RECLAMATION
Managing Water in the West

Independent External Peer Review Report: Thermal Regime of the Columbia River at Lake Roosevelt

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Regional Office
Boise, Idaho

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U.S. Department of the Interior

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Mission of the Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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1 PROJECT SUMMARY

The Pacific Northwest (PN) Region developed a white paper, *The Thermal Regime of the Columbia River at Grand Coulee Dam and Lake Roosevelt*, in response to regional requests to examine the potential for Grand Coulee to be operated to reduce downstream temperatures. These requests are based on a long-standing hypothesis in the region (outside of Reclamation) that the impoundment behind Grand Coulee (Franklin D. Roosevelt Reservoir, commonly referred to as Lake Roosevelt) could be used to help cool downstream water temperatures to benefit Endangered Species Act (ESA) listed salmon in the Columbia River. Reclamation began collecting temperature data in the reservoir in 2000. This data will contribute to a better understanding of what role Grand Coulee Dam could potentially play in reducing water temperatures in the Columbia River. The purpose of this paper presented for peer review is to examine data collected in Lake Roosevelt, as well as upstream and downstream of Grand Coulee Dam in the lower Columbia River, to characterize the current thermal regime. This paper also examines Grand Coulee Dam operational purposes and constraints, to provide a context to the regional request to use Grand Coulee to help cool water temperatures in the lower Columbia River.

The white paper is considered influential scientific information as defined by Office of Management and Budget Final Information Quality Bulletin for Peer Review (70 FR 2664-2677) and the Reclamation Manual Policy CMP P14 Peer Review of Scientific Information and Assessments. The nexus of this determination is that this document may provide a clearer understanding of the Columbia River thermal regime, opportunities or constraints at Grand Coulee Dam. There is potential that this information could inform ongoing processes in the basin, including the comprehensive Environmental Impact Statement (EIS) effort on the Columbia River System Operations being conducted by the Bureau of Reclamation, Army Corps of Engineers, and Bonneville Power Administration. Additionally, the information portrayed in this white paper may be useful to Environmental Protection Agency (EPA) for an anticipated need for a temperature Total Maximum Daily Load (TMDL) process for the Columbia River. This peer review is considered required based upon Reclamation Manual Policy CMP P14.

2 INDEPENDENT EXTERNAL PEER REVIEW PROCESS

The subject of this review is to consider the known information about the Columbia River at Grand Coulee Dam, including temperature data upstream, downstream and in the reservoir, to characterize the thermal regime of the Columbia River. This information combined with a discussion of project configurations and operations addresses questions concerning whether and

to what extent operational changes of Grand Coulee could influence downstream water temperatures to benefit ESA listed salmon in the Columbia River.

The peer reviewers were selected based on experience (at least 10 years) with expertise in hydrology, water quality, and water management. They were identified as technical experts that understand Columbia River water temperature and associated processes, and that understand reservoir/system operations. Peer reviewers have education, professional experience, and peer recognition in their field, and have contributed to their field. Peer reviewers are external to Reclamation.

Three groups of peer reviewers were selected, peer reviewers are associated with Bonneville Power Administration (BPA), the Army Corps of Engineers (Corps), and Portland State University (PSU). For more details, including qualifications, see Appendix A.

3 RESULTS OF THE INDEPENDENT EXTERNAL PEER REVIEW

The draft report integrated most of the comments from peer reviewers (Appendix A), many were editorial, to improve the content of the final paper. See Appendix B for comments and responses.

4 APPENDIX A: REVIEWERS QUALIFICATIONS

Three groups of reviewers that have experience with Columbia River water quality and Columbia River System operations.

4.1 Bonneville Power Administration:

4.1.1 Kim Johnson, Environmental Engineer, PE

BPA Environmental Strategist (2015-Present)

- Policy Advisor and Technical Authority on Clean Water Act issues

Corps of Engineers, Northwestern Division, Environmental Engineer (2009-2013)

- NEPA and Water Quality Policy SME

EPA, Region 10 & Region 7, Environmental Engineer (1997-2008)

- Clean Water Act and Clean Air Act SME

Bureau of Reclamation, Great Plains Region, Civil Engineer (1992-1997)

- Water Resources, Design and NEPA SME

USDA Forest Service, Montana Civil Engineer (1988-1992)

- Design, NEPA and Contract Administration

4.1.2 Mildred Chenell, Operations Research Analyst

Water Resources Modeling Experience, 2013-2018

CE-QUAL-W2 Modeling Experience, 2018

MESM, Water Resources Management, UCSB, 2009

4.2 Army Corps of Engineers

4.2.1 Kathryn Tackley (title)

Kathryn Tackley is a Physical Scientist with the U.S. Army Corps of Engineers, Portland District, a position she has held for the last ten years. Prior to that, Kathryn worked as a contractor for the Corps of Engineers, Environmental Research and Development Center in Vicksburg, Mississippi. Her work experience ranges from the study of benthic macroinvertebrates in the Mississippi and Ohio Rivers to water temperature and total dissolved gas management in the Columbia, Snake and Willamette Rivers. From 2016-2017 she was on the Board of Directors for the Oregon Lakes Association. She currently sits on the Corps of Engineers Committee on Water Quality and is the Water Quality Technical Manager for the Columbia River System Operations Environmental Impact Statement.

4.3 Portland State University

4.3.1 Scott Wells, Ph.D, PE

Professor of Civil and Environmental Engineering, Portland State University, Portland, OR 97207-0751

wellss@pdx.edu; 503-725-4276

Overview: He has a Ph.D. from Cornell University in Civil and Environmental Engineering, and graduate and undergraduate degrees from MIT and Tennessee Technological University. Since 1987 he has been at Portland State University and is currently Professor of Civil and Environmental Engineering after serving for 12 years as Department Chair. His research areas are in modeling of environmental fluid mechanics: surface water quality and hydrodynamics and solid-liquid separation processes. He has written over 100 technical publications.

He has received 2 Fulbright scholar awards, one to the Ukraine and the other to Israel where he taught and did research at the Earth Institute at Hebrew University and at the Israeli Geologic Survey in Jerusalem, Israel. During that time he worked on the environmental impacts of the proposed Peace Conduit between the Gulf of Aqaba and the Dead Sea.

He is the co-author of the water quality and hydrodynamic model, CE-QUAL-W2, used throughout the world for temperature and water quality modeling studies or rivers, lakes and reservoir systems. He and his research team are active as peer-reviewers for the US EPA, State of California, the State Department, and many other organizations.

He regularly teaches classes in water quality and hydrodynamic modeling at Portland State University, as well as workshops on modeling CE-QUAL-W2. He has presented an EPA sponsored webinar to a national audience on the Impact of Sediments on Water Quality, was an invited participant to EPA Region 6 workshop on water quality modeling, and was selected by EPA to serve on the Cayuga Lake Technical TMDL Review Team.

He has been a frequent invited seminar speaker and keynote speaker at conferences in the US and abroad (China, Netherlands, Brazil) and is currently a Principal Investigator for the Collaborative Center for Geo-hazards and Eco-Environment in Three Gorges Area, Hubei Province, Three Gorges University, Yichang, China.

Expertise: Environmental fluid mechanics: surface water quality and hydrodynamics and solid-liquid separation processes.

Experience in surface water quality and hydrodynamic studies: He has been involved in over 100 water body studies. In *Oregon*, he has been involved in hydrodynamic/water quality modeling on the Tualatin River, Hagg Lake, the Columbia Slough system (Lower Columbia Slough, Upper Columbia Slough, Smith and Bybee Lakes, Peninsula Canal), Klamath River, Russel Creek (near Eugene), Coast Fork of the Willamette River, Bull Run Reservoir #2, Bull Run Reservoir #1, Bull Run Reservoir #3, Bull Run Lake, Upper and Lower Bull Run River,

Willamette River (Oregon City Falls to Columbia River, including Multnomah Channel, Willamette River basin), Johnson Creek, Ashland Creek, Cooper Creek Reservoir, Skipanon River, Schooner Creek, Siletz Bay, South Santiam River, Middle Fork Willamette River, Bear Creek, Stone Creek below Timothy Lake, Laurance Lake, Waldo Lake, South Slough off Coos Bay, Yaquina Bay and Yaquina River, the Clackamas River Basin (Clackamas River, Timothy Lake, Lake Harriet, Frog Lake, North Fork Reservoir, Faraday Lake, Estacada Lake) and areas of Tillamook Bay and the Columbia River (Bonneville Dam to St. Helens). His experience also includes water quality and hydrodynamic studies in *Hawaii* (Wahiawa Reservoir), Virginia (N. Anna Reservoir), *Tennessee* (Center Hill Lake), *Kentucky* (Laurel River Reservoir), *Idaho* (Boise River, Lower Snake River from Brownlee Reservoir to C. J. Strike Reservoir, Brownlee Reservoir, C. J. Strike Reservoir, Spokane River, Oxbow Reservoir, Hells Canyon Reservoir, Coeur D'Alene Lake, Pend Oreille River and Lake), *California* (Folsom reservoir, Oroville Thermalito diversion pool, Klamath River, Philbrook Reservoir, DeSabla Reservoir, Butte Creek, Millerton Lake, Lake Spaulding, Bowman Lake, Rollins Reservoir, Fordyce Reservoir, Jackson Meadows Reservoir), *Washington* (Columbia River, Clear Lake, Spirit Lake, Spokane River, Long Lake, White and Puyallup Rivers, Snohomish River and Estuary, Green River, Lake Roosevelt, Chelan River, Pend Oreille River, Tolt Reservoir, Lake Chaplain, Budd Inlet/Capitol Lake/Deschutes River, Chester Morse Reservoir, Cedar River, Banks Lake, Keechelus Reservoir, Kachess Reservoir), *Colorado* (Cherry Creek Reservoir), *Wisconsin* (Kinnickinnic River, Lake George), *North Carolina* (Jocassee and Keowee Reservoirs), *Oklahoma* (Tenkiller Reservoir on the Illinois River, Eucha Reservoir, Spavinaw Reservoir), Texas (Lake Lavon, Lake Travis), *Florida* (Tampa Bay Water Supply Reservoir, Reservoir C-44), *Montana* (Warm Springs Ponds, Butte, MN) , *New York* (Conesus, Hemlock, Cayuga, and Honeoye Lakes*), West Virginia, Pennsylvania, Ohio* (Ohio-Alleghany-Monongahela Rivers), *China* (Three Gorges Reservoir), *Spain*, *Peru* (Chaglla Reservoir), *Brazil* (Tabajara Reservoir), *Guyana* (Amaila Reservoir), *Costa Rica, Canada* (Lake Lagopede, Pit Lakes region lakes), *Israel* (Lake Kinneret or Sea of Galilee, Jordan River, Dead Sea, experimental ponds at Dead Sea Works), and in the *Ukraine* (Dnieper River-reservoir system and Kiev Sea).

Education: Ph.D. Cornell Univ.; S.M. MIT; BSCE Tennessee Technological Univ., P.E. in Civil Engineering and in Environmental Engineering

Reviewer: National Science Foundation Research Proposals, USGS Water Resource Research Institute Proposals, Fluid/Particle Separation Journal, Powder Technology, Separations Technology, Separation Science and Technology, Journal of Environmental Engineering ASCE, Journal of Geotechnical Engineering ASCE, Journal of Hydrologic Engineering ASCE, Journal of Hydraulic Engineering ASCE, Journal of Irrigation and Drainage ASCE, Environmental Science and Technology, Water Resources Research, International Journal of Heat and Mass Transfer, Estuarine, Coastal and Shelf Science, Journal of HydroInformatics, American Society of Agricultural and Biological Engineers.

Partial list of research and consulting partners: METRO (Portland); Rhone-Poulenc Chemical Company; State of Oregon; Scientific Resources, Inc.; OBEC Consulting Engineers; AMTRAK; EWEB; Woodward-Clyde Consulting Engineers; Fishman Environmental Services;

Black/Veatch; Cornforth Consultants, Inc; HDR Engineering, Inc; CH2MHill; Carollo Engineers; SECOR; R. M. Towill Corporation; LimnoTech, Inc; City of Bremerton; EPA; City of Sutherlin, OR; Lincoln City, OR; Tulalip Indian Tribes; Portland General Electric; City of Portland; Washington Department of Ecology; Israeli Geologic Survey; Idaho Power Company, AVISTA Corporation; USBLM; US BurRec; PacifiCorp; Chelan Public Utility District; City of Kansas City; Pacific, Gas and Electric Company; Stormwater Management 360; City of Toledo; MWH Engineering; HyQual Engineering; Waterways Experiments Station (Corps of Engrs); Corps of Engrs (Portland District); Oregon DEQ; Idaho DEQ; Friends of Blue Lake; King County (WA); Clackamas County (OR), CRITFC, US Forest Service; CDS Inc.; Clackamas River Water Supply group; Middle Fork Irrigation District; USGS; West Consultants, Seattle, WA; ConTech Inc., Portland, OR.

Selected publications: Dr. Wells' publications have appeared in the following Journals: Aquatic Ecology, Ecological Modeling, Water Resources Bulletin, ASCE Journal of Hydraulic Engineering, Research Journal of the Water Pollution Control Federation, Fluid/Particle Separation Journal, ASCE Journal of Environmental Engineering, Water Research, Water Environment Research and have appeared in Proceedings for the following conferences: ASCE World Water and Envir. Resources, Water Resources and Envir. Engr., WEF National TMDL Science and Policy, International Reservoir Limnology and Water Quality, Federal Interagency Hydrologic Modeling, IAHR Hydroinformatics, Ecohydraulics, American Filtration Society, and American Bar Association Water Law conferences. He also has written almost 100 technical reports. A full-list can be found at http://www.cee.pdx.edu/~scott. A selected list of publications since 2005 are shown below:

Al-Zubaidi, H. A. M., and Wells, S. A. (2018) "3D Hydrodynamic and Water Quality Model Development and Verification in Surface Water Bodies", Journal of Hydraulic Research, in-print.

Berger, C. and Wells, S. (2017) "Modeling the Impact of Water Quality and Food Web Structure on Bull Trout in Two Washington Reservoirs," ASCE EWRI Congress, Sacramento, May.

Van Glubt, S., Wells, S., and Berger, C. (2017) "Hydrodynamic and Water Quality Modeling of the Chehalis River in Washington," ASCE EWRI Congress, Sacramento, May.

Al-Murib, M., Wells, S., and Talke, S. (2017) "Estimation of Surface Water Temperature of the Tigris River System in Iraq," ASCE EWRI Congress, Sacramento, May.

Al-Zubaidi, H. A. M., and Wells, S. A. (2017) "3D Numerical Temperature Model Development and Calibration for Lakes and Reservoirs: A Case Study, ASCE EWRI Congress, Sacramento, May.

Daobin, J, Wells, S. A., Yang, Z., Liu, Defu, Huang, Y., Ma, J. and Berger, C. (2017) "Impacts of water level rise on algal bloom prevention in the tributary of Three Gorges Reservoir, China," Ecological Engineering, Volume 98, January 2017, Pages 70-81.

Wells, S. and Berger, C. (2016) “Modeling the Response of Dissolved Oxygen to Phosphorus Loading in Spokane Lake,” Lake and Reservoir Management, 32:3, 270-279, (DOI:10.1080/10402381.2016.1211910).

Annette B.G. Janssen, George B. Arhonditsis, Arthur Beusen, Karsten Bolding, Louise Bruce, Jorn Bruggeman, Raoul-Marie Couture, Andrea S. Downing, J. Alex Elliott, Marieke A. Frassl, Gideon Gal, Daan J. Gerla, Matthew R. Hipsey, Fenjuan Hu, Stephen C. Ives, Jan H. Janse, Erik Jeppesen, Klaus D. Jöhnk, David Kneis, Xiangzhen Kong, Jan J. Kuiper, Moritz K. Lehmann, Carsten Lemmen, Deniz Özkundak, Thomas Petzoldt, Karsten Rinke, Barbara J. Robson, René Sachs, Sebastiaan A. Schep, Martin Schmid, Huub Scholten, Sven Teurlincx, Dennis Trolle, Tineke A. Troost, Anne A. Van Dam, Luuk P.A. Van Gerven, Mariska Weijerman, Scott A. Wells, Wolf M. Mooij (2015) “Exploring, exploiting and evolving diversity of aquatic ecosystem models: a community perspective”, Aquatic Ecology, Volume 49, Issue 4, 513-548, DOI 10.1007/s10452-015-9544-1.

Ma, Jun; Liu, Defu; Wells, Scott A.; Tanga, Hongwu; Jif, Daobin; Yang, Zhengjian (2015) “Modeling density currents in a typical tributary of the Three Gorges Reservoir, China”, Ecological Modeling, Volume 296, 24 January 2015, Pages 113–125, doi:10.1016/j.ecolmodel.2014.10.030

Berger, C. J., Bigham, G., and Wells, S. A. (2014) “Prediction of GHG Emissions from a New Reservoir,” Proceedings World Environmental and Water Resources Congress, EWRI, ASCE, Portland, OR, pp. 1010-1019.

Martinez, V. I., Wells, S. A. and R. C. Addley (2014) “Meeting Temperature Requirements for Fisheries Downstream of Folsom Reservoir, California,” Proceedings World Environmental and Water Resources Congress, EWRI, ASCE, Portland, OR, pp. 1081-1092.

Shoajei, N. and Wells, S. A. (2014) “Automatic Calibration of Water Quality Models for Reservoirs and Lakes,” Proceedings World Environmental and Water Resources Congress, EWRI, ASCE, Portland, OR, pp. 1020-1029.

Wells, S. A. (2014) “Integrating Fish Bioenergetics and Volitional Movement in Water Quality and Hydrodynamic Models,” Proceedings Water Environment Federation Conference, New Orleans, September 2014.

Berger, C. J.; Wells, S. A..; and Wells, V. (2012) "Modeling of Water Quality and Greenhouse Emissions of Proposed South American Reservoirs," Proceedings of the 2012 World Environmental & Water Resources Congress, Albuquerque, New Mexico, May 20-24, 2012, pp. 911-923.

Wells, S. A..; Wells, V., and C. J. Berger (2012) " Impact of Phosphorus Loading from the Watershed on Water Quality Dynamics in Lake Tenkiller, Oklahoma, USA," Proceedings of the 2012 World Environmental & Water Resources Congress, Albuquerque, New Mexico, May 20-24, 2012, pp. 888-899.

Wells, V. I. and Wells, S. A. (2012) “CE-QUAL-W2 Water Quality and Fish-bioenergetics Model of Chester Morse Lake and the Cedar River,” Proceedings World Environmental and Water Resources Congress, EWRI, ASCE, Albuquerque, NM, pp. 2756-2767.

Mooij WM, Trolle D, Jeppesen E, Arhonditsis G, Belolipetsky PV, Chitamwebwa DBR, Degermendzhy AG, DeAngelis DL, De Senerpont Domis LN, Downing AS, Elliott JA, Fragoso Jr CR, Gaedke U, Genova SN, Gulati RD, Håkanson L, Hamilton DP, Hipsey MR, ‘t Hoen J, Hülsmann S, Los FJ, Makler-Pick V, Petzoldt T, Prokopkin IG, Rinke K, Schep SA, Tominaga K, Van Dam AA, Van Nes EH, Wells SA and Janse JH (2010) “Challenges and opportunities for integrating lake ecosystem modelling approaches,” Aquatic Ecology:DOI:10.1007/s10452-010-9339-3,44(3):633-667.

Cheslak, E; Berger, C; Annear, R., and Wells, S. (2009) “Protecting Spring-Run Chinook Salmon: The Use of a Two-dimensional Water Temperature Model to Evaluate Alternative Hydroelectric Operations,” WaterPower XVI Proceedings, Spokane, WA, July 27-30, 2009

Berger, C.; McKillip, M.; Annear, R.; Wells, V., and Wells, S. (2009) “Modeling the Spokane River-Lake Roosevelt System,” Proceedings IAHR 33rd Congress, Vancouver, BC, August 9-14, pp. 6223-6230.

Berger, C. and Wells, S. (2008) “A Macrophyte Water Quality and Hydrodynamic Model,” ASCE, Journal of Environmental Engineering, Volume 134, Issue 9, pp. 778-788 (September 2008).

Wells, S. A., J. R. Manson, and J. L. Martin (2007) “Numerical Hydrodynamic and Transport Models for Reservoirs,” Chapter 4 in Energy Production and Reservoir Water Quality, ASCE.

Annear, R. L., and S. A. Wells (2007), A comparison of five models for estimating clear-sky solar radiation, Water Resour. Res., 43, W10415, doi:10.1029/2006WR005055.

Berger, C. J. and Wells, S. A. (2007) "Development and Calibration of Lake Whatcom Water Quality Model," Proceedings of the Water Environment Federation TMDL Conference, Seattle, WA, June 24-27.

Berger, C. J. and Wells, S. A. (2007) "Modeling Effects of Channel Complexity and Hyporheic Flow on Stream Temperatures," Proceedings Water Environment Federation TMDL Conference, Seattle, WA, June 24-27.

McKillip, M. and Wells, S. (2006) “Hydrodynamic, water quality and fish bioenergetics modeling in Lake Roosevelt Washington USA using CE-QUAL-W2,” Proceedings, 5th International Conference on Reservoir Limnology and Water Quality, Brno, Czech Republic, August 27-September 2.

Harrison, J. R.; Wells, S. A.; Rychert, R. C.; Naymik, J. (2005) “Searching For A Practical Approach To Partition Biomass And Detritus For Ecological Models Applied To The

Snake River And Its Reservoirs," Proceedings ASLO Conference, Salt Lake City, UT, February 24-25.

Wells, S. A. (2005) "Use and Misuse of Computer Models in Water Disputes," Proceedings American Bar Association 23rd Annual Water Law Conference, San Diego, CA.

4.3.2 Chris Berger, Ph.D., PE

Research Assistant Professor, Department of Civil and Environmental Engineering, Portland State University

Expertise: Water Quality and Hydrodynamic Modeling; Development and application of CE-QUAL-W2 water quality model; Ground Water Modeling; Computer Programming; Water Quality Sampling; Environmental Data Analysis

Experience: Currently participating in the development of CE-QUAL-W2 water quality models. Responsibilities include computer programming, model calibration, water quality sampling, analysis of management scenarios, and the development of specialized macrophyte/epiphyton/algal and culvert simulation algorithms. Contributed to the development of water quality models of the Tualatin River, Oregon; Columbia Slough, Oregon; Willamette River, Oregon; Lake Whatcom, Washington; Cooper Creek Reservoir, Oregon; Spokane River, Washington; Lake Whatcom, Washington; Laurance Lake, Oregon; the Snake River, (Brownlee Reservoir, Hells Canyon Reservoir, and Oxbow Reservoir) Idaho; and Wahiawa Reservoir, Hawaii. He was a contract worker with the U. S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi (October, 1996 to December, 1996) and conducted literature review of biological and chemical rate coefficients used in water quality modeling. He worked as a Junior Engineer for Mackenzie Engineering Incorporated, Portland (June, 1991 to December, 1991, site development work including the design of storm sewers, sanitary sewers, roads, parking lots, and water utilities) and was Assistant Watermaster for the Tualatin River District in Washington County. Oregon (June, 1990 to September, 1990, measured stream flows, maintained stream gaging stations, helped regulate water rights, surveyed stream gaging sites, and inspected wells in the Tualatin River basin). Author of over 35 technical reports and 9 publications.

Education: PhD. ESR/CE, Portland State University; MS CE, PSU, BS Civil Engineering, PSU; BS Physics, Oregon State University.

Professional registration: Professional Engineer, P. E., Oregon #48590, Civil Engineering

Reviewer: Hydrobiologia; Jour. of the North American Benthological Society; Jour. of Hydrological Engineering; Water Resources Research

Selected Publications:

Berger, C. and Wells, S. (2017) “Modeling the Impact of Water Quality and Food Web Structure on Bull Trout in Two Washington Reservoirs,” ASCE EWRI Congress, Sacramento, May.

Van Glubt, S., Wells, S., and Berger, C. (2017) “Hydrodynamic and Water Quality Modeling of the Chehalis River in Washington,” ASCE EWRI Congress, Sacramento, May.

Wells, S. and Berger, C. (2016) “Modeling the Response of Dissolved Oxygen to Phosphorus Loading in Spokane Lake,” Lake and Reservoir Management, 32:3, 270-279, (DOI:10.1080/10402381.2016.1211910)

Berger, C. J.; Bigham, G. N..; and Wells, S. A. (2014) Prediction of GHG Emissions from a New Reservoir," Proceedings of the 2014 World Environmental & Water Resources Congress, Portland, Oregon, June 1-5, 2014.

Berger, C. J.; Wells, S. A..; and Wells, V. (2012) "Modeling of Water Quality and Greenhouse Emissions of Proposed South American Reservoirs," Proceedings of the 2012 World Environmental & Water Resources Congress, Albuquerque, New Mexico, May 20-24, 2012.

Wells, S. A..; Wells, V., and C. J. Berger (2012) " Impact of Phosphorus Loading from the Watershed on Water Quality Dynamics in Lake Tenkiller, Oklahoma, USA," Proceedings of the 2012 World Environmental & Water Resources Congress, Albuquerque, New Mexico, May 20-24, 2012

Cheslak, E; Berger, C; Annear, R., and Wells, S. (2009) “Protecting Spring-Run Chinook Salmon: The Use of a Two-dimensional Water Temperature Model to Evaluate Alternative Hydroelectric Operations,” WaterPower XVI Proceedings, Spokane, WA, July 27-30, 2009

Berger, C.; McKillip, M.; Annear, R.; Wells, V., and Wells, S. (2009) “Modeling the Spokane River-Lake Roosevelt System,” Proceedings IAHR 33rd Congress, Vancouver, BC, August 9-14, pp. 6223-6230.

Berger, C. and Wells, S. (2008) “A Macrophyte Water Quality and Hydrodynamic Model,” ASCE, Journal of Environmental Engineering,Volume 134, Issue 9, pp. 778-788 (September 2008).

Berger, C. J. and Wells, S. A. (2007) "Development and Calibration of Lake Whatcom Water Quality Model," Proceedings of the Water Environment Federation TMDL Conference, Seattle, WA, June 24-27, 2007.

Berger, C. J. and Wells, S. A. (2007) "Modeling Effects of Channel Complexity and Hyporheic Flow on Stream Temperatures," Proceedings of the Water Environment Federation TMDL Conference, Seattle, WA, June 24-27, 2007.

Wells, S. A., Berger, C. J., Annear, R. L., McKillip, M. and Jamal, S. (2003) "Willamette River Basin Temperature TMDL Modeling Study," Proceedings National TMDL Science and Policy Conference, Chicago, IL, November 16-19, 2003.

Berger, C.; Annear, R. and Wells, S. (2002) “TMDL Development of the Spokane River-Long Lake System using CE-QUAL-W2,” Proceedings, Water Environment Federation National TMDL Science and Policy Conference, Phoenix, Nov 13-16, 2002.

Berger, C.; Annear, R. and Wells, S. (2002) “Willamette and Columbia River Waste Allocation Model,” Proceedings, 2nd Federal InterAgency Hydrol. Modeling Conf., Las Vegas, July 28-Aug 1, 2002.

Berger, C. and Wells, S. (1999) "Macrophyte Modeling of the Columbia Slough," Proceedings International Water Resources Engineering Conference, ASCE, Seattle, Wa, Aug.8-11.

Wells, S. and Berger, C. (1998) "Water Quality Impacts of Urban Stormwater Runoff from the Portland International Airport on the Columbia Slough," Proceedings Gdanska Fundacja Wody, Podczysczanie Wod Opadowych Wymagania Formalnoprawne I Mozliwosci Technicne, Gdansk, Poland.

Wells, S. A.; Berger, C. J., Abrams, M. (1996) "Winter Storm Event Impacts on Dissolved Oxygen Levels in the Columbia Slough System," The Pacific Northwest Floods of February 6-11, 1996, Proceedings of the Pacific Northwest Water Issues Conference, ed. by A. Laenen, American Institute of Hydrology, pp.107-126.

Berger, C. and Wells, S. A. (1995) "Effects of Management Strategies to Improve Water Quality in the Tualatin River, Oregon," in *Water Resources Engineering*, Vol. 2, ed. by W, Espey Jr. and P. Combs, ASCE, 1360-1364.

APPENDIX B: TABLES OF REVIEW COMMENTS AND RESPONSES.

Review of Thermal Regime of the Columbia River at Lake Roosevelt
(April 2016)

Reviewer	Pg	Line	Comment	Suggested Revision	Comment Resolution
M. Chennell	1	2	Warm water events affect many species, not just anadromous	Insert “and other” prior to “species”	Adopted
K. Johnson	1	5	Report is looking at ability to influence water temp in future	Replace “have been” with “be”	Adopted
K. Johnson	1	6-10	Sentences starting with “Some storage reservoirs..” are awkward, and the references to lake behavior here are confusing.	Recommend revising to focus on stratification and ability to release cool water to mitigate downstream temperatures.	Adopted
M. Chennell	1	9	Odd phrasing	Strike “much of their”	Adopted
K. Johnson	1	34-37	Outflow water temperatures are also highly influenced by inflow temperature.	Recommend adding the concept of inflow temps and boundary conditions.	Adopted
M. Chennell	3	61	Might say in text that temp control often to release warmer water…	…noted in footnote on line 77	Adopted
K. Johnson	3	71-73	“data” and “near the dam” is repeated in this sentence. Also it would be helpful to provide more detailed information.	Recommend rewording to say something like, “The data was collected using a string of temperature loggers at different depths from 2000-2016 to document the thermal conditions of Lake Roosevelt near the dam.”	Adopted
K. Johnson	4	90	There are actually 31 federal dams in the Federal Columbia River “Power System.” Figure 2-2 also shows some of the federal non-power	May want to use a different map, or revise the language to be consistent with Figure 2-2.	Noted

Reviewer	Pg	Line	Comment	Suggested Revision	Comment Resolution
			dams – so the number of federal dams on this map is >31.		
M. Chennell	4	92	Flood risk mitigation	Change to Flood risk management	Adopted
K. Johnson	7	117	"As shown by Table 2-1." Is not a sentence	Edit	Adopted
M. Chennell	7	123	M&I abbreviation should be used earlier	Use on pg 4, line 84, read "M&I water supply"	Adopted
M. Chennell	7	128+	Table: 3rd column label: kcfs, 5th column label superscript 2 looks…	Like squared.	Adopted
K. Johnson	8	140	Note in last row of table has a single "("		Adopted
K. Johnson	8	145	"warm" is a relative statement	Recommend replacing "warm" with "warmer"	Adopted
K. Johnson	9	154-159	This description is confusing – slightly lower in July and then later in summer shifts to cooler.	Recommend revising to say "starting in July outflows are cooler" or adding more detail for the later in the summer (months and temp difference).	Adopted
M. Chennell	9	157	Patter should read pattern	Edit	Adopted
M. Chennell	9	160	Figure 2-3 missing a key.	Add key	Adopted
K. Johnson	10	176-179	Temperature data is available for Priest Rapids and other mid-C dams (year round) at the follow website: http://pweb.crohms.org/ftppub/water_quality/tdg/	May want to replace "Presumable" with a reference to the site and update the language that data is limited.	Adopted
K. Johnson	10	180	Sentence is awkward	Add "to" between Dam and Pasco, WA and possibly add a reference to Table 2-3.	Adopted
M. Chennell	11	188	Confusing to include Clearwater data here	Wait until discussing Dworshak	Adopted
M. Chennell	11	201	Extra close paren	Remove	Adopted

Reviewer	Pg	Line	Comment	Suggested Revision	Comment Resolution
K. Johnson	11	208	The Mid-Cs are not technically "privately-owned," but rather are owned by "Public Utility Districts."	Replace "privately owned," with something a little more accurate – since line 175 already identifies the dams, maybe just keep the same PUD reference.	Adopted
K. Johnson	11-13	197-217	Is there a reason that 2009 was chosen for this discussion?	Add why 2009 if there is a reason.	This year was selected as just an example year – typical ops, thermal situation. Added explanatory sentence.
K. Johnson	15	251-260	It would be interesting to add a sentence or two about the Columbia River sockeye in 2015, since they migrated through the river below Grand Coulee	Language should be readily available in the NOAA report.	Added language about Columbia River Sockeye in 2015.l
K. Johnson	15	263	Typo 2-9 x 2		Adopted
M. Chennell	22	341	Not sure key is helpful.	Explain U1-18 (Units 1-18=L&R PHs), etc.	Added explanation.
M. Chennell	23	357	Add "of Grand Coulee Dam" after "configuration"	Edit	Adopted
K. Johnson	23	363	Recommend adding a reference to the Vernita Bar Agreement		Adopted
K. Johnson	23	367	Footnote 7 – says successfully winter operations		Adopted
M. Chennell	24	384	Define TMT	Also, add to list of Acronyms	Adopted
M. Chennell	25	Ftnt.	Unclear PP vs PH. Earlier PH was used. Be consistent	Plant for Project, House for Sub-Project?	Used power plant to be consistent with other Reclamation documents.
K. Johnson	25	413	Recommend deleting references to voluntary and involuntary spill – not relative to this discussion re: Grand Coulee operations.		Adopted

Reviewer	Pg	Line	Comment	Suggested Revision	Comment Resolution
K. Johnson	25	414-415	The actual TDG water quality standards are established by the states and approved by EPA.	Recommend deleting the Clean Water Act sentence and add “consistent with state water quality standards.” After coordinated together to minimize TDG in the following sentence.	Adopted
M. Chennell	25	417	Add “system” before “TDG” & “with forebay elevation” prior to …	“below 1265.5”	Adopted
M. Chennell	25	420-2	Remove parens, replace significant with “as much” or something…	Edit	Adopted
K. Johnson	25	420 & 422	Repetitive language in these lines referring to drum gates not generating significant TDG	Recommend deleting the first reference in parenthesis.	Adopted
M. Chennell	22-6	All	Edit for consistent voice with other parts of the paper.	Edit	Adopted
M. Chennell	26	446	This section seems to require a new heading (not summer specific)	Add Heading	Adopted
K. Johnson	27	461	Does this operation represent a specific year or just a typical year	Add language	Adopted
K. Johnson	28	466	This sentence sounds like all the constraints prevent operation of the Dam	Revise language to read constraints effect the operational flexibility.	Adopted
K. Johnson	28	468-487	This section seems to be answering a question about operational flexibility that would help with temperature, but up to this point all the data says there is no cool water available even if there was flexibility to modify operations.	May be helpful to spell out the flexibly operations question at the beginning of this section and then show that operational flexibility is limit even if there was cool water available.	We wanted to make both points, that cool water is not available and the project is highly constrained operationally.
M. Chennell	28	490	“is provided to provide” repetitive	Edit	Adopted
M. Chennell	29	522	Remove extra close paren	Edit	Adopted
M. Chennell	32-3	All	These are the same graph. Why include both	Remove one of the graphs	Adopted

Reviewer	Pg	Line	Comment	Suggested Revision	Comment Resolution
M. Chennell	34	Fig	Add key, also add DWR release temps or something for context		Adopted
M. Chennell	28-34	All	Work on comparison DWR to GCL. Specific Temps? Tables?	Inflow/Outflow? Feels lacking a bit…	We added to the DWR comparison section, but don't want to over-emphasize this section.
M. Chennell	46	658+	What does invert elevation mean?		Added language to clarify.
M. Chennell	47-52	All	These seem to show greater than 1 degree dif. I'd hesitate to use		We left in, reporting all available information.
			As folks may want to cut off all 3rd PH gen in times of high temps.		Not possible due to operational constraints.

Review of Thermal Regime of the Columbia River at Lake Roosevelt
(April 2016)

Reviewer	Pg	Line	Comment	Suggested Revision	Comment Resolution
Tackley	1	6-7	Confusing sentence; consider revising.	*USBR edit: Storage reservoirs that have the ability to mitigate increasing temperatures exhibit thermal stratification and behave similar to lakes.*	Adopted
	11	186	Table 2-3. Is this table showing the monthly average of the mean daily river temperatures? If mean daily, then why is there only one reading per month?	Fixed to state Median monthly no Median daily	Adopted
	11	207-208	Reference Section 2.3 which describes constraints. Also, could you use the drum gages		Interesting concept. For this paper we avoided

Reviewer	Pg	Line	Comment	Suggested Revision	Comment Resolution
			to discharge warm surface water out of the reservoir in the summer and potentially cool the reservoir in the fall? Has this been looked into?		speculating about operational changes and focus on current constraints. Future studies may warrant modification to operations, although in the example you suggest we would then be just shifting the high temperature releases into summer to potential aid fall. At this time the concern we hear more about is summer temperature issues in the lower river.
	13	214-216	Are these the only available outlets at Grand Coulee Dam?		Yes – there are two levels of functioning regulating outlets. Both are described.
	14	232	What about heat gain from solar inputs?		The RT influences the relative influence of the advective influence. So with lower RT the net gain of energy from solar radiation on the reservoir should be more influential.
	14		General comment: Consider a conclusion that ties Section 2.2.3.1 back to water temperatures.		Added a summary sentence to the section.
	18	313	Consider adding a conclusion. Where is the so what statement(s)?		Added a sentence in the summary paragraph to

Reviewer	Pg	Line	Comment	Suggested Revision	Comment Resolution
					high-light that Grand Coulee released the coolest water possible during the 2015 sockeye migration season.
	22	344	Section 2.3: Either put in the front, or tie operational constraints more to water temperature discussion		We've gone back and forth on order of the operations/temperature issue. We decided to put temperature at the front because that is the focus of this paper, but added language to try and tie the constraints to the temperature discussion.
	24	386-400	Move section under Section 2.3.3??		Adopted
	34	581	There is some thermal stratification in the summer, however there is no cold water reserves like that found in Dworshak Res.		Included

Reviewer	Pg	Line	Comment	Suggested Revision	Comment Resolution
Berger	8, Table 2-2	140	Formatting error in last row		Corrected
Berger	10	176-179	Suggest breaking sentence into 2 sentences. Also, "Data" is plural	"Presumable fall and winter temperatures are very similar from below Grand Coulee Dam to below Priest Rapids Dam near Pasco, Washington (upstream of the confluence with the Snake River). Data are limited at Pasco, Washington in the fall and winter."	Adopted
Berger	10	182-185	Suggest breaking sentence into 2 sentences.	"The last few days in August into September the temperatures in Lake Roosevelt are at their annual peak, and atmospheric conditions are such that water actual cools as it travels downstream. This condition likely holds until the reservoir becomes more isothermal in October (as described in the next section)."	Adopted
Berger	10, Table 2-3 caption	189	"Data" is plural	"at Spalding, ID data are for comparison…"	Adopted
Berger	12, Figure 2-5		It would be helpful to show penstock elevations in this figure.		Good suggestion, included.
Berger	15	263	Format error, "Figure 2-9" referenced twice		Fixed

Reviewer	Pg	Line	Comment	Suggested Revision	Comment Resolution
Berger	16	272-275	Suggest breaking sentence into 2 sentences.	"In 2015, Grand Coulee outflows during June and early July were 1 to 2 degrees cooler than Columbia River temperatures upstream at the international boundary (Figure 2-10). This is a pattern that occurs each year where Grand Coulee Dam releases water that is cooler than inflows during spring and summer and warmer during fall and winter.	Adopted
Berger	18	311	edit	"as it moves downstream **in** the Middle-Columbia reach,"	Adopted
Berger	18, Table 2-5		Text quality in table is low. Also table extends beyond margins.	Re-insert table into document	Fixed
Berger	30	543	The longer residence time of Dworshak could also be listed in the bullets		Added
Berger	36	602	A space is needed between "Figure 5-1" and "is"		Adopted
Wells		41	"Grand Coulee Dam has no potential to mitigate for downstream temperatures". The words "no potential" are probably not correct. I think that we could probably explore many pathways to affect temperatures downstream but they would impact power production and Banks Lake. So I think it is safer to say "limited" rather than "no" potential.	Change this to "has limited potential to mitigate for downstream temperatures".	Adopted
Wells	10		Fig 2.4 – nice figure – it says a lot!	None	Thank you.

Reviewer	Pg	Line	Comment	Suggested Revision	Comment Resolution
Wells	13	230	"The RT controls the significance of the advective source of heat, with shorter RT corresponding to increased influence of advective heat gain." During cooling periods this would affect not heat gain, but heat loss.	"The RT controls the significance of the advective source of heat, with shorter RT corresponding to increased influence of advective heat gain or loss."	Adopted
Wells	32,33		Fig 2-20 and 2-21 appear to be duplicates	Eliminate one of the figures.	Fixed
Wells	34	576	"to develop thermal stratification behind the dam"	"to develop thermal stratification."	Adopted
Wells	34	583	"No additional potential exists…"	"Little additional potential exists…"	Adopted