivers important at the CRB scale.[48] For example, the economic region includes the coastal cities of Vancouver, British Columbia, and Seattle, which are located outside the Basin, as well as inland cities across the continental divide.[49] In addition, the Columbia River hydropower system is integrated with the energy transmission grid down the West Coast to Southern California and Arizona.[50] Both the province of British Columbia and the United States participate in river management,[51] but both cover geographic regions much larger than the hydrologically defined basin itself.

Once the unit of scale is defined, the resilience assessment begins with a basin characterization accomplished through literature review of the changes in social interaction with the riverine ecosystem of the Columbia River Basin over time.[52] This will provide the basis for identification of historic eras for the purposes of assessing (1) changes in cross-scale interaction for purposes of water governance, and (2) the changes in resilience over time.[53] The history of the Columbia River Basin is complex and there are likely many ways to divide historic eras; we have chosen the dividing points (detailed below and in Table 3) to represent changes in interaction between the social and ecological system that are manifest in changes to river governance, use, or development. In addition, we have chosen historic eras that continue to have legacy effects today.

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46. *Paul R. Seaber et al., Hydrologic Unit Maps: United States Geological Survey Water-Supply Paper 2294 1 (1987), available at http://pubs.usgs.gov/wsp/wsp2294/pdf/wsp_2294.pdf.*

47. *See* Craig Anthony (Tony) Arnold & Lance Gunderson, *Adaptive Law and Resilience*, 43 ENVTL. L. REP. 10,426 (2013), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2225619.

48. WALKER & SALT, *supra* note 6, at 17 (describing the process of assessing influences at the scale both above and below the scale of focus).

49. *About Us: Background & History*, PAC. NORTHWEST ECON. REGION, http://www.pnwer.org/about-us.html (last visited Nov. 5, 2014).

50. Pacific Northwest Consumer Power Preference Act, 16 U.S.C. § 837(g)-1 (2006).

51. Treaty Relating to Cooperative Development of the Water Resources of the Columbia River Basin, U.S.-Can., Jan. 17, 1961, 15 U.S.T. 1555 [hereinafter Columbia River Basin Treaty].

52. Resilience Alliance, *supra* note 7, at 7.

53. *Id.* at 7–8.

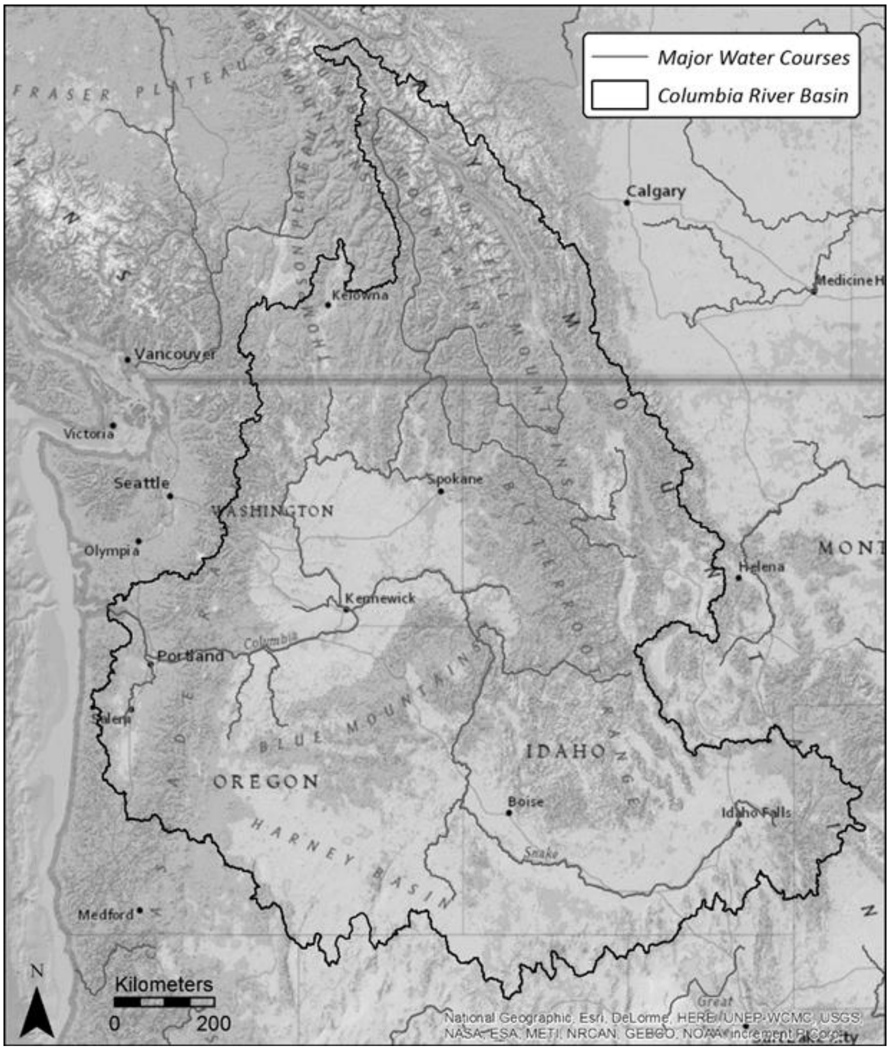

FIGURE 1. Map of the hydrologically defined Columbia River Basin

B. Assessment of Resilience

To apply the concept of resilience to a specific context we must not only ask, "The resilience of what to what?," but also, "When?"[54] Historical analyses of the Columbia River Basin reveal relatively discrete eras in basin development, reflecting the dominant societal values of the time; these eras are marked by transitions of relatively short duration reflecting either a change in the makeup of the dominant society, its core values, or the technology available to interact with the river sys-

54. *See* RESILIENCE ALLIANCE, *supra* note 7, at 19–20.

tem.[55] To identify the changes in resilience over time, we first assess resilience within each of these eras. The values placed on various ecosystem services and the addition of engineered services will define the "resilience of what" for each time period. For historical analysis, the question of "resilience to what" is answered by the historic record. However, our final assessment of the resilience going forward must be cast in terms of resilience to the specific driver of change.

The resilience of the Columbia River Basin going forward is viewed in the context of a key driver of change—climate and its resulting impact on water supply and demand.[56] In the current review process of the international Columbia River Treaty, discussed below, basin stakeholders have expressed a desire to continue and even enhance basin services with respect to hydropower, flood control, ecosystem integrity, navigation, irrigation, and recreation.[57] Thus, the answer to the question of resilience of what to what is: the resilience of the provision of hydropower, flood control, ecosystem integrity, fish production, navigation, irrigation, and recreation to population growth and climate change.

Multiple forms of indicators, surrogates, propositions, and/or principles of resilience frameworks are being developed in the literature to assess or quantify resilience.[58] Most likely a single framework will not apply to all complex social-ecological systems.[59] Nevertheless, despite the lack of consensus so far on how precisely to conduct a resilience assessment, general principles in resilience assessment have emerged.[60] Notably Biggs et al., in an attempt to synthesize prior approaches, identify the following important factors and considerations: (1) maintenance of diversity and redundancy, (2) management of connectivity, (3) management of slow variables and feedbacks, (4) fostering an understanding of SESs as complex adaptive systems, (5) encouragement of learning and experimen-

55. Barbara Cosens, *Transboundary River Governance in the Face of Uncertainty: Resilience Theory and the Columbia River Treaty*, 30 UTAH ENVTL. L. REV. 229, 246 (2010).

56. See Alan F. Hamlet et al., *Twentieth-Century Trends in Runoff, Evapotranspiration, and Soil Moisture in the Western United States*, 20 J. CLIMATE 1468, 1468–86 (2007); Alan F. Hamlet et al., *Effects of Projected Climate Change on Energy Supply and Demand in the Pacific Northwest and Washington State*, 102 CLIMATE CHANGE 103, 165 (2010); Alan F. Hamlet et al., *Effects of Temperature and Precipitation Variability on Snowpack Trends in the Western United States,* 18 J. CLIMATE 4545, 4559 (2005); C. H. Luce & Z. A. Holden, *Declining Annual Streamflow Distributions in the Pacific Northwest United States*, 1948-2006, 36 GEOPHYSICAL RES. LETTERS 1 (2009); C. H. Luce et al., *The Missing Mountain Water: Slower Westerlies Decrease Orographic Enhancement in the Pacific Northwest USA*, 342 SCI. 1360 (2013); Philip W. Mote et al., *Declining Mountain Snowpack in Western North America,* 86 BULL. AM. METEOROLOGICAL SOC'Y 39, 44 (2005); Iris T. Stewart et al., *Changes Toward Earlier Streamflow Timing Across Western North America*, 18 J. CLIMATE 1136 (2005).

57. *See* Barbara Cosens et al., COMBINED REPORT ON SCENARIO DEVELOPMENT FOR THE COLUMBIA RIVER TREATY REVIEW (2011), *available at* http://www.columbiarivergovernance.org/UI_OSU_CRT_Scenario_Development__Combined_Report_-_FINAL-1.pdf [hereinafter COMBINED REPORT] (documenting report on interviews by students at the University of Idaho and Oregon State University); Matthew McKinney et al., *Managing Transboundary Natural Resources: An Assessment of the Need to Revise and Update the Columbia River Treaty*, 16 HASTINGS W.-NW. J. ENVTL. L. & POL'Y 307 (2010) (reporting on interviews by students at the University of Montana).

58. Reinette Biggs et al., *Toward Principles for Enhancing the Resilience of Ecosystem Services,* 37 ANN. REV. ENVTL. & RES. 421, 448 (2012).

59. Brian Walker et al., *A Handful of Heuristics and Some Propositions for Understanding Resilience in Social-Ecological Systems*, 11 No. 1 ECOLOGY & SOC'Y Art. 13 (2006) [hereinafter *A Handful of Heuristics*], available at http://www.ecologyandsociety.org/vol11/iss1/art13/.

60. Biggs, *supra* note 58, at 421–48.

tation, (6) broadening participation, and (7) promotion of polycentric governance systems.[61] We used these general dimensions to discuss broader, system-level aspects of resilience in the Columbia River Basin.[62]

While these are generalized statements of resilience that aid in framing the discussion, actual measurement of resilience runs up against the barrier of complexity.[63] Instead, researchers have developed qualitative approaches to resilience assessment that allow consideration of changes in resilience within a specific context.[64] Recently, Nemec et al. built on these approaches in developing a rapid assessment that relies on existing information rather than the collection of resilience specific data, and a numerical method that—while not a methodology that provides an absolute measure of resilience—can be used to compare system to system using a single team of experts who apply a common standard to a single system and thereby reveal changes in relative resilience over time.[65] The method uses a scoring system of 1–5 to quantify relative resilience of both the social and ecological system under the nine properties of resilience proposed by Walker and Salt (Table 2).[66]

Resilience Category	**Attribute of the system (Walker and Salt 2006)**	**Social and/or Ecological**
1. Diversity	"A resilient world would promote and sustain diversity in all forms."	Both
2. Variability	"A resilient world would embrace and work with ecological variability."	Biophysical
3. Modularity	"A resilient world would consist of modular components."	Both
Resilience Category	**Attribute of the system (Walker and Salt 2006)**	**Social and/or Ecological**
4. Acknowledging slow variables	"A resilient world would have a policy to focus on 'slow,' controlling variables associated with thresholds."	Social
5. Tight feedback	"A resilient world would possess	Both

61. *Id.* at 422.
61. *A Handful of Heuristics*, *supra* note 59.
62. *See infra* discussion in Part IV.
63. See A Handful of Heuristics, supra note 59.
64. RESILIENCE ALLIANCE, *supra* note *7*, at 7; WALKER & SALT, *supra* note 6.
65. Nemec et al., *supra* note 42.
66. WALKER & SALT, *supra* note 6, at 17; *see also* Nemec, *supra* note 42 (The article details the scoring system in which a score of five is counted when the system exhibits resilience with respect to each property, three if neutral, and one if the system lacks this property of resilience.).

	tight feedbacks (but not too tight)."	
6. Social capital	"A resilient world would promote trust, well-developed social networks, and leadership (adaptability)."	Social
7. Innovation	"A resilient world would place an emphasis on learning, experimentation, locally developed rules, and embracing change."	Both
8. Overlap in governance	"A resilient world would have institutions that include 'redundancy' in their governance structures and a mix of common and private property with overlapping access rights."	Social
9. Natural and engineered Services	"A resilient world would include all priced and unpriced ecosystem services in developmental proposals and assessments."[67]	Both

TABLE 2. Nine measures of system resilience and descriptions with rankings[68]

In this study, we further modified the methodology of Walker and Salt,[69] and Nemec et al.[70] First we asked local experts to complete the resilience assessment survey based on the modified questionnaire from Nemec et al., but to identify themselves as either a social or biophysical expert and respond only to the relevant properties within their category (Table 1).[71] The separation of assessment into separate social and ecological categories would deny the very relation we seek to study—i.e. that of a social-ecological system. Thus, our assessment uses ecosystem services in both the social and ecological categories as a bridging concept to capture the point of interaction and feedback. Furthermore, because the Columbia River Basin, as with most North American water basins, has been heavily developed resulting in the replacement of many ecosystem services with engineered services, we focused on ecosystem and engineered services as a single category of assessment. This allowed us to determine which of the nine properties of resilience change as society moves from ecosystem to engineered services and whether any shift may play a role in vulnerability.

In the second step we did statistical analysis on the results.[72] Third, a post-survey dialogue was added to the assessment methodology of Nemec et al.

67. Although the questionnaire did not expressly indicate that both natural and engineered services should be considered in this category, the dialogue indicated that respondents had interpreted it that way.

68. WALKER & SALT, *supra* note 6, at 17.

69. WALKER & SALT, *supra* note 6, at 17.

70. Nemec, *supra* note 42.

71. *See infra* Table 1; *but see id.* (asking all experts to score in every category).

72. For the statistical analysis we calculated the median score for each property for both the social (n = 5) and biophysical (n = 7) groups across the four eras. We performed a chi-squared test to quantify whether scores significantly deviated from an expected score of the number of responses divided by the number of score categories (3).

The dialogue was a structured conversation to further understand the reasoning for individuals scoring criteria and to assess consensus, or lack of consensus, for each resilience category. We did not have the panel re-score the assessment, as the Delphi technique would.[73] However, we gained a deeper understanding of views on the Columbia River Basin's resilience through structured communication among experts. Experts in ecology, social science, hydrology, geology, economy, history, law, and political science contributed.[74] Because terminology, approach to uncertainty, and value judgments vary considerably among disciplines,[75] and given the breadth of the concept and represented disciplinary knowledge, we felt it important to conduct a participatory dialogue to receive further feedback on how people interpreted components of the survey, including where they had the largest concern with assigning a number and where the uncertainties laid. The dialogue was structured by the eras as shown below and in Table 3.

IV. RESULTS OF THE COLUMBIA RIVER BASIN RESILIENCE ASSESSMENT

This part presents our resilience assessment of the Columbia River Basin. It begins with the characterization of historic eras and governance of the social-ecological system. It then presents the assessment of relative resilience over time, and finally, a discussion pointing toward a potential future window of opportunity.

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73. Norman Dalkey & Olaf Helmer, *An Experimental Application of the Delphi Method to the Use of Experts*, 9 MGMT. SCI. 458, 458–60 (1963), *available at* http://socsci2.ucsd.edu/~aronatas/project/academic/delphi%20method%20of%20convergence.pdf; Sanford D. Eigenbrode et al., *Employing Philosophical Dialogue in Collaborative Science*, 57 BIOSCI. 55 (2007), *available at* http://bioscience.oxfordjournals.org/content/57/1/55.full.pdf+html.

74. Many thanks to the gathering of Waters Without Borders, a group of water resource faculty from the University of Idaho and Washington State University, who participated in this dialogue.

75. *See generally* Michael O'Rourke & Stephen J. Crowley, Philosophical Intervention and Cross-Disciplinary Science: *The Story of the Toolbox Project*, 190 SYNTHESE 1937 (2013); Eigenbrode, *supra* note 73.

	PRE-CONTACT			DURING CONTACT			DAM ERA			ENVIRONMENTAL JUSTICE & CIVIL RIGHTS		
SOCIAL SCIENTISTS	Score	*p*	Sig	Score	*p*	Sig	Score	*p*	Sig	Score	*p*	Sig
DIVERSITY	4	0.018	*	3	0.247		1	0.074	.	3	0.247	
MODULARITY	4	0.174		3	0.449		1	0.007	**	2	0.247	
ACKNOW. SLOW VARIABLES	5	0.074	.	1	0.007	**	1	0.074	.	3	0.449	
TIGHT FEEDBACKS	4	0.368		1	0.449		2	0.074	.	3	0.449	
SOCIAL CAPITAL	4	0.074	.	1	0.007	**	1	0.074	.	2	0.449	
INNOVATION	3	0.368		3	0.819		1	0.074	.	3	0.819	
OVERLAP IN GOVERNANCE	4	0.074	.	2	0.247		1	0.007	**	3	0.247	
NAT. AND ENG. SERVICES	5	0.018	*	1.5	0.174		2.5	0.779		3	0.174	
MEDIAN | STD DEV.	4	0.641		1.8	0.943		1	0.594		3	0.463	
BIOPHYSICAL SCIENTISTS												
DIVERSITY	5	0.001	***	4	0.156		2	0.102		1	0.001	***
VARIABILITY	5	0.012	*	5	0.012	*	3	0.368		2	0.001	***
MODULARITY	4	0.247		3	0.247		3	0.819		2.5	0.247	
TIGHT FEEDBACKS	2.5	0.607		1	0.102		3	0.156		3	0.012	*
INNOVATION	3.8	0.607		3.1	0.607		3	0.607		3	0.135	
NAT. AND ENG. SERVICES	3	0.867		1	0.066	.	2	0.368		4	0.156	
MEDIAN | STD DEV.	3.9	1.022		3.1	1.605		3	0.516		2.8	1.021	

SIG. MEANS AGREEMENT AMONG PARTICIPANTS. [*P*-VALUE SCORES: '.' <0.1, * <0.01, ** < 0.01, AND * <0.001]**

TABLE 3. Median scores for each resilience assessment category by time period and survey group. Significance was determined by a χ^2 test.

A. Columbia River Basin Characterization

1. The Pre-Contact Era

Human contact with the Columbia River Basin is documented as many as 9,000 years ago.[76] Whether Native American people of the Columbia River Basin are direct descendants of these early inhabitants or not is a matter of debate,[77] but regardless, within the time frame of oral and then written history, it is clear that native people have had a special relation to the river.[78] The river they encountered would have been free-flowing, a river with an annual flow on average of 200 million acre-feet and seasonal variability in flow of 1:34.[79] They would have been the first to encounter the iconic salmonid species of the Basin whose ten-million-year survival in the face of a highly dynamic coastal environment is a tribute to their resilience.[80] Salmon were not only the primary protein source for indigenous people in the Basin but also formed the cornerstone of their religion, culture, and econo-

76. Bonnichsen v. United States, 367 F.3d 864, 871 (9th Cir. 2004).

77. *Id.* at 880–82.

78. *See* Mary L. Pearson, *The River People and the Importance of Salmon*, *in* THE COLUMBIA RIVER TREATY REVISITED: TRANSBOUNDARY RIVER GOVERNANCE IN THE FACE OF UNCERTAINTY 70 (Barbara Cosens ed., 2012).

79. Barbara A. Cosens & Mark Kevin Williams, *Resilience and Water Governance: Adaptive Governance in the Columbia River Basin*, 17 No. 4 ECOLOGY & SOC'Y Art. 3 (2012), *available at* http://www.ecologyandsociety.org/vol17/iss4/art3/.

80. Michael C. Healey, *Resilient Salmon, Resilient Fisheries for British Columbia, Canada*, 14 No. 1 ECOLOGY & SOC'Y Art. 2 (2009), *available at* http://www.ecologyandsociety.org/vol14/iss1/art2/; *see also* Paul W. Hirt, *Developing a Plentiful Resource: Transboundary Rivers in the Pacific Northwest, in* WATER, PLACE, & EQUITY 147, 155 (John M. Whiteley et al. eds., 2008) (noting that pre-European settlement salmon runs were estimated at 12–15 million salmon).

my;[81] the people adapted to the natural variation in ecosystem services by taking advantage of river morphology to harvest salmon.[82] The life cycles of Columbia Basin fisheries were used to mark time, suggesting a strong integration between indigenous culture and ecosystem services.[83] Evidence also exists that indigenous practices served to regulate fish harvest.[84]

While salmon was the primary protein source, evidence suggests that native people in the Basin used fire to enhance production of grasslands and camas root.[85] Archaeological evidence suggests movement from nomadic to sedentary lifestyles with greater resource specialization approximately 4,000 years ago.[86] Nevertheless, the absence of irrigated agricultural practices necessitated constant focus on obtaining food, and indigenous people augmented their salmon protein source with occasional trips across the continental divide to hunt buffalo.[87] With the introduction of

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81. Pearson, s*upra* note 78, at 77; United States v. Washington, 384 F.Supp. 312, 350 (W.D. Wash., 1974), *aff'd*, 520 F.2d 676 (9th Cir. 1975) ("These fish were vital to the [northwest] Indian diet, played an important role in their religious life, and constituted a major element of their trade and economy. Throughout most of the area salmon was a staple food and steelhead were also taken, both providing essential proteins, fats, vitamins, and minerals in the native diet."). For an example of the role of salmon in indigenous mythology see DONALD M. HINES, TALES OF THE NEZ PERCE 146–47 (1984) (From *The Maiden and Salmon*, "And now Salmon came up the river after making a phenomenal recovery to life. 'I go now to have revenge.' He came up the river. He would swim along for awhile; then, he would go ashore to walk along, up the valley. While he was thus walking, he saw a lodge with smoke wafting from it. 'Let me just go in.' He entered noiselessly ['*xu-l*']. There sat an old man spinning; it was Spider. Salmon said to him, 'Why are you spinning, old man?' 'Oh just to sew my clothes,' he replied. But Salmon knew well enough what he was doing, that he was making a fishnet. The old man had told him this, because from the very beginning he had identified him, by smell, as Salmon. Salmon went outside and said to all the salmon, 'You will swarm past here, all of you salmon. You will come to the old man; you will thus take pity on him.'").

82. *See* DAN LANDEEN & ALLEN PINKHAM, SALMON AND HIS PEOPLE: FISH AND FISHING IN NEZ PERCE CULTURE (A NEZ PERCE NATURE GUIDE) 65–89 (1999). Each year thousands of Native Americans from numerous tribes gathered at locations such as Celilo Falls (now inundated by water behind The Dalles Dam) to fish and trade. The falls hindered salmon in their up-river migration causing them to collect and making it easier to harvest large quantities.

83. *Id.* ("Then came Hesu'al [Ha-soo-ahl], the time when the hesu [eels] move to the upper tributaries.]Hesu was a favored fish in the Nez Perce diet]. Next came Qoyst'sal [Khoy-tsahl], the season of the run of the blue back salmon [k'ohyl-ehkts] in the upper tributaries. . . . Then came Nat'soxliwal [Nah-t' sohkh-le-wahl], the time when the nat'sox [chinook salmon] return to the upper rivers, ready to journey to the spawning streams. August was Wawama'ayqll'al [wa-wam-aye-k'ahl], the time when the chinook salmon reach the canyon streams and fishermen move to the upper rivers. September was Piq'uunm'ayq'al [Pe-khoon-mai-kahl], the season when the fall salmon run upstream and when the fingerlings journey down river.").

84. Katrine Barber, *Canneries on the Columbia: The Native Fishery: The Old and the New*, OR. HIST. PROJECT (2006), http://www.oregonhistoryproject.org/narratives/canneries-on-the-columbia/the-native-fishery/the-old-and-the-new/#.VFrrxlYgGu0 ("After what must have been much trial and error, Indians developed social and political structures that allowed them to successfully regulate their fishery. Native fishers gained access to specific fishing sites on the Columbia River through tribal or band affiliation, inheritance, or relationships such as marriage—a practice that limited access to the resource. Moreover, community leaders determined when fish could be harvested. Edicts such as those that prevented night fishing allowed "escapement," so that a portion of a run could continue upstream. Ceremonial practices instilled harvest limits by determining when the fishing could begin and end." In addition, the method of fishing through use of "[d]ipnets, for example, required a significant amount of human labor to operate, and individuals could only harvest a small percentage of a given fish run.").

85. Douglas Deur, *Salmon, Sedentism, and Cultivation: Toward an Environmental Prehistory of the Northwest Coast*, *in* NORTHWEST LANDS, NORTHWEST PEOPLES: READINGS IN ENVIRONMENTAL HISTORY 129, 141 (Dale D. Goble & Paul W. Hirt eds., 1999).

86. *Id.* at 135–36.

87. ALVIN M. JOSEPHY, JR., THE NEZ PERCE INDIANS AND THE OPENING OF THE NORTHWEST 20 (1965).

the horse, apparently through other tribes rather than European explorers, these people's hunting and fishing range was greatly increased.[88] *We refer to this initial historic era prior to European contact, and arguably remaining dominant until the mid-1800s, as the pre-Contact era.*

2. The Post-Contact Era

The Lewis and Clark Expedition documented initial contact between the indigenous people of the Basin and Europeans as occurring on September 20, 1805.[89] This initial contact did not alter the dominance of native people in the region.[90] For approximately three decades following contact, Nez Perce-European interaction focused on trade, in particular for fur, which benefited the tribes as much as the white traders.[91] These conditions changed as the onslaught of Euro-Americans transitioned from those passing through to those seeking to settle.[92] For the salmon fishery, competition from commercial fishing and an influx of canneries began in 1866,[93] and the corresponding decline of the fishery led to the first hatchery in the Basin in 1877.[94] Development of agriculture led to wholesale changes in upland cover to monoculture and altered natural drainage systems.[95] The influx of settlers of European descent had direct impacts on indigenous populations through war and disease.[96] Negotiations concerning tribal territory in the mid-eighteen hundreds was driven by the desire to expand settlement opportunities for emigrants and by railroad interests.[97] Those who held out were defeated in battle,[98] and many succumbed

88. *Id.* at 27–28.

89. *Id.* at 5 ("[O]n September 20, 1805, about three miles south of the present town of Weippe, Idaho, William Clark recorded the entrance of the first known white men, weary, bedraggled, and starving, into the Nez Perce homeland.").

90. *Id.* at 15 (In reference to the Nez Perce, Josephy states that "[a]t the time of the explorers' visit, the tribe was one of the more numerous and powerful in the Northwest, estimated to number between 4,000 and 6,000 persons.").

91. *Id.* at 40.

92. *Id.*

93. RICHARD WHITE, THE ORGANIC MACHINE 32 (1995).

94. John Harrison, *Hatcheries*, N.W. POWER & CONSERVATION COUNCIL (Apr. 23, 2012), http://www.nwcouncil.org/history/hatcheries; *see generally* MARK FIEGE, IRRIGATED EDEN: THE MAKING OF AN AGRICULTURAL LANDSCAPE IN THE AMERICAN WEST (1999).

95. *See, e.g.*, FIEGE, *supra* note 94.

96. United States v. Washington, 384 F. Supp. 312, 352 (W.D. Wash. 1974) ("There was a sharp decline in Indian population in the case area in the period after extensive contact with Europeans and Americans which occurred around 1780. It has been estimated that Indian populations in the Puget Sound region declined by approximately 50% between 1780 and 1840, but pre-treaty censuses were often incomplete and inaccurate. The Gibbs-Stevens census of 1854 shows a total of 7,559 Indians for all of Western Washington. A decline in population continued during the decades following the signing of the treaties, due in large part to diseases introduced by non-Indians.").

97. JOSEPHY, *supra* note 87, at 292–332. Although accounts differ on the extent of pressure applied to the tribes to enter the treaties presented by Stevens, no question exists concerning his goals. *See, e.g.*, *id.* at 292–93 (" . . . Isaac I. Stevens, an impatient, politically ambitious military man who arrived in the Northwest wearing three official hats simultaneously. . . . [He] applied successfully for the governorship of the newly created Washington Territory, which carried with it the position of Superintendent of Indian Affairs for the territory . . . and had also won the role of leader of the most northerly of four Pacific Railroad Survey groups being dispatched by the War Department . . . . Still a young man of 35 . . . Stevens saw all three of his jobs complementing each other toward a single grand end. As a governor who would build up the population and prosperity of his territory, he was intent on winning Congressional approval for a railroad that would terminate at Puget Sound. That meant not only finding a northern route through the moun-

to disease.[99] The devastating impact of this period on native people is magnified by the fact that it happened predominantly within the time period of a single generation.[100] The changes in the territorial sovereignty of the Nez Perce provide an illustration of the speed of change. Prior to 1855 the aboriginal territory of the Nez Perce was seventeen million acres.[101] In 1855, the Nez Perce agreed with the United States to a territory of roughly seven million acres.[102] In 1863, negotiations reduced the territory to 750,000 acres following the discovery of gold within the 1855 reservation.[103] The 1893 allotment of the reservation under the Dawes Act,[104] and subsequent opening to homesteading would reduce tribal trust land to roughly 113,000 acres.[105] Thus the reduction in land held exclusively for the tribe from seventeen million acres to 113,000 acres occurred over less than half a century (almost a single generation). *We refer to this era of transition from a dominant indigenous society to a dominant Euro-American society as the Post-Contact Era.*

3. The Dam Building Era

In the later stages of this transition period, the US Army Corps of Engineers (USACE) began transforming the Columbia River for navigation with locks at the Cascades (now Cascade Locks) as early as 1896, with numerous dams to follow.[106] Consideration of major dams on the Columbia River was underway in the United States by the 1920s.[107] Development of the Columbia River was part of the twentieth century effort "to transform rivers into engines of economic growth."[108] With the onset of the Great Depression in the 1930s, transformation of the river became part of the major federal public works projects under the New Deal, leading to the construction of Bonneville Dam and later Grand Coulee Dam, which would provide for irrigation and flood control and permanently block salmon from the upper Columbia Basin in Canada.[109] In addition, the transformation of the arid west for

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tains, cheaper and more practicable for a railroad than any route farther south, but also ensuring its safety from Indians."). During the period from 1854 through 1855, Stevens negotiated eleven treaties with several different northwest tribes. *Washington*, 384 F. Supp. at 330.

98. JOSEPHY, *supra* note 87, at 512–633.

99. *Washington*, 384 F. Supp. at 352.

100. *See generally id.*

101. *Frequently Asked Questions*, NEZ PERCE TRIBAL WEBSITE, http://www.nezperce.org/Official/FrequentlyAskedQ.htm#where (last updated Apr. 11, 2011).

102. Treaty with the Nez Perces, 1855, U.S.–Nez Perce, June 11, 1855, 12 Stat. 957.

103. Treaty with the Nez Perces, 1863, U.S.–Nez Perce, June 9, 1863, 14 Stat. 647.

104. General Allotment Act of 1887, ch. 119, 24 Stat. 388 (1887) (also referred to as the Dawes Act after Senator Dawes of Massachusetts who sponsored it).

105. VALDASUE STEELE, A GUIDE TO LIVING ON THE NEZ PERCE RESERVATION (2013), *available at* http://extension.uidaho.edu/nezpercereservation/files/2013/02/Guide-to-Living-on-the-Nez-Perce-Reservation1.pdf.

106. WHITE, *supra* note 93, at 37.

107. Jeremy Mouat, *The Columbia Exchange: A Canadian Perspective on the Negotiation of the Columbia River Treaty, 1944–1964*, *in* THE COLUMBIA RIVER TREATY REVISITED: TRANSBOUNDARY RIVER GOVERNANCE IN THE FACE OF UNCERTAINTY 15 ((Barbara Cosens ed., 2012).

108. Paul W. Hirt & Adam M. Sowards, *The Past and Future of the Columbia River*, *in* THE COLUMBIA RIVER TREATY REVISITED: TRANSBOUNDARY RIVER GOVERNANCE IN THE FACE OF UNCERTAINTY 119 (Barbara Cosens ed., 2012).

109. *Id.*; *see History*, BONNEVILLE POWER ADMIN., http://www.bpa.gov/news/AboutUs/History/Pages/default.aspx (last visited Nov. 5, 2014) ("Franklin Roosevelt delivered a speech in Portland during the 1932 presidential campaign. He promised that the next great

agriculture by the Bureau of Reclamation documented in Marc Reisner's *Cadillac Desert*[110] did not overlook the Columbia River Basin.[111] Today, roughly 7.8 million acres are irrigated within the Columbia River Basin from a combination of Reclamation and other projects and individual diversions including groundwater.[112]

Meanwhile, the transformation of the mainstem of the Columbia would not be complete until the United States and Canada acted in concert to that end. Major flooding in 1948[113] catalyzed transboundary cooperation[114] to increase storage capacity on the river from six percent to forty percent of the average annual flow with three dams in Canada and ultimately several more dams on tributaries in the United States.[115] The 1964 Columbia River Treaty between the United States and Canada resulted in joint operation of the river and sharing of benefits at a level that was unprecedented in international water arrangements of the time.[116] The Canadian dams also allowed alteration in the timing of flow to correspond with energy de-

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federal hydroelectric project would be built on the Columbia River to prevent extortion against the public by the giant electric utility holding companies then dominant in the region. The U.S. Government built Bonneville and Grand Coulee Dams in the 1930s and 1940s. Power from these massive projects strengthened the Northwest economy and brought electricity to rural areas that were not served by existing utilities."); *see also Grand Coulee Dam*, U.S. BUREAU RECLAMATION, https://www.usbr.gov/projects/PrintFacilityAttributes.jsp?fac_Name=Grand%20Coulee%20Dam (last updated Jan. 3, 2013) (noting the dam's roughly 9.6 million acre-feet of total storage capacity with about 5.2 million acre-feet active storage capacity, which represents the upper pool of water that can be released before the lake level falls below the outlet); *see generally* WHITE, *supra* note 93.

110. MARC REISNER, CADILLAC DESERT: THE AMERICAN WEST AND ITS DISAPPEARING WATER (1993); *see also* DAVID P. BILLINGTON ET AL., THE HISTORY OF LARGE FEDERAL DAMS: PLANNING, DESIGN, AND CONSTRUCTION IN THE ERA OF BIG DAMS (2005), *available at* http://www.usbr.gov/history/HistoryofLargeDams/LargeFederalDams.pdf.

111. *Columbia Basin Project*, U.S. BUREAU RECLAMATION, http://www.usbr.gov/projects/Project.jsp?proj_Name=Columbia+Basin+Project (last updated Dec 4, 2013); *see also Pacific Northwest Region Project Map*, U.S. BUREAU RECLAMATION, http://www.usbr.gov/pn/maps/pnmap.pdf (last visited Nov. 5, 2014).

112. *Irrigation*, FOUND. WATER & ENERGY EDUC., http://fwee.org/environment/what-makes-the-columbia-river-basin-unique-and-how-we-benefit/irrigation/ (last visited Nov. 5, 2014); *see also* Clear Springs Foods, Inc. v. Spackman, 252 P.3d 71, 81, 150 Idaho 790, 797 (2011); Mark Fiege, *Creating a Hybrid Landscape: Irrigated Agriculture in Idaho*, *in* NORTHWEST LANDS, NORTHWEST PEOPLES: READINGS IN ENVIRONMENTAL HISTORY 364 (Dale D. Goble & Paul W. Hirt eds., 1999); *see generally* FIEGE, *supra* note 94.

113. James D. Barton & Kelvin Ketchum, *The Columbia River Treaty: Managing for Uncertainty*, *in* THE COLUMBIA RIVER TREATY REVISITED: TRANSBOUNDARY RIVER GOVERNANCE IN THE FACE OF UNCERTAINTY 43–44 (Barbara Cosens ed., 2012) (Even though the total upper basin snowpack was near average, runoff occurred rapidly and peaked with a flood in May that destroyed the town of Vanport, Oregon, with estimated flow of greater than one million cubic feet per second (28,317 m^3/s). Average peak flows are less than half the rate estimated during the flood.).

114. *See* Columbia River Basin Treaty, *supra* note 51, at art. 1; *see also* Hirt & Sowards, *supra* note 108, at 121.

115. Anthony G. White, *The Columbia River: Operation under the 1964 Treaty*, *in* THE COLUMBIA RIVER TREATY REVISITED: TRANSBOUNDARY RIVER GOVERNANCE IN THE FACE OF UNCERTAINTY 53–58 (Barbara Cosens ed., 2012); Barton & Ketchum, *supra* note 113, at 47–48; John Shurts, *Rethinking the Columbia River Treaty*, *in* THE COLUMBIA RIVER TREATY REVISITED: TRANSBOUNDARY RIVER GOVERNANCE IN THE FACE OF UNCERTAINTY 193 (Barbara Cosens ed., 2012) (Hungry Horse Dam on the South Fork of the Flathead was completed in 1953 for hydropower and flood control—although it is nevertheless a Bureau of Reclamation Dam—), and Dworshak Dam on the North Fork of the Clearwater, a United States Army Corp of Engineers dam was completed in 1972).

116. Barton & Ketchum, *supra* note 113, at 43 (average peak flows are less than half the rate estimated during the flood).

mand.[117] Toward the end of the federal development of the Columbia River, a national debate took place concerning the value of public versus private power. The battle came to a head in the competing federal and private proposals for development of the Snake River, a major tributary to the Columbia, in Hells Canyon.[118] Private power (albeit with Federal Energy Regulatory Commission regulation) won with three relatively small dams, known as the Hells Canyon Complex, constructed in the 1960s by Idaho Power on the Snake River.[119] In total, dams constructed without fish passage blocked salmon from forty percent of their former habitat.[120] Fisheries within the Basin were engineered through the development of hatcheries which now supply eighty to ninety percent of the anadromous fish runs.[121] *We refer to this period of engineered alteration of the river from the 1920s to the 1960s as the dam building era.*[122]

4. The Era of Environmental Justice and Civil Rights

With the exception of the private development on the Snake River, the Dam Building Era was dominated by federal investment and control with limited local involvement and no evidence of consultation with Native American tribal government.[123] By the 1970s the anadromous fish runs on the Columbia had declined from the estimated precontact numbers of ten to twenty million fish to less than one million with sixty to eighty percent produced in hatcheries.[124] At the same time, the Civil Rights movement and the American Indian movement gave rise to increased civil and legal activism to assert the rights of indigenous people.[125] A federal district court interpreted treaty language to grant four of the Basin's tribes fifty percent of the harvest,[126] and in a later case, the US Supreme Court upheld a ruling that the

117. *Id.* at 44.

118. *Id.*

119. *Id.* at 17–18.

120. John Harrison, *Fish Passage at Dams*, N.W. POWER & CONSERVATION COUNCIL (Oct. 31, 2008), http://www.nwcouncil.org/history/fishpassage.

121. Chris Peery, *The Effects of Dams and Flow Management on Columbia River Ecosystem Processes*, *in* THE COLUMBIA RIVER TREATY REVISITED: TRANSBOUNDARY RIVER GOVERNANCE IN THE FACE OF UNCERTAINTY 138 (Barbara Cosens ed., 2012); *see also* Dale D. Goble, *Salmon in the Columbia Basin: From Abundance to Extinction*, *in* NORTHWEST LANDS, NORTHWEST PEOPLES: READINGS IN ENVIRONMENTAL HISTORY 229, 249 (Dale D. Goble & Paul W. Hirt eds., 1999).

122. *See, e.g.*, BILLINGTON ET AL., *supra* note 110, at 185.

123. *See generally* COLUMBIA RIVER TREATY REVISITED: TRANSBOUNDARY RIVER GOVERNANCE IN THE FACE OF UNCERTAINTY (Barbara Cosens ed., 2012).

124. *The Plan: Wy-Kan-Ush-Mi Wa-Kish-Wit*, COLUMBIA RIVER INTER-TRIBAL FISH COMMISSION, http://www.critfc.org/fish-and-watersheds/fish-and-habitat-restoration/the-plan-wy-kan-ush-mi-wa-kish-wit (last visited Nov. 6, 2014) (estimating a population of 10–20 million salmon before development, which declined below 500 thousand after development); *see also* COLUMBIA RIVER INTER-TRIBAL FISH COMM'N, 1 WY-KAN-USH-MI-WA-KISH-WIT: SPIRIT OF THE SALMON iii (1996) (estimating 5-11 million salmon declined to fewer than 500 thousand); Bonneville Power Admin. et al., *Frequently Asked Questions*, SALMON RECOVERY, http://www.salmonrecovery.gov/Files/Fact%20sheets/Frequently%20asked%20questions.pdf (estimating 10–16 million salmon before development) (last visited Nov. 6, 2014).

125. RICHARD N. L. ANDREWS, MANAGING THE ENVIRONMENT, MANAGING OURSELVES: A HISTORY OF AMERICAN ENVIRONMENTAL POLICY 225–26 (2d ed. 1999).

126. United States v. Washington, 384 F. Supp. 312, 343 (W.D. Wash. 1974), *aff'd*, 520 F.2d 676 (9th Cir. 1975). The treaty language interpreted can be found in each of the treaties of the four tribal governments: the Nez Perce, the Confederated Bands of the Yakama Nation, the Confederated Tribes of the Umatilla Indian Reservation, and the Confederated Tribes of the Warm Springs Reservation. From the Nez

State of Washington had no authority to regulate the tribal fishery.[127] In the wake of these rulings, the four tribal governments that benefited from the ruling formed the Columbia River Inter-Tribal Fish Commission (CRITFC),[128] and developed fisheries and policy departments that would become a significant voice in Columbia River fish management for four of the fifteen tribes in the US portion of the Basin.[129]

At the same time, passage of major environmental laws began to signal a change in values nationwide.[130] The desire for conservation and fish and wildlife restoration was manifest in the 1980 passage of the Northwest Power Act,[131] which allowed the States of Idaho, Montana, Oregon, and Washington to enter an interstate compact for the formation of a Council[132] to oversee power planning for the region, mandating that conservation be first priority, followed by use of renewable resources.[133] In addition, it required the compact to include development of a program for the restoration of fish and wildlife populations in the Columbia River Basin.[134] Although the hope was that the Council would solve the fish recovery problem,[135] frustration with progress led to petitions to list various species of anadromous fish under the Endangered Species Act.[136] The National Marine Fisheries Service began listing anadromous fish in the Columbia River system in 1991, and

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Perce Treaty, the relevant language is found in Article 3: "The exclusive right of taking fish in all the streams where running through or bordering said reservation is further secured to said Indians; as also the right of taking fish at all usual and accustomed places in common with citizens of the Territory , , , ," Treaty with the Nez Perces, 1855 art. 3, U.S.–Nez Perce, June 11, 1855, 12 Stat. 957.

127. Washington v. Wash. State Commercial Passenger Fishing Vessel Ass'n, 443 U.S. 658, 696 (1979).

128. *See The Founding of CRITFC*, COLUMBIA RIVER INTER-TRIBAL FISHING COMMISSION, http://www.critfc.org/ about-us/critfcs-founding/ (last visited Nov. 6, 2014)

129. *See, e.g.*, Barbara Cosens, *Changes in Empowerment: Rising Voices in Columbia Basin Resource Management*, *in* THE COLUMBIA RIVER TREATY REVISITED: TRANSBOUNDARY RIVER GOVERNANCE IN THE FACE OF UNCERTAINTY 63 (Barbara Cosens ed., 2012) .

130. *Cf.* 16 U.S.C. §§ 1531–1544 (2012) (showing the period between 1968 and 1980 saw the passage of numerous federal acts including: Wild and Scenic Rivers Act of 1968, Pub. L. No. 90-542, 82 Stat. 906 (1968) (current version at 16 U.S.C. §§ 1271–1287 (2012)); National Environmental Policy Act of 1969, Pub. L. No. 91-190, 83 Stat. 852 (1969) (current version at 42 U.S.C. §§ 4321–4370h (2012)); Clean Air Amendments of 1970, Pub. L. No. 91-604, 84 Stat. 1676 (1970) (current version at 42 U.S.C. §§ 7401–7671q (2012)); Federal Water Pollution Control Act Amendments of 1972, Pub. L. No. 92-500, 86 Stat. 816 (1972) (current version at 33 U.S.C. §§ 1251–1387 (2012)); Safe Drinking Water Act Amendments of 1974, Pub. L. No. 93-523, 88 Stat. 1660 (1974) (current version at 42 U.S.C.S. § 300f (2012)); Toxic Substances Control Act of 1976, Pub. L. No. 94-469, 90 Stat. 2003 (1976) (current version at 15 U.S.C. §§ 2601–2697 (2012)); Comprehensive Environmental Response, Compensation and Liability Act of 1980, Pub. L. No. 96-510, 94 Stat. 2767 (1980) (current version at 42 USC §§ 9601–9675 (2012)); *see also* Hirt & Sowards, *supra* note 108, at 125–26.

131. *See* Pacific Northwest Electric Power Planning and Conservation Act (Northwest Power Act), Pub. L. No. 96-501, 94 Stat. 2697 (1980) (current version at 16 U.S.C. § 839 (2012)).

132. 16 U.S.C. § 839b(a)(2) (2012).

133. 16 U.S.C. § 839b(e)(1) (2012).

134. 16 U.S.C. § 839b(a)(1) (2012).

135. Michael C. Blumm, *The Northwest's Hydroelectric Heritage*, *in* NORTHWEST LANDS, NORTHWEST PEOPLES: READINGS IN ENVIRONMENTAL HISTORY 281 (Dale D. Goble & Paul W. Hirt eds., 1999). [hereinafter Blumm, Heritage]; MICHAEL C. BLUMM, SACRIFICING THE SALMON: A LEGAL AND POLICY HISTORY OF THE DECLINE OF COLUMBIA BASIN SALMON 133 (2002) [hereinafter BLUMM, SALMON].

136. Blumm, Heritage, *supra* note 135, at 284; *see* BLUMM, SALMON, *supra* note 135, at 151.

today eight salmon and four steelhead species that rely on habitat within the Basin are listed.[137]

In the middle of this period of change in values and empowerment, another event occurred that would impact the Columbia River hydropower system for decades to come: the 1973 oil embargo. With rapid growth in energy demand following World War II, drafters of the 1964 Columbia River Treaty between the United States and Canada anticipated that thermal power (in particular nuclear power) would be needed to replace hydropower as the firm load supply of energy for the Pacific Northwest, and that the value of the hydropower system would be dramatically reduced.[138] Instead, in response to the oil embargo, conservation replaced new power generation and the hydropower system, contrary to expectations, has remained quite valuable as the firm load for the region even into the next twenty-year planning cycle of the Northwest Power and Conservation Council.[139]

While these changes played out in the United States, similar change occurred north of the border. Great Britain granted Canada full sovereignty in 1982, when the Canadian Constitution was patriated,[140] and the Constitution Act of 1982 recognized aboriginal and treaty rights, including rights acquired through land claim agreements, of aboriginal people in Canada.[141] Canada's equivalent to the Endangered Species Act, the Species at Risk Act,[142] was not passed until 2002 after salmon had been blocked from the mainstem of the Columbia in Canada.[143] Nevertheless, the passage signals a change in value and provides a platform for regulation to prevent species decline. In addition, Canada has numerous environmental laws including the Canadian Environmental Protections Act,[144] and recently bolstered enforcement of many of its environmental statutes through passage of the Environ-

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137. 50 C.F.R. § 223.102 (2013) (listing salmon species found in the Columbia Basin: Snake River Sockeye (endangered), Upper Willamette River Chinook (threatened), Lower Columbia River Chinook (threatened), Upper Columbia River spring-run Chinook (endangered), Snake River fall-run Chinook (threatened), Snake River spring/summer-run Chinook (threatened), Lower Columbia River Coho (threatened), and Columbia River Chum (threatened)). Note that four evolutionarily significant units (ESUs) of steelhead are also currently listed. *See* Endangered and Threatened Species: Proposed Listing Determinations for 27 ESUs of West Coast Salmonids, 69 Fed. Reg. 33102, 33105 (June 14, 2004); Endangered and Threatened Species: Final Protective Regulations for Threatened Upper Columbia River Steelhead, 71 Fed. Reg. 5177, 5178 (Feb. 1, 2006); *see also Status of ESA Listings & Critical Habitat Designations for West Coast Salmon & Steelhead*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES (updated Oct. 31, 2012), http://www.westcoast.fisheries.noaa.gov/publications/protected_species/salmon_steelhead/status_of_esa_salmon_listings_and_ch_designations_map.pdf.

138. *See generally* Shurts, *supra* note 115, at 92.

139. Harrison, *Fish Passage at Dams*, *supra* note 120.

140. *Id.*

141. Canadian Charter of Rights and Freedoms, Part II of the Consitution Act, 1982, *being* Schedule B to the Canada Act, 1982, c. 11 (U.K.).

142. Species at Risk Act, S.C. 2002, c. 29 (Can.), *available at* http://laws-lois.justice.gc.ca/eng/acts/S-15.3/.

143. However, chinook salmon are listed on a tributary to the Columbia which joins the river below Chief Joseph Dam. *See* Gov't Can., *Species at Risk Public Registry*, CAN. (last modified Oct. 21, 2014), http://www.registrelep.gc.ca/search/advSearchResults_e.cfm?stype=species&lng=e&advkeywords=&op=2&locid=1&taxid=4&desid=1%2c2%2c3%2c4%2c5&.

144. Canadian Environmental Protection Act of 1999, S.C. 1999, c. 33 (Can.), *available at* http://laws-lois.justice.gc.ca/eng/acts/C-15.31/index.html.

mental Enforcement Act in 2010.[145] *We refer to this period from the end of dam building to the present as the era of environmental justice and civil rights.*

Despite the lines drawn between historical eras, not only is there overlap in the transition period between each era, but legacy effects of each era continue through subsequent eras and even persist in the present. For example, the cultural importance of salmon to human inhabitants of the Basin during the Pre-Contact Era and the devastating impacts on that culture in the Post-Contact and Dam Building Eras not only remain as an added layer of complexity in those subsequent eras, but formed the backdrop against which the Era of Environmental Justice and Civil Rights has played out in this particular basin. Similarly, the Environmental Justice and Civil Rights Era did not eliminate the value people of the Basin place on the benefits of hydropower as a clean, cheap energy source, and the value of protection from flood. Interviews of stakeholders in the Basin indicate that the importance of those benefits remain high, while ecosystem function has risen to the level of the third co-equal value.[146] The interests stemming from these different eras are all apparent in the current governance of the Basin's water resource. Characterizing current governance is the next step in the resilience assessment of the Columbia River Basin.

B. Governance of the Columbia River Basin

Governance of a water-based social-ecological system refers to the means through which political actors choose the goals of water management, development, and protection, and the means through which they take action to achieve those goals.[147] Thus, water governance includes not only the laws, regulations, policies, and processes of government, but also the institutional framework in which government acts, the private actors who take a role in the political process, and the societal norms that influence those choices and actions.[148]

Of importance in adaptive governance is not only who acts, but how different actors interact.[149] Use of geographic information systems (GIS) to map the jurisdictional reach of governmental and non-governmental entities and network model-

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145. Gov't Can., *Environment Canada: Canada's Environmental Enforcement Act (EEA)*, CAN. (last modified July 23, 2013), http://www.ec.gc.ca/alef-ewe/default.asp?lang=En&n=2AAFD90B-1.

146. *See generally* BARBARA COSENS ET AL., COMBINED REPORT ON SCENARIO DEVELOPMENT FOR THE COLUMBIA RIVER TREATY REVIEW (Shanna Knight et al. eds., 2011), *available at* http://www.columbiarivergovernance.org/UI_OSU_CRT_Scenario_Development__Combined_Report_-_FINAL-1.pdf (report on interviews by students at the University of Idaho and Oregon State University); *see also* McKinney et al., *supra* note 57.

147. Huitema et al., *supra* note 4. More generally, from the resilience and environmental governance literature, *see* Carl Folke et al., *Adaptive Governance of Social-Ecological Systems*, 30 ANN. REV. ENVTL. & RES. 441 (2005), *available at* http://www.annualreviews.org/doi/pdf/10.1146/annurev.energy.30.050504.144511; *see also* Maria Carmen Lemos & Arun Agrawal, *Environmental Governance*, 31 ANN. REV. ENVTL. & RES. 297 (2006), *available at* http://www.annualreviews.org/doi/pdf/10.1146/annurev.energy.31.042605.135621.

148. *Id.*

149. Folke et al., *supra* note 147; *see also* Barbara A. Cosens, *Legitimacy, Adaptation, and Resilience in Ecosystem Management*, 18 No. 1 ECOLOGY & SOC'Y Art. 3 (2013), *available at* http://www.ecologyandsociety.org/vol18/iss1/art3/.

ing[150] are tools to develop a robust understanding of these processes in a specific basin, but require considerable resources and have not yet been applied at the basin scale in the Columbia River Basin. A qualitative understanding of the types and impacts of cross-scale interaction can nevertheless be applied to each historical era through the lens of the adaptive cycle[151] and nested governance. The adaptive cycle is an observed pattern in complex systems in which growth and accumulation of resources leads to rigidity in the system.[152] At this point the system is vulnerable to collapse in the face of a perturbation.[153] Collapse leads to innovation and renewal, and growth begins again (Figure 2).[154] Nested governance refers to the hierarchical yet overlapping roles of individual, local, regional, federal, and international levels of action and provides a means to consider cross-scale interactions in relation to adaptive capacity (Figure 2). [155] In reference to the adaptive cycle, although adaptive capacity is high during periods of renewal and innovation, achieving this only in response to crisis of revolt reduces the desirability.[156] Thus, much of our legal system is designed to provide stability, in particular for economic pursuits.[157]

150. Hans Bressers et al., *Networks as Models of Analysis: Water Policy in Comparative Perspective*, 3 ENVTL POL. 1 (1994), *available at* http://doc.utwente.nl/2217/1/7965.pdf.

151. *See* PANARCHY, *supra* note 22, at 25–62.

152. *Id.*

153. *Id.*

155. *Id.*

156. *Id.*

157. COSENS ET AL., *supra* note 146; Arnold & Gunderson, *supra* note 47, at 10,428.

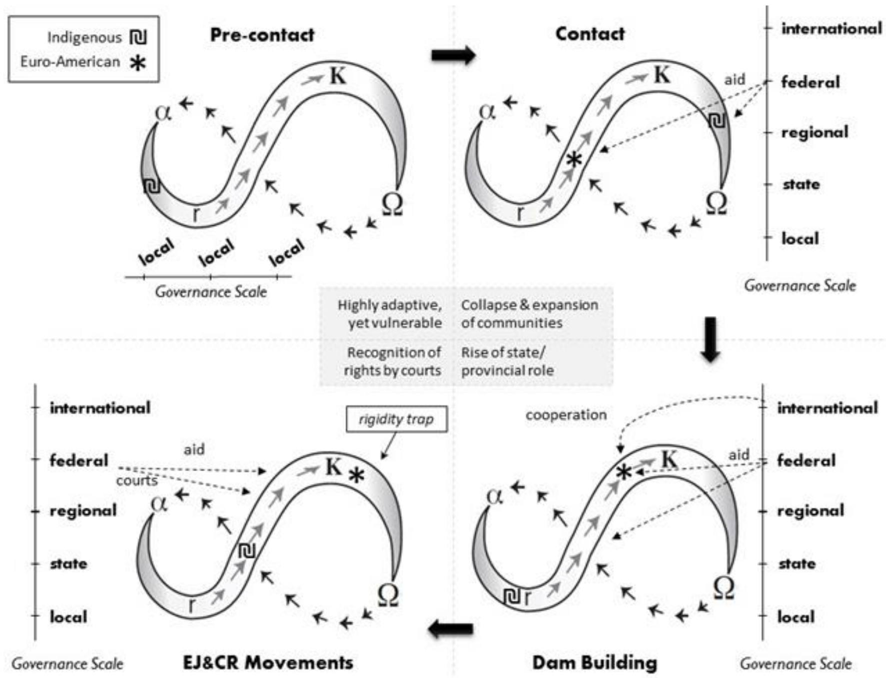


FIGURE 2. The adaptive cycle at the basin scale is shown with cross-scale interaction from different levels of governance.

What consideration of nested governance adds to the adaptive cycle is the notion that higher levels of governance may provide inputs to avoid impending crisis, resources for innovation, and simply stability within which innovation may occur at lower levels and on a smaller scale without threat to an entire system. At the same time, rigid control from higher levels may impede innovation and adaptation, a common criticism of the command and control approach of certain federal environmental regulation. Applying the concept of nested governance to our four historical eras illustrates the interaction between different levels and the impact on position within the adaptive cycle (Figure 2).

1. The Pre-Contact Era

Historic accounts suggest a high degree of mobility that would lead to a high level of adaptive capacity to respond to ecological changes (e.g. changes in timing of salmon runs).[158] Yet, at the same time, the governance structure in Pacific Northwest tribes was relatively horizontal (as opposed to hierarchical), thus, resources or assistance were not available from higher levels to aid in the event of an unexpected crisis, such as the malaria epidemic of the mid-1800s, or the onslaught

158. *See generally supra* Part IV.A.1.

of European settlers.[159] The high level of adaptation to an ecosystem that varied within historic parameters, and absence of outside assistance left indigenous populations vulnerable to surprise.

2. The Post-Contact Era

From the perspective of the resilience of indigenous people, contact with Europeans was a crisis imposed from the outside. Although indigenous people survived in the Columbia River Basin, European contact led to a regime shift in which outside assistance from the federal government would be essential to survival by providing food and supplies as they reduced tribal territory to sizes that could not support a hunter-gatherer existence, and it would be over a century before indigenous communities in general would enter a period of renewal and growth. As for the resilience of the European settlers, they were entirely dependent on outside assistance from the federal government including its military, its land, and its investment in highways of commerce, and from private entities in the eastern United States for capital and trade. During this period, the federal government used its resources to stimulate innovation and growth in the western United States through acts such as the 1872 Mining Law[160] and the Homestead Act of 1862,[161] both of which allowed federal lands to go into private ownership in exchange for nominal fees and a showing of the application of effort by the individual to make the land productive. Toward the end of this period, the global economic crisis of the Great Depression and the ensuing poverty within the Basin highlighted the fact that the rural, agricultural west could not sustain this level of wealth and productivity without external resources such as federal investment in water infrastructure. In terms of nested governance and the adaptive cycle, this is an example of a higher level of government preventing collapse of a lower level through provision of resources and technology for continued growth.

3. The Dam Building Era

The major federal investment in dams, in part to bring the country out of the Depression, began a period of renewal and growth and relative economic stability at the local level. Toward the end of the era, it was recognized that further growth would not be possible without partnership with Canada. The 1964 Columbia River Treaty[162] led to development of additional dams and integration of the hydropower system throughout the Basin. As described by Vogel, this international level agreement was necessary to actually empower the subnational regions on each side of the border to work in concert.[163]

159. *See* William G. Robbins, *The Native Context and the Arrival of Other Peoples: Old World Contagions*, OR. HIST. PROJECT (2002), http://www.ohs.org/education/oregonhistory/narratives/subtopic.cfm?subtopic_ID=17.

160. *See generally* General Mining Act of 1872, ch. 152, 17 Stat. 91 (1872) (codified as amended at 30 U.S.C. §§ 22–47 (1994)).

161. *See generally* Homestead Act of 1862, ch. 75, 12 Stat. 392 (1862) (repealed 1976).

162. Columbia River Basin Treaty, *supra* note 51.

163. Eve Vogel, *Can an International Treaty Strengthen a Region and Further Social and Environmental Inclusion? Lessons from the Columbia River Treaty*, *in* THE COLUMBIA RIVER TREATY

4. The Environmental Justice and Civil Rights Era

The environmental and civil rights movements began at the grassroots level at points of inflexion on the adaptive cycle (termed "remember" and "revolt"). At these points, the system is characterized by change and innovation, which is typically influenced by cross-scale interactions such as collective action that permeates to higher levels. However, the failure of local and state government in many parts of the United States to respond led the leaders to seek assistance from a higher level. Federal environmental laws,[164] as well as increased understanding of the importance of tribal self-determination in federal law,[165] stepped in to fill the gap. This period saw improvements in water and air quality, tribal economic development and empowerment, as well as increases in prosperity in the Basin as a whole due in part to optimization of hydropower production and irrigation made possible by federal investment. At the same time, the legacy effect of the Dam Building Era is thought to have limited improvements to salmon runs[166] and the rigid command and control approach of federal regulatory intervention began to be viewed as an impediment to innovation.[167] The development of the water resource to its optimum level left very little room for adaptation. Thus, the Basin can be seen as on the upper level of the growth curve on the adaptive cycle, and is held there at a high level of efficiency and development and with limited capacity for innovation or room for adaptation because of both inputs and constraints from a higher (federal) level in the nested governance hierarchy. If this scenario is at all accurate, the Basin is not in an optimal position to withstand a major perturbation.

C. Assessing the Columbia River Basin Resilience

This study provides a modified framework to assess resilience in large river basins, or more generally, complex adaptive social-ecological systems. The survey of resilience properties, conducted by Nemec et al. and Walker and Salt, help to define attributes of the system to gauge change through time in the context of resilience thinking.[168] Here we report a semi-rigorous statistical evaluation of the survey and discuss results by historical era while also looking into the future era defined by climate change.

REVISITED: TRANSBOUNDARY RIVER GOVERNANCE IN THE FACE OF UNCERTAINTY 82 (Barbara Cosens ed., 2012).

164. KARL BOYD BROOKS, PUBLIC POWER, PRIVATE DAMS: THE HELLS CANYON HIGH DAM CONTROVERSY 5–9 (2006).

165. Indian Self-Determination and Education Assistance Act of 1975, Pub. L. No. 93-638, 88 Stat. 2203 (1975).

166. *See 2014 Spirit of the Salmon Plan: Remaining Problems and Gaps*, COLUMBIA RIVER INTER-TRIBAL FISH COMMISSION, http://plan.critfc.org/2013/spirit-of-the-salmon-plan/about-spirit-of-the-salmon/remaining-problems-and-gaps/ (last visited Nov. 6, 2014).

167. *See generally* Carmen Thomas Morse, *When Courts Run Regulated Rivers: The Effects of Scientific Uncertainty*, *in* THE COLUMBIA RIVER TREATY REVISITED: TRANSBOUNDARY RIVER GOVERNANCE IN THE FACE OF UNCERTAINTY 48–49 (Barbara Cosens ed., 2012).

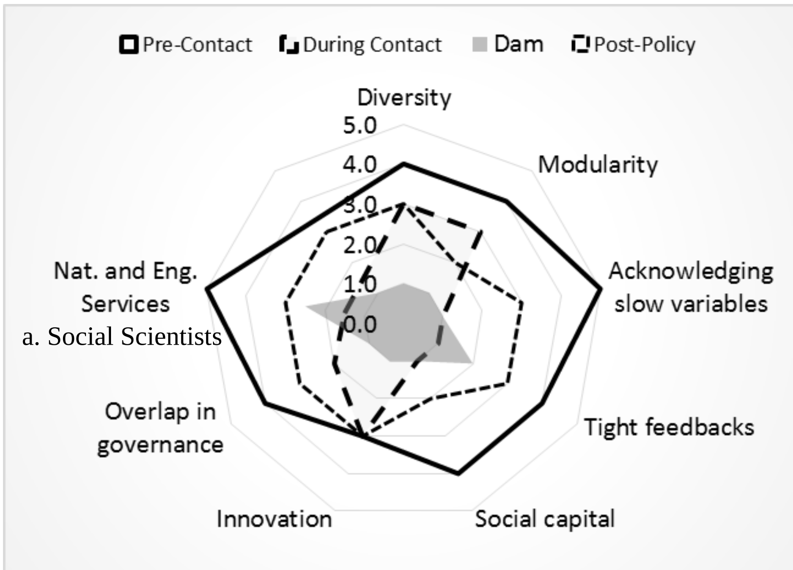
168. *See generally* WALKER & SALT, *supra* note 19; Nemec et al., *supra* note 42.

1. Results of Survey of Experts

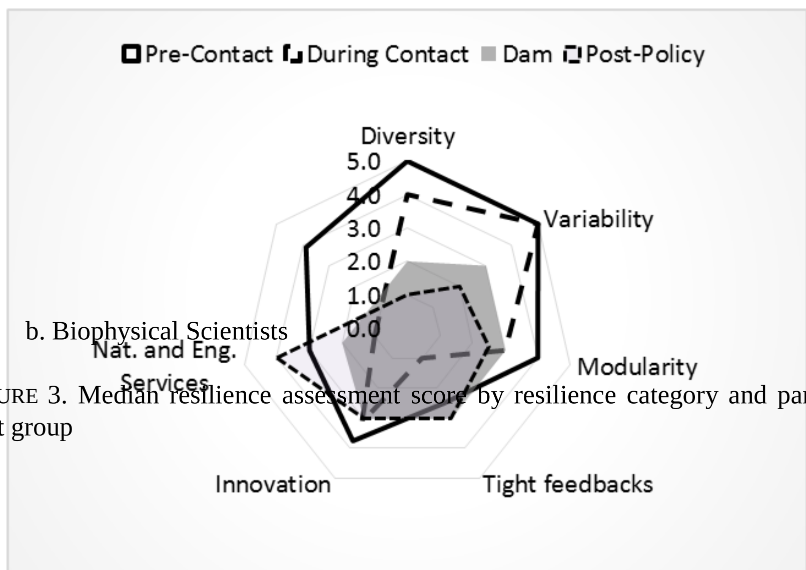
Though the numbers of our survey and observations from the dialogue are not exhaustive and represent an initial cut at an assessment, we can still draw a number of observations about the resilience of the Columbia River Basin. The statistics from Table 1 suggest that the scores are statistically uncertain 77% of the time (35/52); nevertheless, observations from the raw data and dialogue discussion illustrated a higher level of agreement among participants than initially thought.[169] The dialogue revealed that variability among scores was caused, in part, by problems of definition and interpretation of the category prompts.

Agreement among experts was further evident when scores were summed for each time period (Figure 4), and in particular, experts agreed on the relative trends across time periods during the dialogue. The raw data and statistical analysis suggest that the greatest uncertainty in scoring was in the categories of tight feedbacks, innovation and ecosystem services. For example, it was acknowledged that the term "variability" required more context and most participants agreed that "locally developed rules" in the innovation category would not always build desired system resilience unless nested within higher levels of authority to provide standards and stability. The tight feedbacks and innovation categories were discussed at length, which improved clarity of their meaning throughout the discussion. Variability in the ecosystem services scoring originated in part from the merged concepts of natural and engineered services, but also from disagreement in importance of services gained and diminished. In sum, the scores suggests that a systematic resilience assessment, accompanied by dialogue to assure that the metrics are well understood, provides value for understanding change in resilience for large river basins, though methodological challenges remain.

169. The lack of statistical significance implies agreement among the scores and a lower level of uncertainty among the responses. A lack of statistical significance does not mean disagreement per se because many of the responses show a trend toward agreement. The statistical test we performed should be considered conservative because of the small sample size and alpha value of < 0.05; significant agreement occurs when scores are almost identical.



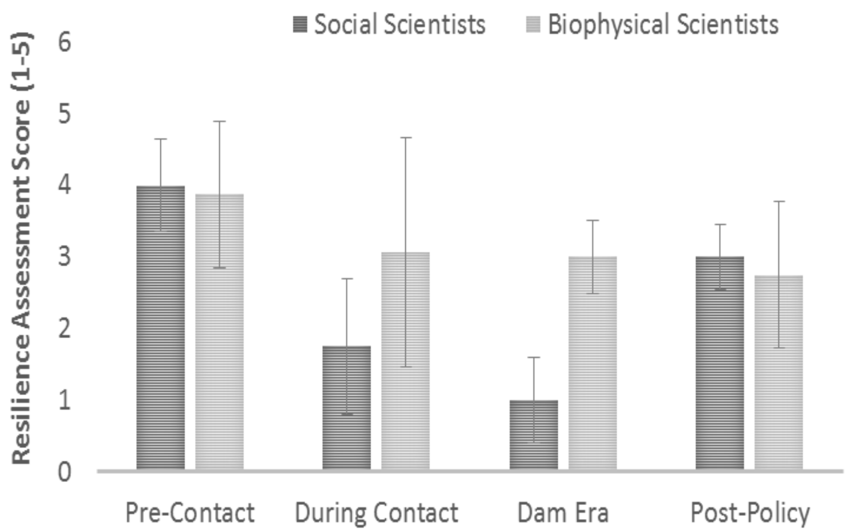
a. Social Scientists



b. Biophysical Scientists

FIGURE 3. Median resilience assessment score by resilience category and participant group

FIGURE 4. Median resilience assessment scores summed by participant



a. The Pre-Contact Era

The resilience assessment illustrates general agreement among both social and biophysical scientists that the Columbia River Basin had higher general resilience to the types of ecological perturbations present during the Pre-Contact Era (Table 3, Figure 4). This assessment is consistent with the limited anthropogenic impacts on the ecosystem, the relatively horizontal, highly modular social system reflected in independent bands of indigenous communities without hierarchical governance, and with very tight feedbacks from change in the ecosystem to a need for response from the social system. This allowed rapid response and adaptation to changes in the ecosystem.

b. The Post-Contact Era

The social science scores show a general, but substantial, trend toward reduced resiliency during the Contact Era. This result may reflect the lack of resilience of indigenous populations to major outside disturbances including disease and war and the fact that the Euro-Americans entering the Basin in this period were almost entirely dependent on outside support. This strong dependence on and tie to the eastern United States may have masked any feedback from local ecological change within the Basin to basin governance because people could rely on supplies, food, capital, and other resources from the east buffering the impact of any change in the system. Attributes of social capitol such as trust would have been low in this era. The biophysical scores show a reduction in both ecosystem services and feedbacks. The expert dialogue revealed that the almost wholesale alteration of arable land in the Basin to monoculture during this period and the decline in salmon because of commercial fisheries leading to the introduction of hatcheries explains what the experts considered to be the reduction in ecosystem services. Moreover, the reliance on input from the east to supplement services severed ties between action and impact on the biophysical system.

c. The Dam Building Era

The social science scores decline in almost every factor during this period except services and feedbacks (Figure 3). The declines reflect the complete dependence of basin communities on the federal government for economic and knowledge inputs and the shift of water management to a predominantly federal level. Because we have defined services to reflect both natural and engineered services, the increase in this category reflects the benefits within the Basin from economic development, hydropower production, and flood control. Most revealing is the shift in factors in the biophysical scores showing a loss of variability, diversity, and modularity as a result of the simplification of the ecological system through the use of dams and structural methods to control floods and alter the hydrograph. Notably, modularity was interpreted differently by physical scientists and ecologists. Flow regulation by dams on the Columbia mainstem reduced vulnerability to flooding downstream by increasing the modularity in the system; that is, dams further parsed the river system into divided units that improve a manager's ability to mitigate flooding. For salmon populations, however, scores reflect that blockage of salmon from 40% of their former spawning grounds reduced modularity of the system. Modularity in spawning habitat and life histories helps protect the Pacific salmon population from basin scale disturbance through variable timing of salmon runs, and is thought to have been a factor in their ten-million-year resilience.[170]

Both social and biophysical resilience decline through the Dam Building Era (Figure 4) and cannot be understood without reference to specific categories of resilience (Figure 3). That is, the loss of resilience with increasing non-Native American settlement in Figure 4 is not through a reduction in all resilience categories, but of some that were degraded for in the interest of other categories, such as variability and modularity for hydropower and flood control (Figure 3).

d. The Environmental Justice and Civil Rights Era

During the Environmental Justice and Civil Rights Era, the resilience of the social system in all factors begins to rebound (Figure 4) possibly reflecting the empowerment of formerly marginalized populations, greater involvement in decision making at the basin scale, and the resulting increase in diversity of viewpoints. However, the general decline in the biophysical resilience continues through this period (Figure 4), with particular reductions in diversity and variability. The dialogue suggested that this decline represents the legacy effect of the Dam Building Era on the ecosystem which continues to decline. Some improvement in services may reflect the attention to habitat restoration and salmon recovery during this period.

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170. Healey, *supra* note 80.

e. Implications for the Era of Climate Change

Along with many parts of planet Earth, the Columbia Basin is moving into a period of accelerated climate change. In the Columbia River Basin, predictions do not suggest a substantial change in the amount of precipitation annually; however, at lower elevations and latitudes, the current trend toward a flip from snow to rain-dominated watersheds is expected to continue.[171] The consequences of this shift in the dominant form of precipitation include earlier peak runoff, lower summer and fall contributions to the river flow, and higher water temperature.[172] In addition, scientists are beginning to consider secondary impacts of climate change in the Columbia Basin including increased demand for summer electric power for air conditioning within the Basin[173] and increased demand for irrigation because of changes in the growing season.[174] Studies are also underway to identify any potential cascading effects of these changes such as impacts to water temperature and river flow regime, as well as legacy effects like nutrient cycling that could lead to the extirpation of salmon runs. In short, while high levels of uncertainty surround efforts to translate global climatic change into consequences for local water supply, it is certain that the governance of a water-based social-ecological system like the Columbia River Basin must be prepared to adapt. However, as our assessment of social resilience shows, the change from ecosystem to engineered services has reduced the feedback from changes in the natural system to society through our systems of governance. As a result, while the Adaptive Water Governance project considers climate change to be a catalyst for change in governance,[175] it is difficult to imagine a response to the types of gradual changes currently underway in the Columbia River Basin as going beyond incremental adjustment in reservoir operation. Difficult to imagine, that is, were it not for a current window of opportunity[176] made possible by review of the Treaty governing international management of the river.[177]

In the Columbia Basin, treaty negotiations progressed slowly until catalyzed by an extreme flood event.[178] In 2014, certain flood control provisions of the resulting 1964 Treaty expire,[179] and, as a result, the 1964 Treaty is under review.[180] The

171. *See generally* Mote et al., *supra* note 56 (concluding losses of snowpack will continue and likely accelerate).

172. *See generally Effects of Temperature and Precipitation Variability on Snowpack Trends in the Western United States*, *supra* note 56.

173. *See generally Effects of Projected Climate Change on Energy Supply and Demand in the Pacific Northwest and Washington State*, *supra* note 56.

174. *See e.g.*, *West-Wide Climate Risk Assessments*, U.S. DEP'T INTERIOR: BUREAU RECLAMATION (last updated Sept. 22, 2014), *available at* http://www.usbr.gov/WaterSMART/wcra/; SANFORD EIGENBRODE, REACCH, REGIONAL APPROACHES TO CLIMATE CHANGE FOR PACIFIC NORTHWEST AGRICULTURE: CLIMATE SCIENCE NORTHWEST FARMERS CAN USE, (Kristy Borrelli et al. eds., 2014), *available at* https://www.reacchpna.org/files/2613/9336/7697/REACCHReportyear3.pdf.

175. *See* Cosens et al., *supra* note 3.

176. *Id.* at 2345; Olsson et al., *supra* note 9 (footnotes omitted) ("Social-ecological transformations toward adaptive governance occur in three phases. First, systems are generally prepared for the changes that are about to occur. The second phase involves a transition to a new social context for ecosystem management. The third phase is building the resilience of the new direction."). The authors go on to note that a window of opportunity is what links phase one to phase two. *Id.*

177. Shurts, *supra* note 115, at 75–248.

178. Barton & Ketchum, *supra* note 113, at 43–44.

179. Columbia River Basin Treaty, *supra* note 51.

Treaty contains no automatic termination date or renegotiation clause; instead, 2024 is the earliest date on which either party may unilaterally terminate the Treaty.[181] The Treaty requires at least ten years notice of termination, thus review of the Treaty began in 2010 with a target for completion in fall 2014.[182] The regional recommendation from review led by the U.S. Entity called for modernization of the Treaty with consideration of ecosystem function as a third purpose,[183] and was transmitted to the Department of State in December 2013.[184] The Provincial review recommendations were transmitted to the Provincial Cabinet in December 2013,[185] and in March 2014 the Province of British Columbia announced its position to continue, but improve the Treaty within the existing framework.[186] Many participants in the treaty review process view this as a window of opportunity for modernizing of the 1964 Treaty.[187] Whether that modernization will include increases in adaptive capacity and restoration of some of the prior variability, connectivity, and/or diversity of the natural system, remains to be seen.

V. CONCLUSIONS

Applying constructs of resilience and ecosystems services for large water basins is instructive for assessing change and envisioning lasting improvements in a time of complexity. The qualitative approach to assessment may be prone to bias and in a scientific publication we would include numerous recommendations for improvements in methodology, but only briefly cover this here. For purposes of this article the process nevertheless revealed the types of changes needed in both engineered and natural ecosystem services to provide room for adaptation and the governance barriers to doing so. Thus, recommendations will follow the discussion of methodology.

The general approach for assessing resilience provided qualitative data on how expert participants view the resilience of ecosystem services in the CRB. The dialogue and data analysis also confirmed that definitional problems remain in efforts to quantify resilience. Yet, the Delphi method coupled with the dialogue supported deeper discussion on the conceptual hurdle of assessing resilience. Further, the assessment was improved by a clear basin characterization and codified list of ecosystem services of interest. Yet, the dialogue and data analysis also confirmed that definitional problems remain in efforts to quantify resilience.

The addition of the expert dialogue to previous assessment methods revealed that uncertainty was generated from a lack of understanding in the definition of

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180. *Regional Recommendation*, COLUMBIA RIVER TREATY 2014/2024 REVIEW, http://www.crt2014-2024review.gov/RegionalDraft.aspx (last visited Nov. 6, 2014).

181. Columbia River Basin Treaty, *supra* note 51, at art. XIX.

182. *Id*.

183. The two purposes of the Columbia River Treaty are hydropower and flood control. *Id.* at Preamble.

184. *Regional Recommendation*, *supra* note 180.

185. *Columbia River Treaty Review: Draft B.C. Recommendation*, BRITISH COLUMBIA (2013), http://blog.gov.bc.ca/columbiarivertreaty/files/2012/07/Columbia-River-Treaty-Draft-BC-Recommendation.pdf.

186. *Columbia River Treaty Review: B.C. Decision*, BRITISH COLUMBIA (2014), http://blog.gov.bc.ca/columbiarivertreaty/files/2012/03/BC_Decision_on_Columbia_River_Treaty.pdf.

187. *See, e.g.*, Shurts, *supra* note 115, at 223–28.

specific factors when applied to an entire basin. Discrepancies in scores were explained and general agreement emerged during the dialogue. The raw data and statistical analysis suggest that the greatest uncertainty in scoring was in the categories of tight feedbacks, innovation, and ecosystem services. For example, it was acknowledged that the term "variability" required more context and most participants agreed that locally developed rules in the innovation category would not always build desired system resilience unless nested within higher levels of authority to provide standards and stability. The tight feedbacks and innovation categories were discussed at length which improved clarity of their meaning throughout the discussion. Variability in the ecosystem services scoring originated in part from the merged concepts of natural and engineered services, but also from disagreement in importance of services gained and diminished. A pre-scoring meeting to discuss and refine definitions would help address these issues.

Assessing resilience for the Pre-Contact Era fomented lengthy discussion. Our panel had specific expertise on pre-contact times, yet determining if the system had more or less resilience suffered from differing views on resilience to what. Those who considered the resilience of indigenous people to ecological change relevant to the timeframe rated resilience high due to the mobility and modularity of the society. Those who considered the resilience of indigenous people to an unanticipated disturbance, such as European contact, rated it low as history illustrates.

Our own sense is that the numbers in Table 4 romanticize the Pre-Contact Era, but may also reflect the absence of metrics for public health, food security, and wealth. Likewise, the survey numbers generally paint a dire picture of the Dam Building Era in which the entire nation was pulling together to move out of the economic turmoil of the Depression. This period of adjustment and reorganization was in response to an economic shock to the system and intervention from the federal level to stabilize the local economy. The analysis of this era would also benefit from the addition of metrics for public health, food security, and wealth, all of which were likely to improve during this era.

Despite the flaws, the process of performing a resilience assessment brought a group of experts together to envision and re-envision the CRB which will hopefully lead to more integration to tackle problems facing complex SESs, particularly large-scale, stressed water basins. The resilience assessment helped our thinking as we move closer to a window of opportunity to enhance overall resilience in the Columbia River Basin. The resilience assessment reveals that re-engineering the river by diversifying flood control, restoring habitat, and increasing modularity in the ecosystem by restoring salmon runs to currently blocked portions of the river while still retaining the benefits of the hydropower system may increase system resilience by providing room to adapt. Through the lens of resilience, we gained optimism that the thinking that produced the policies of the '70s and '80s has potentially helped the CRB become more resilient to climate change and that attention to re-engineering the system to introduce complexity where possible, while retaining the vast benefits from the system, may lead to parallel improvements in ecosystem resilience.

At the same time, assessment revealed necessary changes to governance. Continual federal intervention in the form of subsidy for water infrastructure development, while benefiting the basin social system, has also buffered the basin communities from loss of ecosystem services and led to development of the river to such a high degree of efficiency and optimization that it is vulnerable in the face of climate change. Nevertheless, both federal and international response is needed to help the Basin move to a more resilient position. The review of the Columbia River Treaty presents a window of opportunity in which the entire basin has been involved in identifying the need for more flexible and adaptive governance for the future of the Columbia River Basin.