Summary Report of the Peer Review for the 2020 Annual Project Report

Bureau of Reclamation Order No. 140R4021F0024

Prepared for:

US Bureau of Reclamation

Upper Colorado Regional Office

125 South State Street, Room 8100

Salt Lake City, UT 84138-1147

11/15/2021

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125 South State Street, Room 8100
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Prepared by:

Wood Environment & Infrastructure Solutions, Inc.

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Acronyms

CRe	Colorado River ecosystem
GIS	Geographic Information Systems
GCDAMP	Glen Canyon Adaptive Management Program
GCMRC	Grand Canyon Monitoring and Research Center
LTEMP	Glen Canyon Dam Long-Term Experimental and Management Plan
P	phosphorus
ROD	Record of Decision
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

The operations of Glen Canyon Dam and other management activities have significant impact on ecological, hydrological, and cultural systems along the Colorado River from the forebay of the Glen Canyon Dam to upper Lake Mead, referred to as the Colorado River ecosystem (CRe). The Glen Canyon Adaptive Management Program (GCDAMP) provides a process for adaptive management of dam operations, including monitoring and research, integration, and management of natural, cultural, and recreational resources affected by Glen Canyon Dam operations. The Grand Canyon Monitoring and Research Center (GCMRC) conducts scientific research on the effects of dam operations and associated management and provides robust, objective scientific data on the impact of dam operations.

There are eleven priority resources identified in the Long-Term Experimental and Management Plan (LTEMP). These eleven priority resources include archeological and cultural resources, natural processes, humpback chub, hydropower and energy, other native fish, recreational experiences, sediment, tribal resources, rainbow trout fishery, nonnative invasive species, riparian vegetation.

As part of the Science Advisors Program which provides independent review on the research programs, five peer reviewers were selected to provide a peer review of the *Fiscal Year 2020 Annual Project Report to the Glen Canyon Dam Adaptive Management Program* (USGS 2020). The reviewers represent a breadth of expertise related to fisheries and aquatic ecology, vegetation management and riparian ecology, hydrology of river systems, GIS data management and remote sensing, socioeconomics related to tribal resources, monitoring, and adaptive management. The peer reviewers were also selected to avoid conflicts of interest with the GCDAMP.

The peer reviewers evaluated the material provided by the GDCAMP, which included the annual report and associated project presentations. The review focused on two broad questions about goals and objectives as well as specific feedback on research design, program outcomes, indicators, and methods. While reviewers responded with suggestions and recommendations for improvements, they agreed the research programs being pursued by the GCDAMP are overall connecting to LTEMP goals.

1.0 BACKGROUND

The Glen Canyon Adaptive Management Program (GCDAMP) was established in following the 1996 Record of Decision (ROD) on the Operation of Glen Canyon Dam to comply with the 1992 Grand Canyon Protection Act. Dam operations affect river hydrology, sediment dynamics, temperature and chemistry, food web dynamics, and aquatic and riparian species and communities along the Colorado River from the forebay of Glen Canyon Dam to upper Lake Mead, referred to as the Colorado River ecosystem (CRe).

With an updated 2016 ROD, the activities of GCDAMP came under governance of the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP). LTEMP established key resource priorities in eleven areas and requires adaptive management of these resources through experimental and management actions such as, but not limited to, fall and spring high-flow experiments, humpback chub translocation, macroinvertebrate production flows, mechanical removal of rainbow trout, and riparian vegetation restoration. By monitoring these management actions, the Grand Canyon Monitoring and Research Center (GCMRC) provides credible, objective scientific information regarding the effects of Glen Canyon Dam operations on the CRe.

One element of the GDCAMP is a Science Advisors Program where outside experts in relevant fields evaluate and give feedback on the research and monitoring programs. These periodic independent reviews ensure scientific credibility by providing recommendations regarding monitoring and research, integration, and management of natural, cultural, and recreational resources affected by Glen Canyon Dam operations.

Independent scientific peer reviews offer perspective on how well technical conclusions are supported by data and analyses and whether research being conducted aligns with LTEMP key resource priorities. This is a key step in guaranteeing GCMRC provides credible, objective scientific information about the effects of Glen Canyon Dam operations on the CRe.

The purpose of this peer review is to review and provide feedback on each project element included in the *Fiscal Year 2020 Annual Project Report to the Glen Canyon Dam Adaptive Management Program* (2020 Annual Report). The review included evaluating whether projects aligned with expectations laid out in the LTEMP. The individual reviews are provided in **Appendix A**.

The period of performance for this peer review was 07/01/2021-9/30/2021.

2.0 PEER REVIEWERS

Peer reviewers were selected according to their previous experience conducting similar reviews, relevant expertise, independence from GCDAMP, and publishing records in scientific journals. All peer reviewers were provided the language from the OMB (Office of Management and Budget) Bulletin (2004) with regard to independence and conflicts of interest, with respect to both GCDAMP and GCMRC.

The combined panel was selected to provide the following expertise:

- Fisheries and aquatic ecology
- Aquatic macroinvertebrates and food web ecology
- Vegetation management and riparian ecology
- Sediment transport, geomorphology, and/or hydrology of river systems, particularly those impacted by dams
- GIS data management and remote sensing
- Socioeconomics related to energy generation and/or tribal resources
- Monitoring and adaptive management

The five peer reviewers selected were mid- to senior-level scientists with PhDs in a relevant field who have previously conducted similar reviews or provided reviews of research for scientific literature. The full resumes for the peer reviewers are presented in **Appendix B**. The peer reviewers and their primary expertise were:

- Michael E. Colvin, PhD, Associate Professor at Mississippi State University – expertise with big river fisheries, salmonids, and arid ecosystems
- Stefanie A. Kroll, PhD, Assistant Research Professor at Academy of Sciences of Drexel University – expertise with food webs, aquatic macroinvertebrates, and community science
- Lynne Y. Lewis, PhD, Professor at Bates College – expertise in economics, hydropower, and community science
- Ben Livneh, PhD, Assistant Professor at University of Colorado – Boulder – expertise in sediment transport, hydrogeomorphology, and arid ecosystems
- John C. Stella, PhD, Professor at State University of New York – expertise in riparian vegetation ecology

Two reviewers have worked with Tribes in relation to river projects; although this is not considered a primary expertise, their prior experience was valuable during the peer review.

3.0 SUMMARY OF RESPONSES

Reviewers were asked to evaluate the 2020 Annual Report, any appendices, and recorded presentations from the Annual Report meeting. Reviewers were asked to focus on two main questions when evaluating the report:

1. Is the best information being provided to meet the needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission?
2. Does the combined effectiveness of the programs advance understanding of the Grand Canyon ecosystem; ensure progress in defining and conducting adaptive management experiments; monitor resources affected by Glen Canyon Dam operations and the effects of those operations; provide options for managing these effects; and facilitate coordination and balancing among resource programs?

Reviewers only reviewed projects for which they felt they had a technical expertise to effectively review. In some cases, a reviewer only commented on a portion of a project within their technical expertise. The following summary provides the key points provided by the reviewers. The full reviews (**Appendix A**) include additional details and suggestions. **Table 1** summarizes which reviewer's provided comments on which projects (A – N) and appendices (1 – 3).

Table 1. Summary of Reviewer's Response by Project

Reviewer	A	B	C	D	E	F	G	H	I	J	K	L	M	N	1	2	3
1	■	■	■	■	■	■	■	■	■	■	■	■					■
2	■	■			■	■				■							
3	■	■	■	■	■					■	■	■	■	■	■	■	
4		■	■					■		■				■	■		
5	■		■														

Project A: Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem

Reviewer 1: Sustainability requires a look to the future to forecast the effect of operations on sand resources, or possibly a retrospective analysis of what has happened in the past. Are the specific targets for sand or fine sediment resources defined? If so, what are they? The mass balance model could be used to parameterize a dynamic model that can be linked to dam operations, environmental conditions, and used to evaluate sustainability in sand resources over time.

Reviewer 2: There appears to be tension between the goal of supplying sufficient sediment to maintain sandy banks and sand bars for recreational and tribal activities, competing with the problems that turbidity is causing for biota.

Reviewer 3: Overall, progress has been made in terms of collating, analyzing, and modeling the CRe to identify drivers of sand and limitations in historical monitoring. A large number of data products, reports, and presentations indicate good progress, generally sound methods, and potential applications for further high flow analysis.

The continuous monitoring of sand would support greater understanding of the sustainability of current and future sand resources and critical connections between sand concentrations and high flows and other factors. It is difficult to interpret the uncertainty associated with flood flows in the Little Colorado River Basin. Long-term precipitation gage data could improve regressions and understanding of variability, relationships, and uncertainty. Reporting long-term rates of change and their uncertainties would be useful for overall planning and overall context.

Reviewer 4: No comment.

Reviewer 5: How does annual and seasonal variability of sediment storage and transport, water quality, and discharge factor into whether the system is sustainable, and over what timeframes? The bullet-point summary of results is informative, clear, and geared appropriately toward management. The insights on negative feedback interactions between water discharge and sand supply provide clear sideboards for management regarding dam releases and Paria River floods and highlight the true narrowness of the decision space available for dam management. Including a figure or two to illustrate the sediment budget in different reaches of the system would be helpful.

Project B: Sandbar and Sediment Storage Monitoring and Research

Reviewer 1: Overall, it would be good to couple monitoring efforts of sandbars with recreational experience quality. A number of methodological suggestions were provided. Additional information about uncertainty is needed, as well as ways to tie results to the objectives and adaptive management.

Reviewer 2: The modeling and monitoring effort is well designed. There is a tension here between the goal of supplying sufficient sediment to maintain sandy banks and sand bars for recreational and Tribal activities, competing with the problems that turbidity is causing for biota.

I do not know if the hypothesis that sand can be managed to achieve all goals of the GCMRC can hold true for this topic. High Flow Experiments should be monitored in terms of the objectives of Projects E, F, and others to ensure that supporting one objective does not end up detracting from another objective.

Reviewer 3: Numerous data products, publications, and presentations indicate good progress, generally sound methods, and potential applications linking high-flow events with sand and camping impacts. Monitoring and data sharing are important continued activities from this project. Suggestions for future work and analysis are provided, particularly around camping, climate change, and remote sensing. Further exploration is warranted into potential applications of the Bayesian framework as a tool for quantifying reach-scale sediment deficits and surplus relevant for future studies.

Reviewer 4: High flow experiments benefit campsites by causing temporary increases in campsite area, yet vegetation encroachment causes campsite declines. The relationship of this work to campsites needs to be clarified and any recommendations for recreational experience included (which is generally missing from all the projects, not just this one).

Reviewer 5: No comment.

PROJECT C: RIPARIAN VEGETATION MONITORING AND RESEARCH

Reviewer 1: Vegetation monitoring for composition and cover, with emphasis on nonnative species appears to provide robust data that can be used for status and trend analysis, including statistical analysis. However, it was unclear how the long-term changes were evaluated and on what metric. How well did the model perform? It was not clear what the specific objectives were or how they provide decision support for management actions?

Reviewer 2: No comment.

Reviewer 3: This provides a useful set of monitoring data and methods that connect vegetation with flow, environmental variables, and management, with a good webpage. There are some details that would be helpful to have reported (e.g., criteria for error checking, fraction of woody riparian vegetation, uncertainties). Remote sensing could be a useful technology to support this research. The analysis relating climate variables with vegetation patterns (Butterfield et al. 2018) is interesting and should continue to be pursued. Additional data should be reported/collected to help inform management of campsites and other recreational areas.

Reviewer 4: Information specific to campsites was missing, including relevant goals and objectives. A summary and/or recommendations related to camping area, landscape beauty, and shade should be included and tied to Project J.

Reviewer 5: In the next phase of this research, it would be helpful to focus on integration and synthesis, to understand how these interactions between plants and the fluvial system either support or undermine the multiple LTEMP goals. What are the most likely restoration actions (e.g., flow prescriptions, biological control, physical removal, horticultural plantings), how do they support the LTEMP goals, and what scientific questions still need to be answered?

Though investigating these plant-environment associations using niche models is common and informative, it is unclear how useful they will be for predicting the effects of environmental change. Niche models are less useful for understanding relationships when environmental variables are changing faster than the plants can adapt or disperse. Will the hotter and drier conditions result in more vegetation encroachment due to a reduced disturbance regime, or conversely a narrowing of the vegetated zone? Will these changes favor non-native species, and if so, what are options for reducing this risk?

Project D: Geomorphic Effects of Dam Operations and Vegetation Management for Archaeological Sites

Reviewer 1: An evaluation of how flow and non-flow actions affect cultural resources, preservation of resources, vegetation, and sediment dynamics should be completed. Can the monitoring objectives be clarified? Can this monitoring be used to inform a risk model? Clarifications on metrics, how they are estimated, and how those metrics fit with the LTEMP resource goals and overall monitoring objectives would be helpful. Lastly, clarification is needed on how weather data is used to achieve monitoring objectives.

Reviewer 2: No comment.

Reviewer 3: The meteorological monitoring and data collection described by Caster et al. (2018) is extremely valuable and its continuation should be prioritized. Spaceborne remote sensing could complement existing aerial imagery.

Reviewer 4: No comment.

Reviewer 5: No comment.

Project E: Nutrients and Temperature as Ecosystem Drivers: Understanding Patterns, Establishing Links and Developing Predictive Tools for an Uncertain Future

Reviewer 1: The metrics monitored may not directly relate to LTEMP resource goals but are a necessary precondition to achieving LTEMP resource goals related to biota (humpback chub, rainbow trout, other native fish). There are several questions related to methods and how results inform adaptive management.

Reviewer 2: The approach to monitoring and studying P dynamics is well designed. The studies before and after fire are also sound, and the shift to studying gross primary production is a good step toward characterizing the dynamics of nutrients in the system, especially regarding the food web. Was P historically limited or higher in this area, or how do levels compare with inputs into reservoirs? From the studies presented, the turbidity seems to be a greater limitation to algal growth and macroinvertebrate success (along with hydropeaking flows, of course), than bioavailable P into the system.

Improved analysis and modelling of food web dynamics is needed to better understand the bottom-up controls of P concentrations, turbidity, and flows through the food web and in connection to the dynamics of the fish communities. Relative to Projects E and F,

macroinvertebrate diets could be analyzed using DNA metabarcoding of their whole abdomens to understand which diatoms and prey are most dominant in diets. Additional suggestions for improved data collection and analysis were included.

Reviewer 3: While improvements in the predictive model resulted from using solar radiation as a predictor, details of the radiation data were entirely missing. Clearer justification of the water temperatures chosen should be provided in the context of existing pool temperatures and temperatures relevant for other project components.

Reviewer 4: No comment.

Reviewer 5: No comment.

PROJECT F: AQUATIC INVERTEBRATE ECOLOGY

Reviewer 1: The project illustrates good interaction with other projects to support inference and provides auxiliary information that might be needed to explain among year differences in higher trophic levels, like native fish and trout. The bases appear to be covered in terms of monitoring instream drifting and emerging aquatic invertebrates.

Reviewer 2: Weekend "breaks" are an excellent idea for egg survival and other possible mechanisms for macroinvertebrate success and increasing diversity. Once this experiment is complete, will there be another study on how weekend flows can be best designed as ecological flows for macroinvertebrates? The community science involved in this project was a great component, but there are ways to build on the work already started by following up with stakeholders and increasing opportunities for Tribal members and other groups not typically involved in this type of community science.

In this case, access to rafting trips may limit the participation of a diverse audience who 1) are not tourists and therefore may not consider participating in such a trip 2) are financially limited and may not be able to afford such a trip, and 3) have been historically excluded from such activities.

Reviewer 3: No comment.

Reviewer 4: No comment.

Reviewer 5: No comment.

PROJECT G: HUMPBACK CHUB POPULATION DYNAMICS THROUGHOUT THE CRE

Reviewer 1: The project provides advanced approaches to estimate population dynamics and project results have the potential to inform decisions. There are a few technical questions included related to methodology and relevance of particular data elements to management. The population appears to be increasing. With goal of the effort to monitor status and trend, how is the population trend evaluated? Will translocation decisions be informed by monitoring?

Reviewer 2: No comment.

Reviewer 3: No comment.

Reviewer 4: No comment.

Reviewer 5: No comment.

PROJECT H: SALMONID RESEARCH AND MONITORING

Reviewer 1: There needs to be more detail provided for Project H.1 to determine if can sufficiently inform operations and provide information relevant to objectives. The coupled brown trout, rainbow trout, and humpback chub models used to evaluate management scenarios are an interesting application. The salmonid research and monitoring project tied to experimental dam operations associated with meeting LTEMP resource objectives is valuable research. How will this long-term datasets be used to evaluate experimental flows?

Reviewer 2: No comment.

Reviewer 3: No comment.

Reviewer 4: There is significant overlap in topic with this project and Project J. It would be helpful if the connections between projects was more explicit. The economic value data is from 2016. Has more recent data been collected and how does it compare? There is little economic information provided about the recreational fishery or how operations impact the economic value. Results or an update related to the incentive program are valuable and should be included. The reviewer suggested using the term "Community Science" rather than "Citizen Science".

Reviewer 5: No comment.

PROJECT I: WARM-WATER NATIVE AND NONNATIVE FISH RESEARCH AND MONITORING

Reviewer 1: It appears these efforts support The LTEMP "Goal 10. Nonnative invasive species. Minimize or reduce the presence and expansion of aquatic nonnative invasive species" and helps inform the "mechanical removal of nonnative fish near the Little Colorado River confluence".

There are a number of important details that were either not included or were unclear. The following are some notable questions that were unanswered:

- How trends are calculated from monitoring data and this is likely important for informing adaptive operations of Glen Canyon dam and whether operations can achieve management objectives?
- Why is Asian tapeworm monitoring important and how does this support GCDAMP and LTEMP?
- How does this sampling inform a) sampling efforts needed at a larger scale to detect warm-water invasive fish and b) if warm-water invasives are expanding in range?
- How is the eDNA persistence from upstream factored into the eDNA analysis completed?

Reviewer 2: No comment.

Reviewer 3: No comment.

Reviewer 4: No comment.

Reviewer 5: No comment.

PROJECT J: SOCIOECONOMIC RESEARCH IN THE COLORADO RIVER ECOSYSTEM

Reviewer 1: The applied decision and scenario analysis is an interesting application to evaluate and identify optimal management actions that presumably links back to socioeconomic values. A table linking back to the LTEMP and management actions is suggested. How will survey information from the Tribes be used to inform decision making and adaptive management?

Reviewer 2: The inclusion of some deliverables related to the use of USGS science by Tribal communities is valuable. Are there other ways to engage Tribal collaborators besides workshops? A list of outreach and meetings and the associated stakeholders would be informative. There are issues with the way some of the surveys have been designed relative to Tribal input and suggestions are provided about how to improve those. Are there other (non-Tribal) stakeholders involved with the Willingness to Pay research?

Reviewer 3: Overall, this project is an important component of the CRe, GCMRC, and GCDAMP, because it allows for a broad assessment of the connections of ongoing activities with needs and economics downstream. Therefore, it is recommended to continue prioritizing this area of analysis. The proposal to evaluate nonstationary climate impacts using the Donovan et al. (2019) model its an important priority; however, realistic constraints need to be used.

Reviewer 4: The section on Tribal Resources is difficult to review since the reports are not available and audio for that portion of the meeting was not available. There are concerns about how the contingent valuation was designed that limit its utility.

The decision about which model to apply to willingness to pay data is not neutral and sensitivity analysis is important. It would be interesting to use some of the more commonly used approaches such as the non-parametric Turnbull with this data.

The report gives a brief description of the bioeconomic dynamic programming model that evaluates the tradeoffs between protecting humpback chub and rainbow trout abundance. Where is a summary of the findings? Who are the decision-makers?

Recreational fishing is covered above, but the rainbow trout fishery is also discussed in several of the other projects. There needs to be some summary material in this report that weaves these related topics together.

There is no mention of the on-going severe drought or climate change. Will new low-flow scenarios be tested? Are there recommendations going forward related to climate change? And how does the renegotiation of the Colorado River Compact impact this report?

Reviewer 5: No Comment.

Project K: Geospatial Science and Technology

Reviewer 1: It was uncertain what the needs of the GCDAMP and LTEMP are for geospatial science and data technology or how these systems support decision-making. There has been an impressive set of tools developed, however, to support the GCDAMP and LTEMP. There appears to be a significant effort to provide information to stakeholders and researchers.

Reviewer 2: No comment.

Reviewer 3: The migration of data into databases and cloud computing resources is an important innovation with payoffs over the long term. ArcGIS may not be the most effective tool due to the size of data sets. Other more powerful and efficient tools should be considered for these larger datasets and analyses. Tableau may not be a good long-term cost-benefit decision.

Reviewer 4: No comment.

Reviewer 5: No comment.

Project L: Overflight Remote Sensing in Support of GCDAMP and LTEMP

Reviewer 1: It was unclear from the summary what the expected outcomes of this effort are, how the outcomes of these efforts will support the GCDAMP, or how this integrates with the LTEMP. A table that shows the relationship between expected products and their applications in projects would be helpful.

Reviewer 2: No comment.

Reviewer 3: The details of the overflight are not clearly articulated, although there is value in additional remote sensing. Evaluating opportunities to integrate remote sensing imagery with publicly available spaceborne imagery could provide cost-effective benefits.

Reviewer 4: No comment.

Reviewer 5: No comment.

Project M: Administration

Reviewer 1: No comment.

Reviewer 2: No comment.

Reviewer 3: A minor comment is that the citizen science programs extend budgets and elevate the awareness of visitors.

Reviewer 4: No comment.

Reviewer 5: No comment.

Project N: Hydropower Monitoring and Research

Reviewer 1: No comment.

Reviewer 2: No comment.

Reviewer 3: Continue to coordinate with partners to identify opportunities to improve hydropower and energy resources. For example, the impact of high flow experiments on total outflows, the sensitivity of greenhouse gas emissions to reservoir levels, etc.

Reviewer 4: Goals and objectives could be clearer. Project N needs more detail (i.e., tables or other results summaries) and is lacking information about the economic value of hydropower. Several suggestions for improving the presentation and questions to clarifying methods and assumptions were included.

Reviewer 5: No comment.

APPENDIX 1: LAKE POWELL WATER QUALITY MONITORING

Reviewer 1: No comment.

Reviewer 2: No comment.

Reviewer 3: The collaboration with EPA should continue to be prioritized.

Reviewer 4: No comment.

Reviewer 5: No comment.

APPENDIX 2: DELIVERABLE (PRODUCTS) FY 2018-2020

Reviewer 1: The program appears to be highly productive and the development of varying web-based resources to serve, process and summarize data is an asset.

Reviewer 2: No comment.

Reviewer 3: No comment.

Reviewer 4: No comment.

Reviewer 5: No comment.

APPENDIX 3: BUDGETS, ALL PROJECTS

Reviewer 1: No comment.

Reviewer 2: No comment.

Reviewer 3: No comment.

Reviewer 4: No comment.

Reviewer 5: No comment.

4.0 SUMMARY

All reviewers provided suggestions to improve data presentation and use. All reviewers provided suggestions for additional analysis or expanded methodologies in one or more projects. All reviewers also identified multiple projects where it was hard to tie the project to the relevant LTEMP objective and related management actions. All reviewers commented on one or more projects that it was not easy to determine whether a metric could evaluate a goal or be used for decision-making (i.e., adaptive management).

Only some reviewers commented on Tribal involvement and engagement, but those that did all agreed that there appeared to be a disconnect with what were likely Tribal priorities in one way or another. They also made suggestions for improving Tribal involvement and engagement.

The socioeconomics elements were particularly difficult for reviewers to understand how projects impacted them or how they were tied to other projects. This is an area of great interest to stakeholders and yet was poorly presented throughout the 2020 Annual Report.

5.0 REFERENCES

Butterfield, B.J., Palmquist, E.C., and Ralston, B.E. 2018. Hydrological regime and climate interactively shape riparian vegetation composition along the Colorado River, Grand Canyon—poster presentation: Bozeman, MT, July 22-27, 2018, Natural Ecosystems as Benchmarks for Vegetation Science, International Association of Vegetation Scientists 61st Annual Symposium.

Donovan, P., Bair, L.S., Yackulic, C.B., and Springborn, M.R. 2019. Safety in numbers—Costeffective endangered species management for viable populations: Land Economics, v. 95, no. 3:435-453.

Reclamation. 2016a. Glen Canyon Dam Long-Term Experimental and Management Plan and Final Environmental Impact Statement (October 2016). US Department of Interior, Bureau of Reclamation and National Park Service. Denver, CO.

Reclamation. 2016b. Record of Decision for Glen Canyon Dam Long-Term Experimental and Management Plan. US Department of Interior, Bureau of Reclamation and National Park Service. Denver, CO.

USGS. 2020. Fiscal Year 2020 Annual Project Report to the Glen Canyon Dam Adaptive Management Program. US Geological Survey, Grand Canyon Monitoring and Research Center. Flagstaff, AZ.

APPENDIX A: INDIVIDUAL REVIEWS

Reviewer 1 (Colvin) – August 2021

Reviewer 2 (Kroll) – August 2021

Reviewer 3 (Livneh) – July 2021

Reviewer 4 (Lewis) – September 2021

Reviewer 5 (Stella) – September 2021

Peer Review

AGENCY:	US Bureau of Reclamation, Glen Canyon Dam Adaptive Management Program (GCDAMP)
MATERIAL(S) REVIEWED:	2020 Grand Canyon Monitoring and Research Center (GCMRC) Annual Report
REVIEWED BY:	Michael E. Colvin, Mississippi State University
DATE:	August 26, 2021

I. Project A: Streamflow, water quality, and sediment transport and budgeting in the Colorado River Ecosystem

A. General overview

1. The project indicates an understanding needed to identify conditions (dam operations and tributary conditions) that lead to sand accumulation in CR reaches. Mass balance results of sand mass changes over the fiscal year are presented for stream reaches.

B. Link to LTEMP

1. The project links to LTEMP resource goals related to natural resources (p2) and sediment (p5).
2. Are the specific targets for sand or fine sediment resources defined? If so, what are they?

C. Sustainability of sand resources

1. The sustainability of sand resources is referenced as a guiding question and hypothesis for Glen Canyon Dam. Sustainability requires a look to the future to forecast the effect of operations on sand resources, or possibly a retrospective analysis of what has happened in the past. The change in sand resources over the near or long term can then be evaluated for increases or decreases. The mass balance approach applied to evaluate sand mass dynamics and results shown in table demonstrate changes from one year to the next for varying reaches. Are there ways to aggregate this to the system level? The mass balance model could be used to parameterize a dynamic model that can be linked to dam operations, environmental conditions, and used to evaluate sustainability in sand resources over time. For example, at the system level, the analysis might evaluate if the change in sand mass is approximately 0 indicating that the current sand resources are being sustained.

2. Related to the science questions of suitability, are dam operations coupled with environmental influences being used to sustain the current amount of sand resources in the (Colorado River ecosystem) CRe? Or is there a need to increase or decrease sand resources and then sustain? The LTEMP resource goals for sediment (p5) indicate increasing and retaining fine sediment within operational constraints, which suggests that sustainability of sand resources might be an objective after some level of increase occurs.

II. Project B: Sandbar and sediment storage monitoring and research

A. Overview, Project goals and objectives and Link to LTEMP

1. Although this project relates to sediment goals of the LTEMP, are there ways to couple monitoring efforts of sandbars and recreational experience quality (p4)?
2. Is there a way to synthesize information on sand bar volume with dam operations and environmental conditions to develop a predictive model of sand bar volume that can then be linked to objectives?

B. Project B.1. Sandbar monitoring using topographic surveys and remote cameras

1. This project element relates to the first purpose of Project B, "track the effects of individual high flow experiments on sandbars".
2. The section was unclear on the application of topographic surveys; were they conducted and, if so, how?
3. Camera use is a neat application to passively monitor sandbars. Will the method provide sufficient power to detect changes and link to dam operations and tributary interactions? Will collecting time series sand bar change on a subset of sand bars be sufficient to inform the potential effects of dam operation and interaction with tributaries?
4. Figure 1 (p17) is there uncertainty associated with the point estimates presented for sandbar volume?

C. Project B.2. bathymetric and topographic mapping for monitoring long-term trends in sediment storage

1. This project element relates to the purpose b, "monitor the cumulative effect of successive HFEs and intervening operations on sandbars and sand conservation and to Investigate the interaction between dam operations, sand transport, and eddy sandbar dynamics".
2. P19. "long term trends in sandbars and sand storage…." How will the former and latter be quantified and how does that relate to the sand budget model where the SNR was determined to be >1?

3. P20. Recent progress in bedload transport models is interesting and a nice extension of the previous models used and can potentially inform adaptive management experiments.

D. Project B.3. Control network and survey support

1. The maintenance of the geodetic framework seems foundational to supporting monitoring efforts. No specific comments.

E. Review specific questions

1. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon ecosystem and ensuring progress in defining and conducting adaptive management experiments."*

   Assessing the report and recorded presentations the monitoring appears to satisfy these questions. The monitoring program quantifies sand and fine sediment dynamics, albeit analyses of trend and link to resources goals can be clarified.

III. Project C: Riparian vegetation monitoring and research

A. Overview, Project goals and objectives and Link to LTEMP

1. The project relates to natural processes and recreational experience LTEMP resource goals. The project is delineated into four elements that link to monitoring changes to riparian vegetation using field and digital data (C.1. and C.2.), developing predictive vegetation composition models related to hydrologic regime (C.3), and integrated science products into decision support tools (C.4)

B. C.1. Ground-based vegetation monitoring

1. Vegetation monitoring for composition and cover, with emphasis on nonnative species appears to provide robust data that can be used for status and trend analysis, including statistical analysis (i.e., illustrated by figure 1 p26).

C. C.2. Imagery-based riparian vegetation monitoring at the landscape scale

1. This project quantified long term changes in total riparian vegetation related to dam release patterns and climate for reaches of the CRe.
2. It was unclear how the long-term changes were evaluated and on what metric. Additionally, the effect of dam operations on riparian vegetation was unclear, although this topic was addressed in C.3.

D. C.3. Vegetation responses to LTEMP flow scenarios

1. The objective of this project was to develop better predictive models of how LTEMP flows will alter vegetation.
2. How well did the models of riparian vegetation perform (p11)? Was a sensitivity analysis performed to evaluate where additional study or flow experiments might be prioritized?

E. C.4. Vegetation management decision support

1. The specific objectives of this project element were unclear. How was decision support provided? What potential management actions came from information provided by this project element? In other words, was information used to evaluate trade-offs in plantings of specific strains of cottonwoods and willows?

F. Review specific questions

1. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon ecosystem and ensuring progress in defining and conducting adaptive management experiments."*

   Assessing the report and recorded presentations the monitoring appears to satisfy these questions. Clarifications on metrics and how they are estimated would be helpful and how those metrics fit with the LTEMP resource goals.

IV. Project D: Geomorphic effects of dam operations and vegetation management for archaeological sites

A. Overview, Project goals and objectives and Link to LTEMP

1. This project links to the LTEMP goal of preserving cultural resources and that preservation in place will be enhanced by implementing the preferred alternative specified in the LTEMP. The high flow experiments (HFE) specified in alternative D may conflict with preservation, eroding terraces containing archeological sites and depositing sand on aeolian dune fields thereby providing protection in the Marble and Grand Canyon.
2. The goal of the project is to quantify geomorphic effects of dam operations and riparian vegetation management with emphasis on HFEs on sediment supply to terraces and culture sites. The project should allow for the evaluation of how flow and non-flow actions affect cultural resources, preservation of resources, vegetation, and sediment dynamics.

B. D.1. Geomorphic effects of dam operations and vegetation management

1. The potential effects of dam operation and vegetation management were monitored with Lidar, weather, and time lapse camera.
2. Can the monitoring objectives be clarified?
3. Appears to be a good census of archeological sites and features in the monitoring portfolio. Can this monitoring be used to inform a risk model?

C. D.2. Cultural resources synthesis to inform historic preservation plan and repeat photography to inform project element D.1.

1. No specific comments

D. Review specific questions

1. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon ecosystem and ensuring progress in defining and conducting adaptive management experiments."*

   Assessing the report and recorded presentations the monitoring appears to satisfy these questions. Clarifications on metrics, how they are estimated, and how those metrics fit with the LTEMP resource goals and overall monitoring objectives would be helpful. Lastly, clarification is needed on how weather data is used to achieve monitoring objectives.

V. Project E: Nutrients and temperature as ecosystem drivers: Understanding patterns, establishing links and developing predictive tools for an uncertain future

A. Overview, Project goals and objectives and Link to LTEMP

1. This project examines patterns in nutrients and temperature in reaches of the CRe. The metrics monitored may not directly relate to LTEMP resource goals but are a necessary precondition to achieving LTEMP resource goals related to biota (humpback chub, rainbow trout, other native fish).

B. E.1. Temperature and nutrients in the CRe

1. What are the biologically important levels for the water nutrients monitored in the CRe?
2. Is DO measured at the sediment water interface (p60)? Periods of anoxia can mobilize P that is otherwise sequestered in benthic sediments, might be negligible in reaches of the CRe (Mortimer 1942).

3. Have nutrient budgets/dynamic models been developed to guide monitoring?
4. With the GPP models developed there is some indication that weekend bug flows influence system level GPP? Is there feedback on dam operations? For example, to modify flows for maximum GPP, or something of that nature?

C. E.2. Linking temperature and nutrients to metabolism and higher trophic levels

1. The project elements seem to build on and address important questions needed to evaluate dam operations and environmental conditions on GPP, which is primarily driven by nutrients and temperature.

D. Review specific questions

1. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon ecosystem and ensuring progress in defining and conducting adaptive management experiments."*

   Assessing the report and recorded presentations, the monitoring appears to satisfy these questions. The utility of monitoring temperature and the extensive modeling of temperature directly applies to dam operations and tributary and solar inputs. The linkage to the LTEMP, specifically through defined metrics and thresholds, was unclear.

VI. Project F: Aquatic invertebrate ecology

A. Goals and objectives

1. The project informs natural resource goals of LTEMP. Specifically, the monitoring efforts are being used to evaluate effects of bug flows from Glen Canyon Dam on aquatic invertebrate production and emergence timing. The project illustrates good interaction with other projects to support inference and provides auxiliary information that might be needed to explain among year differences in higher trophic levels, like native fish and trout.

B. Monitoring of aquatic invertebrates

1. The bases appear to be covered in terms of monitoring instream drifting and emerging aquatic invertebrates. Within the constraints of the project, is the monitoring sufficient to evaluate bug flows (i.e., is sampling sufficient to detect changes in invertebrate production resulting from the flows)?
2. The use of bat echo recordings is an interesting idea and would seem to be another potentially useful source of information indexing aquatic invertebrate production.

3. Monitoring appears to rely on catch rates and emergence. Is it possible and useful to also look at invertebrate biomass production? For example, production rates might provide an additional component, integrating demographics and growth that can be linked to dam operations, albeit the temporal resolution needed might be insufficient for this large of a system.

VII. Project G: Humpback chub population dynamics throughout the CRe

A. Overview, Project goals and objectives and Link to LTEMP

1. This project focused on estimation of abundance and demographic rates of humpback chub in the CRe. Its emphasis is on triggers associated with the Biological Opinion and the potential use of models fit to monitoring data to examine alternative management actions. This project informs humpback chub and native fish LTEMP resource goals.

B. G.1. Humpback chub population modeling

1. The project provides advanced approaches to estimate population dynamics.
2. In Figure 2 (p85), the reduction in uncertainty associated with antennas was not large relative to estimates without antennas. Is the benefit in increased precision worth the associated effort to maintain antenna arrays? Is the use of antennas something that is expected to further increase precision of humpback chub estimates over time?
3. Will translocation decisions be informed by monitoring, such that the effort associated with the translocations will occur when the expected number of adults produced from the effort is maximized?

C. G.2. Annual spring/fall humpback chub abundance estimates in the lower 13.6 km of the LCR

1. From the estimates illustrated in the figure on p87, the population appears to be increasing. With goal of the effort to monitor status and trend, how is trend evaluated?

D. G.3. Juvenile humpback chub monitoring near the LCR confluence

1. No specific comments

E. G.4 Remote PIT-tag array monitoring in the LCR

1. No specific comments

F. G.5. Monitoring humpback chub aggregation relative abundance and distribution

1. With the associated closed mark-recapture estimators, will relationships of CPUE and abundance estimates be considered to evaluate the relationship of catch, effort, and abundance (C/f=q*B)? Specifically, will evaluating if catchability is constant, or may be exhibiting hyperstability or hyperdepletion (i.e., q^x where x <>1), result in a

functional response which may influence the application of capture probability to catch data being used to estimate humpback chub in the Western Grand Canyon?

G. G.6. Juvenile humpback chub monitoring – West

1. No specific comments

H. G.7. Chute Falls translocation

1. See comment above regarding translocations

I. G.9. Backwater seining

1. Will backwater seining be useful to evaluate dam operations? For example, is it expected that these efforts will index age-0 fish production, and in turn be associated with HFEs or other flows? If so, is the sampling effort sufficient to detect potential responses?

J. Review specific questions

1. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon ecosystem and ensuring progress in defining and conducting adaptive management experiments."*

   The project appears to be monitoring many aspects of native fish, with emphasis on humpback chub, life history, demographics, and dynamics. Many applications have direct ability to inform decisions (e.g., translocations) and are informing humpback chub status with population models.

VIII. Project H: Salmonid research and monitoring

A. Overview, Project goals and objectives and Link to LTEMP

1. This project relates to the rainbow trout fishery resource goal of the LTEMP as well as a possible predator or humpback chub. Dam operations include experimental 'trout flows' hypothesized to limit rainbow trout recruitment and dispersal. Recent increases in brown trout may pose a challenge to native fish conservation but provide recreational fishing opportunities.

B. H.1. Experimental flow assessment and trout recruitment

1. Is the level of sampling sufficient to evaluate the objectives of Project H.1?
2. Is it possible to clarify the proposed analytical procedures to evaluate H1.1-4 and the associated timeframe for sufficient learning to inform dam operations?

C. H.2. Rainbow and brown trout recruitment and outmigration model

1. The coupled brown trout, rainbow trout, and humpback chub models used to evaluate management scenarios sounds like an interesting application.

D. H.3. Using early life history and physiological growth data from otoliths to inform management of rainbow and brown trout in Glen Canyon

1. No specific comments

E. H.4. Rainbow trout monitoring in Glen Canyon

1. Was the creel survey, a roving or access creel?

F. Item 2 Review specific questions

1. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon ecosystem and ensuring progress in defining and conducting adaptive management experiments."*

   The salmonid research and monitoring project, like aquatic invertebrate production, is unique in that there are experimental dam operations associated with meeting LTEMP resource objectives directly associated with salmonids. The monitoring of salmonids builds on long term datasets and an overall question that emerges is how will monitoring data be used to evaluate experimental flows?

IX. Project I: Warm-water native and nonnative fish research and monitoring

A. Overview, Project goals and objectives and Link to LTEMP

1. This report section summarizes efforts to monitor warm water nonnative fish and research associated with nonnative fish. A snapshot of results for the 2020 sampling efforts by AGFD (2 mainstem sampling trips). Previous reports indicate that non-native species have decreased. The project also includes a research component associated with the early detection of warm-water nonnative species and predation of native species by nonnative species.
2. It was not explicit what goal of the LTEMP these efforts support but fall under "Goal 10. Nonnative invasive species. Minimize or reduce the presence and expansion of aquatic nonnative invasive species" and helps inform the "mechanical removal of nonnative fish near the Little Colorado River confluence" management action listed in the preferred alternative D of the LTEMP.

B. Goals and objectives

1. The stated goal included trends in abundance and distribution of native and nonnative fish in the Grand Canyon. However, it is unclear from the report section how trend is calculated from monitoring data. Evaluating trend is likely important for informing adaptive operations of Glen Canyon dam and whether operations can achieve management objectives.
2. It is unclear why Asian tapeworm monitoring is important and how it supports GCDAMP and LTEMP. Is there mortality associated with infestations in humpback chubs?

C. Improving early detection of warm-water invasive fish

1. Targeting areas where rare non-natives have been caught as well as warm water areas seems reasonable to the detection process. It is unclear how this sampling a) can inform the sampling efforts needed at a larger scale to detect warm-water invasive fish (i.e., power to detect given presence at low levels) and b) if warm-water invasives are expanding in range.
2. The use of eDNA is a potentially powerful method for monitoring the presence of warm-water invasive fish DNA. However, given stream flows, eDNA detected at a site could be DNA material that has washed downstream. Is there any information on the downstream persistence of DNA in systems like the CRe? Similarly, what concentration of DNA is needed to reliably detect warm-water invasive fish? In other words, is eDNA in this application sensitive enough to provide an early detection system for warm-water invasive fish in the system?

D. Warm water nonnative fish risks to native fish

1. Some details for the field component of this study would be helpful. Was this effort to provide estimates of diet composition which could be further used to inform relative risk?

X. Project J: Socioeconomic research in the Colorado River Ecosystem

A. Integration with GCDAMP and LTEMP.

1. Integration with GCDAMP and LTEMP. This project appears to be integrating science outputs into management actions. A table or bulleted list that explicitly defines the links to the LTEMP and specifically management actions articulated in preferred alternative D.

B. Integration with existing projects

1. The applied decision and scenario analysis described in the report represents interesting applications of dynamic programming to evaluate and identify optimal management actions with a utility that presumably links back to socioeconomic values. Given the use of dynamic programming and value of information referenced in this section, it is exciting to see it applied to real world problems and whether it is

important or not to reduce uncertainty in humpback chub survival and rainbow trout abundance.

2. It is clear from this section that there is much integration with native fish monitoring and management efforts (i.e., translocation of humpback chubs). Additionally, there appears to be integration with the preferred alternative D and monitoring efforts, specifically using dynamic programming to assess trout flows.

C. Use of tribal survey information in AM and decision making

1. It was unclear how the survey information for tribal perspectives will be used to inform decision making and adaptive management. For example, will the outcomes of the survey be used to develop functions representing preference for varying outcomes of management actions? Will the survey instruments inform any weighting of multi-attribute utilities that might be in optimization routines evaluating alternative management actions?

XI. Project K: Geospatial science and technology

A. General overview

1. The investment into managing the experimental and monitoring data generated as part of a program of this size is very important. Impressions from the summary provided in the report is that this project is well positioned to provide the support needed by the science projects and to curate the data.
2. Like most large-scale science and monitoring programs, this effort is shifting to the use of near real time summaries of monitoring data in the form of dashboards which, in turn, can be used to support the GCDAMP and LTEMP.
3. The project demonstrates clear integration and support of other science projects (e.g., Project B, C, E, G, H, G, I) in the text.
4. It was uncertain what the needs of the GCDAMP and LTEMP are for geospatial science and data technology. For example, does the GCDAMP need feedback from information systems to support decision making? Are there monitoring thresholds or triggers identified from the LTEMP that are reported and critical to system operations?

B. Science tools developed

1. The project appears to have developed an impressive set of tools to support the GCDAMP and LTEMP, for example, the lake level and water quality tool for Lake Powell
2. Of particular interest was the use of interest of things (IoT) to migrate data from field sensors to a single field location, potentially increasing the efficiency of offloading sensor data and minimizing personnel effort.

3. Source control. The project development and integration of source version through GIT represents some of the best practices for reproducible analyses - an important component of a program of this size.
4. The project appears to be making the best efforts to provide information to stakeholders and supporting the science associated with the GCDAMP and LTEMP.

XII. Project L: Overflight remote sensing in support of GCDAMP and LTEMP

A. Link to GCDAMP

1. It was unclear from the summary exactly what the outcomes of this effort will be beyond imaging from the river corridor and how the outcomes of these efforts will support the GCDAMP. Specifically, how will remote sensing be used to evaluate the effect of Glen Canyon Dam operations? For example, can this technology be used to evaluate vegetation encroachment on sandbars?
2. Potentially add a table or narrative that lists expected products from remote sensing and potential integration with monitoring the effects of dam operations and potential role in decision making.

B. Support and integration with LTEMP

1. It was unclear from the report summary how this effort will integrate with the LTEMP. From the summary the effort appears to be a singular effort to occur in 2021. How this effort will support the long-term component of the monitoring plan is uncertain.
2. Potentially add a table that lists expected products from remote sensing and potential application and integration with long-term monitoring efforts

C. Clarify link of this effort to other science projects

1. It seems reasonable that remote sensing would be of use to other projects in the portfolio of science efforts. It is unclear how this effort might support those projects and what outputs might be used once the effort is undertaken in 2021.
2. Potentially add a table that lists expected products from remote sensing and potential application to ongoing science projects.

XIII. Project M: Administration

1. No specific comments

XIV. Project N: Hydropower Monitoring and Research

1. No specific comments

XV. Appendix 1. Lake Powell water quality

1. No specific comments, section was a summary of data collected and monitored to support understanding of flows downstream.

XVI. Appendix 2. Deliverable (Products) FY 2018-2020

A. Program productivity

1. The program appears to be highly productive with a great number of peer reviewed articles produced, presentations given, reports and datasets generated.
2. The development of varying web-based resources to serve, process and summarize data is an asset.

XVII. Appendix 3. Budgets, All projects

1. No specific comments

XVIII. Project N: Hydropower Monitoring and Research

1. No specific comments

Mortimer, C.H., 1942. The exchange of dissolved substances between mud and water in lakes. II. J. Ecol. 30, 147–201.

Peer Review

AGENCY:	US Bureau of Reclamation, Glen Canyon Dam Adaptive Management Program (GCDAMP)
MATERIAL(S) REVIEWED:	2020 Grand Canyon Monitoring and Research Center (GCMRC) Annual Report
REVIEWED BY:	Stefanie A Kroll, PhD, Drexel University
DATE:	August 20, 2021

I. Project A & B: Streamflow, water quality and sediment transport and budgeting within the Cre; Sandbar and sediment storage monitoring and research

A. Sediment transport need vs turbidity impacts on biota

1. The modeling and monitoring effort is well designed. The research is well supported by an article in press.
2. I am noting a tension here between the goal of supplying sufficient sediment to maintain sandy banks and sand bars for recreational and tribal activities, competing with the problems that turbidity is causing for biota. While I cannot suggest any solutions to this tension, perhaps the managers of this aspect of flow regulation and the researchers are already working to balance the sediment transport needs and the mechanism for it with the advantages to the biota when turbidity is low.
3. I do not know if the hypothesis that sand can be managed to achieve all goals of the GCMRC can hold true for this topic. It's very ambitious and I appreciate that it is your goal. From the study on the Hualapai Tribe's opinions, there seem to be mixed feelings about the priorities of each activity.
4. It is possible that I don't have enough information, as I see that the report notes that riparian vegetation encroachment and decreased sand from tributaries is responsible for the dynamics of sand erosion/deposition. There may still be some need to connect to the turbidity of Glen Canyon Dam releases for this item. I see that High Flow Experiments (HFEs) are being deployed to this end and note that increasing the number of these events should be monitored in terms of the objectives of Projects E, F and others. The previous study on the 2008 HFEs (Rosi-Marshall et al. 2010) showed declines in *Potamopyrgus antipodarum* and *Gammarus*, which may be desired results if a reduction in the nonnative snail is desired. However, HFEs may put the objective of improving Ephemeroptera,

Plecoptera, and Trichoptera (EPT) communities at risk. It appears that these HFEs improve sand deposition, but that the effects are short-term, if I am understanding properly.

II. Project E: Nutrients and temperatures as ecosystem drivers

A. TP-SRP budgets

1. The approach to monitoring and studying phosphorus (P) dynamics is well designed—it appears that the researchers will continue to work to parse out the soluble reactive phosphorus (SRP) fraction and total phosphorus (TP), and perhaps what other fractions of TP may be biologically available, which should better inform algal dynamics and therefore the food web interactions.
2. Development of a P budget is certainly a priority for understanding how P patterns interact with flow, temperature, turbidity and exert bottom-up controls on the biological communities.
3. The studies before and after fire are also sound, and the shift to studying gross primary production (GPP) is a good step toward characterizing the dynamics of nutrients in the system, especially regarding the food web. In addition, the high variation during storms is an interesting and pertinent research topic.
4. I agree that understanding other forms and amount of bioavailable P is needed as per the experiment notes in E.1.2

B. Seeding P

1. From the question during the presentation about adding P to the system, I agree with the researcher's response that the potential effects are unknown, and that this action may have unwanted results in terms of supporting nonnative fishes, or other effects. This caution seems particularly important given the management actions to reduce brown trout populations in favor of humpback chub and rainbow trout and removing rainbow trout in certain areas to favor humpback chub. Was P historically limited or higher in this area, or how do levels compare with inputs into reservoirs? From the studies presented, the turbidity seems to be a greater limitation to algal growth and macroinvertebrate success (along with hydropeaking flows, of course), than bioavailable P into the system. While I do not have enough information to say this is the case, it would be better to continue the Bug Flows experiment and the analysis of available P forms before considering taking actions to change P dynamics by seeding P.

C. Whole system food web dynamics

1. In the presentation by Yackulic, he noted a desire to better analyze and model food web dynamics. I agree that this research is needed to better understand the

bottom-up controls of P concentrations, turbidity, and flows through the food web and in connection to the dynamics of the fish communities. Food web research would be a high priority for the next steps if I were involved in this program. I support the next steps proposed in E.2.1 to better understand the drivers of variation in GPP.

2. To bring together all the elements regarding energy flows, including metabolism, nutrient dynamics, algal, macroinvertebrate and fish communities, the results of propose sub-element E.2.4 seems like an ideal next step that has a clear and interesting foundation already published.

D. Algal community dynamics as food for macroinvertebrates

1. Relative to Projects E and F, macroinvertebrate diets could be analyzed using DNA metabarcoding of their whole abdomens to understand which diatoms and prey are most dominant in diets, to complement the gut analyses of fish that have been done in previous studies, which I assume would be part of any food web study.

2. The laboratory study in E.2.3. is interesting for *P. antipodarum*. It would be interesting to know, either through field or laboratory studies, if a more diverse set of grazers (including desired EPT and Diptera other than tolerant Chironomids) will respond to changes in upright vs. adnate diatoms. I do not think an additional lab/ artificial stream study on response of invertebrates other than *P. antipodarum* is a high priority, as gut analysis of macroinvertebrates could be cost- and labor-effective. But as the researchers note the varying palatability of *P. antipodarum* to the different fish taxa, the suitability of diatoms as food for higher quality invertebrates could provide interesting information on what may be needed for their successful colonization during bug flow experiments and how that moves through the food web to support more diverse invertebrates. Ideally, native snails and other grazers can eventually reduce the prevalence of the nonnative *P. antipodarum*, but I would consider that a less urgent management issue than increasing macroinvertebrate diversity, abundance, and biomass overall.

E. Temperature

1. The development of high-resolution temperature models is important in watersheds, especially with flow regulation interacting with climate change. This model and approach are well-designed. I am familiar with the modeling approach because some of my colleagues are working on the same topic. I appreciate the user-friendly version being developed for use by stakeholders as well.

2. It is encouraging to see that projected temperature increases due to climate change may benefit humpback chub, even though there is a risk of expansion of largemouth bass or other nonnative fishes. This topic certainly deserves to continue to be monitored for temperature increases and effects throughout the ecosystem.

III. Project F: Bug Flows

A. Experimental design, community science

1. Weekend "breaks" are an excellent idea for egg survival and other possible mechanisms for macroinvertebrate success, and therefore for increasing diversity as well. Once this experiment is complete, will there be another study on how weekend flows can be best designed as ecological flows for macroinvertebrates? I do not see details on how they were determined, but perhaps this aspect has been modeled and assessed previously to set the flows. I am not an expert on ecological flows, so I am not requesting data on the specific flows, but the methodology would be interesting, to know if it's fully developed or another part of the experiment.
2. Sampling of aquatic insects is comprehensive, including sampling in the substrate, drift and adult emergence, and is well-aligned with the goals of the monitoring to inform this objective (i.e., successful growth and reproduction, as food for fishes, overall indicators of ecosystem health).
3. I love the community science involved in this project! I don't know what interactions you have with them after data collection and analysis, but I am sure you know it's important to show them what their work accomplishes and make the results available to them in some form so they can share with their stakeholders and communities.
4. Are there opportunities for Tribal groups and other local communities and stakeholders to take part in the community science programs, including, but not limited to, those run by rafting trips? In this case, access to rafting trips may limit the participation of a diverse audience who 1) are not tourists and therefore may not consider participating in such a trip; 2) are financially limited and may not be able to afford such a trip; or 3) have been historically excluded from such activities. Could this group invest in recruiting stakeholders from diverse groups and funding their participation in this work (even if the recruitment is done by a different office or stakeholder group)? It seems that with so many trips happening in a typical year, a small budget allocation could make a big difference in connecting local stakeholders to the research.
5. At the same time, sparking interest in these community science trips for a diverse audience may help build a more robust and diverse community of recreation guides, scientists, etc., which, as you know, is direly needed in the white-dominated environmental research and recreation sectors. Increasing diversity and inclusion have not been explicitly incorporated into many actions by environmental agencies and research groups and may seem out of place in my review of the scientific merit of this program. However, we must start

incorporating Diversity Equity and Inclusion (DEI) into all our activities, and this seems like an ideal opportunity to add DEI work, with potential for mentoring diverse young people into existing community science activities.

B. Hypothesized effects of bug flows

1. Overall, this experiment seems to be showing success, and I support its continuation to compensate for loss of data in 2020 and gather more data to better understand the patterns of macroinvertebrate response. The presentation by Jeff Muehlbauer was clear and well laid out, as was the report. The 2016 paper by Kennedy et al. was also very helpful in understanding the framework. This represents an important compromise for hydropower to better support aquatic life, and could be applied at many other reservoirs, and I respect and appreciate the objectives and methods.
2. I don't have a problem with the egg desiccation hypothesis as the driver of Bug Flows (in reference to a comment after the presentation) in light of the other findings and the published paper on the topic (Kennedy et al 2016). Hypotheses are meant to be tested, and when they are not supported, lead to other, valid conclusions and hypotheses, so it is always acceptable for a hypothesis to not hold. Jeff Muehlbauer notes that it may or may not be a hypothesis supported by the data, that there are many effects of "bug flows," and he also indicates uncertainty on the mechanism for the increases in EPT abundance and biomass in 2018 and 2020. For example, possible other mechanisms for higher 2018 emergence despite no 2017 bug flows: 1) if there are several cohorts of Hydropsychids per year and bug flows support emergence of adults, not just egg moisture, and 2) if a small number of eggs is able to persist during drying, or if some egg deposits occur at low flows, which are low again at the time of emergence. I appreciate the experiment on this topic and can also appreciate that the researchers understand that bug flows have multiple effects on invertebrate life histories, not just avoiding egg drying. I am not suggesting the researchers try to find out if other mechanisms are responsible, but I am noting that it is entirely possible that the 2018 emergence at the start of bug flows could occur through several different mechanisms. I think if the approach works, a definitive causal analysis may not be needed. The analyses of ecological linkages from P up the food web seems more important than a specific causal analysis of the success of bug flows.
3. As I noted above, it would be of interest to know how flows could be best structured to support macroinvertebrates. Maybe the current form is the best one—I don't have enough information to be sure.
4. Research on bug flows is a great start for restoring and increasing insect biomass and aiming to increase insect diversity. As I note above (in Project E), the

assessment of the food web (adding to fish diet studies) would be helpful—if possible, an analysis of insect diets with DNA barcoding (perhaps combined with Stable Isotope to understand the proportions of food types) could help understand diatom, organic matter, and plant dynamics leading to insect success. In the previous analyses, the group has used stable isotope analysis of fish guts which were informative regarding algal- or insect-dominance in fish diets. However, genus or species-level resolution of fish and insect gut contents may contribute significantly to this work by showing small changes over time and improvement of the macroinvertebrate community or variation among years. As the research over the years done by your group has shown in this area, there are changes longitudinally as well as at low flows, which may also be better understood with greater taxonomic resolution of macroinvertebrates.

5. Related to above, in terms of identifying the genera of macroinvertebrates in samples and in fish diets: one difficulty in designing such restoration practices/ experiments is that we do not always have a clear sense of what recovery will look like or the expected time scale (or longitudinal reach of the effects, depending on the type of restoration). While the initial results are encouraging and the experiment is ongoing, it may be helpful to examine genus-level data in macroinvertebrate samples as well as fish diets to look for early signs of ecosystem recovery. Chironomidae may have a variety of pollution and temperature tolerances, so I would invite examination of the genera to see if any shift within the midge taxa may be an early indicator of improvement, while EPT may lag but are still increasing. You have a lot of samples, so even focusing on certain taxa would be informative.

6. I also support the statement by Kennedy et al. (2016) and in the presentation that macroinvertebrate function should be included in the analyses. Viewing macroinvertebrates and fishes through the lens of functional traits is likely to be important to understanding not only food web dynamics, but ecosystem functions contributed by the biota and changes due to variations in the prominent environmental drivers. In my work using multiple indicators relative to restoration, I have found that using the functional lens along with the structure lens allows me to better understand the biotic communities' relationships with stressors. Using functional traits also allows for target-setting of reasonable, desired increases in % EPT, % disturbance-tolerant or disturbance-sensitive taxa, etc., and can be combined with setting taxon-specific goals as the researchers have for Hydropsychidae and Hydroptilidae. Thus, if a function remains similar but the taxa who perform it change, it may be an indicator of ecosystem resilience, where if we only consider them from a taxonomic viewpoint, we may see only the loss of diversity. It goes without saying that it would not be ideal for different fish species to replace your target management fishes, but for macroinvertebrates, the changes among taxa may be okay if functions are supported.

7. In terms of flattening the sine wave of longitudinal changes in abundance—I understand the researchers would like to see a less patchy distribution. At the same time, the data show that caddisfly biomass/abundance is higher where RBT and HBC are prevalent. Is this because other aspects of habitat are better for both the macroinvertebrate and fish communities in these areas, or is it driven by the changes in base flow levels? It would be interesting to know if less patchiness of bugs makes more areas suitable for these fishes, or if there are other habitat and water quality constraints in those areas. Perhaps I have missed the connection in the report and talks. If a more homogenized distribution of bugs leads to the same for the fish communities, I can see the great value of "flattening the sine curve." Right now, I am inclined (with limited data) to understand that the same habitat is supporting the fishes and caddisflies.
8. While Palmer et al. (2005) encourage us to set goals for ecosystems based on more natural systems, few researchers and restoration practitioners do so because there is a lack of data on recovery of systems, and we do not quite know where to start. This becomes a vicious cycle of not knowing → not setting targets → not being able to provide data for others to use to set targets (back to not knowing). I think it is a good idea to set targets for acceptable/desired amounts of improvement. As above, if the hypothesis is wrong, so be it—it can be updated. But target-setting allows us to really focus on the specific goals of experiments in restoration and to refine the goal-setting process so it can be more commonly adopted by others doing similar work. During early analyses of how close we got to our goals, we may choose not to share them externally for the uncertainty of being held to them. But nonetheless, I think it's an important exercise to undergo, at least internally, within the research group. This approach may not always be possible and may be one of my pet topics, admittedly, but I like to raise it in restoration/management research, in this case improving flows for biota.

C. Bug Flows and the food web, especially diatoms

1. The 1992 study by Hardwick et al indicates changes in diatom communities, which have implications in terms of macroinvertebrate diet. However, turbidity and continuing to experiment with ecological flows seem like the best approaches to understanding how macroinvertebrate communities can improve to better contribute to the food web and shift from midge-dominated to [larger and more nutritious] EPT and Diptera taxa (and for diatom communities to improve as well, as they also seem denser at shallower depths and lower turbidity). Diatom diversity may be less important than the quality of biofilms and habitat suitability in terms of supplying macroinvertebrates with palatable taxa, but macroinvertebrate diets could be analyzed through DNA metabarcoding of macroinvertebrate abdomens for gut contents. The objective in Project E above to analyze other available forms of P would complement this work and may make it unnecessary to have taxonomic

data on diatoms in the macroinvertebrate diets. But I'm sure you know that just as certain macroinvertebrate taxa provide better nutrition to fish, the same is true for diatoms and other algae as food for macroinvertebrates. Thus, any information on the nutrition of biofilms and diatoms in the P experiments can be informative to the macroinvertebrate analyses.

D. Emergence timing and spring "mud"

1. This topic seems to reinforce the negative effects of turbidity over longer time scales on macroinvertebrate communities. In the report, late emergence appears to be interpreted as a negative outcome in relation to spring mud; but in the presentation, Jeff Muehlbauer notes that later emerging insects may be larger and therefore provide a better food source. It will be interesting to see how this pattern evolves with more data collection.
2. Have degree days been related to this later emergence as well in the case that the annual water temperature pattern is also related?
3. The pattern with the fall "mud" does seem to suggest that turbidity affects macroinvertebrates differently at different life stages, with a higher emergence at low turbidity, which would align with general understanding that turbidity negatively affects macroinvertebrates through various mechanisms (food sources, breathing structures, etc.).
4. I understand this topic is still being researched, and it does seem like an important link to turbidity and sediment transport, and thus food web connections. I will be curious to know how this variable compares with flow, light, GPP, etc. in its strength of relationship with measures of the macroinvertebrate community (diversity, biomass, emergence, etc.).

IV. Project J

A. Modes of outreach with tribes

1. I am glad to see that the project team met with tribes and worked to develop communication in ways that tribal leaders preferred and offered them a stipend for participation.
2. In terms of the survey, no reason was given in the report for why the three tribes declined to participate. Is there a member of any of the tribes who is working on your team to design the survey, assist with outreach, and overall be a highly involved member of the team? Are there opportunities for tribal members to be paid more than for surveys, as a part of research and management teams? I assume you are continuing to work on these relationships, that it may take time, and, especially now, may require good timing and specific opportunities to

connect with them. I appreciate this objective of your work and see a need for opportunities to expand it.

3. While it is right to request their input and information, when collaborating for research, it is also important to treat the community as a full partner. What are the concerns and research questions of the Tribes in terms of management of the Grand Canyon and Glen Canyon Dam? To what extent do individuals or leaders from the Tribes want to be involved and informed about your work? In my work in collaboration with community groups, including some Tribal leaders, some decisions need to be bottom-up, from their perspectives, rather than top down, from your research teams and the government agencies they represent. It is a good time to seek ways to allocate funding for deeper involvement of these groups. For example, when we write grant proposals with a community member, they are co-PI of the project. You may have already considered these questions—it was difficult for me to tell from the materials.
4. One survey item, willingness to pay, seems inappropriate for Tribes. It is known nationally that the Navajo Tribe requires greater economic support and access to resources than they currently have, and thus they and other Tribes should not be asked to contribute financially to management of the Grand and Glen Canyon resources. This survey item may be appropriate for non-tribal communities using the water resources, but due to the history of Europeans taking Native American resources and the current topics including the landback movement and reparations it appears inappropriate with respect to Tribes.
5. The results working with the Hualapai Tribe are encouraging in terms of understanding their priorities and perspectives. I think the item "anyone should have access to these areas at any time" deserves special attention. As it is unlikely this area would be given back to Tribal governments, setting aside times and areas for their activities may be appreciated, if that is what is meant in the response to that survey item.

B. Deliverables related to Tribes

1. I am pleased to see some deliverables related to the use of USGS science by Tribal communities, along with the standard academic and data-driven deliverables I see in the report. Have Tribal collaborators weighed in on what they might like to see come as a result of the variety of work going on and their involvement? There may be books, materials, or other items that Tribes are interested in to inform their and other communities of their involvement and practices, to promote their culture and well-being, etc. that should be considered alongside the formal, scientific outputs. I see workshops that appear to be mainly with Tribes—where else should this collaboration with them be shared to highlight the cultural aspects and their

areas of interest? How could such outreach and deliverables directly support them with funding and resources?

C. Inclusion of other stakeholders, Willingness to Pay

1. I am sure you meet with other regional stakeholders such as watershed associations, the Riverkeeper, etc. I know that it can complicate the work to hear from stakeholders with different objectives and different perspectives on how much their opinions should be considered. I think it would be helpful to include more information in the reports, more explicit lists, etc., of meetings held and groups to whom outreach has been done. Have the non-Tribal towns nearby been surveyed about Willingness to Pay? I do think it is an important topic in natural resource conservation and management for non-Tribal users. Are the other stakeholders (governments, recreation groups, watershed associations, etc.) involved in any Water Fund/Willingness to Pay research? I understand that your group may or may not be the convener of large stakeholder meetings, but it would help to know more about participation without having to glean it from workshops and presentations in the Deliverables section.

Peer Review

AGENCY:	US Bureau of Reclamation, Glen Canyon Dam Adaptive Management Program (GCDAMP)
MATERIAL(S) REVIEWED:	2020 Grand Canyon Monitoring and Research Center (GCMRC) Annual Report
REVIEWED BY:	Lynne Lewis, Elmer W. Campbell Professor of Economics Bates College
DATE:	September 15, 2021

Introduction

I have reviewed the report *U.S. Geological Survey Grand Canyon Monitoring and Research Center Fiscal Year 2020 Annual Project Report to the Glen Canyon Dam Adaptive Management Program*

I also viewed the video presentations in or related to my area of expertise, listed in in order of the agenda list;

- Introduction to Modeling Tools for Adaptive Management – Mike Runge
- Sediment in the Grand Canyon – Paul Grams
- Recreational use in Glen and Grand Canyons – Lucas Bair
- Hydropower – Clayton Palmer
- Panel Discussion Modeling Tools for Management
- Lees Ferry Fishery Monitoring – Jan Boyer

I focused particularly on those presentations that address in whole or in part, hydropower and energy, recreation and endangered species as well as those that were more indirectly related, including the rainbow trout materials. I have also reviewed the tribal resources slides (no audio accompanied those).

I have reviewed the following documents that appeared in the references that relate to socio-economic values including recreational fishing and hydropower and some that were located elsewhere.

Lucas S. Bair, David L. Rogowski & Chris Neher. 2016. Economic Value of Angling on the Colorado River at Lees Ferry: Using Secondary Data to Estimate the Influence of Seasonality, *North American Journal of Fisheries Management*, 36(6): 1229-1239, DOI: 10.1080/02755947.2016.1204388

Pierce Donovan, Lucas S. Bair, Charles B. Yackulic and Michae R. Springborn. 2019. Safety in Numbers: Cost-Effective Endangered Species Management for Viable Populations.

Neher, Chris, John Duffield, Lucas Bair, David Patterson, and Katherine Neher. 2017. Testing the limits of temporal stability: willingness to pay values among Grand Canyon whitewater boaters across decades. *Water Resources Research* 53, no. 12: 10108-10120.

Duffield, Neher and Patterson (2016) Economics Analysis of Glen Canyon Angler and Grand Canyon Whitewater Visitor Surveys. Prepared for USGS. https://gcdamp.com/images_gcdamp_com/e/e0/Whitewater_Angler_FINAL_REPORT.pdf

I also looked at some of the survey instruments.

Based on the report structure, my main objective was to review LTEMP Goals on Recreational Experience and hydropower which appear in Projects, B, C, H, J and N as well as in the presentations. Project J is focused exclusively on Socio Economics, (**Project J: Socio-economic Research in the Colorado River Ecosystem);** however, socio-economic values and priorities permeate many of the other projects including Projects, B, C, H and N.

I will make some general comments and then more specific comments below:

General Comments

The report that I was asked to review was extremely difficult to review. The LTEMP goals, listed at the beginning of the project report, do not map directly to the projects themselves. Table 2 is a useful mapping of where those goals appear in the projects, but there is no overall assessment or connection across the related items as far as I could tell. Additionally, the presentations do not map onto particular projects or goals directly either. Many of them covered parts of several projects, but there were no direct articulations of the connections. As such it is not at all clear how a decision-maker might use this information. There are many disparate studies and a clearer delineation and/or compilation with summaries and recommendations would be enormously helpful for any reader to know how they tie together.

Each project area clearly reports their goals and objectives, but many of the results sections are very difficult to follow and some seemed cobbled together. There are some general results, but finding specific details is very challenging. A reader should not have to look up each reference in the hopes of finding the methods or data for a particular study. Prior recommendations should be bulleted with specifics on whether or not those goals were met. Links to survey instruments, data and methods of analysis need to be more clear. Without proper context, it is very difficult to review some of the sections. Since socio-economics permeates several of the projects, the authors might want to discuss how to incorporate a summary of the socio-economics in each project?

That said, the video presentations were excellent. Each presentation started with the goals, followed by the metrics used to measure performance and then what the impact topics are.

Mike Runge, in the first presentation, articulated that decision makers need this monitoring information in order to make predictions and the critical uncertainty is reduced by confronting predictions with data from monitoring. He also said that the decision framework is developed by US Fish and Wildlife and their role is to determine what predictive models they need to help them make those decisions. The example he used was the mallard population. The mallard population is a function of habitat and hunting regulations. In that case the hunting regulation is the decision metric. They can then choose the best performing alternative for this metric using a consequence table. As I understand it, consequence tables he mentioned show which alternative performs best in which scenario. In this case, there are seven scenarios including the status quo. My question then is where is this table? There is no summary table anywhere that I could find and the report does not offer information a decision-maker needs at their fingertips. I had to search through a lot of documents to find the information and am still left with many questions.

Thinking more broadly, how does climate change impact any of the scenarios? What about the current renegotiation of the Colorado River Compact? How is future uncertainty included in these studies? I do not see any specific mention of climate change in the report. I understand the report is primarily monitoring the current situation, but if these are used to form predictions, I wonder if the probabilities of extremely low flow futures are considered.

In my comments below I focus on the report *U.S. Geological Survey Grand Canyon Monitoring and Research Center Fiscal Year 2020 Annual Project Report to the Glen Canyon Dam Adaptive Management Program,* and intersperse what I took from the presentations and references that perhaps could be used in a revision of the report.

General comments on Socio-economics

My area of expertise is economics. There is one chapter in the report labeled socio-economic research, Project J. This section outlines two very different modeling efforts – Tribal surveys and bio-economic modeling. Project J refers to tribal surveys without results or survey instruments to refer to or references. Then it moves on to bio-economic modeling and some results, but does not connect the two or have a general summary on those resulting values. Additionally, socio-economic results are scattered throughout the entire document related to recreational fisheries, endangered species and hydropower. The recreational fisheries values are presented in a different project as far as I could tell. Hydropower economic values are discussed, but not presented in Project N. As a reviewer it is very hard to understand the bigger picture for each of the management scenarios. What were each of the recommendations in conflict with and what is the total value? In fact, one of the LTEMP goals is the recreational experience which is mentioned, but not summarized in any of the projects. For each flow experiment, what are the management recommendations? Which flow regime maximizes economic value or recreational experience and is that outweighed by another priority or not? Answers to such questions and many others are not obvious.

I recommend moving from the use of "citizen science" to the more inclusive term "community science." Many organizations have already made this change to their language referencing public participation in data collection, so it would be appropriate to consider doing the same. The term "citizen science" appears in a number of projects.

Specific Project Comments and Questions

I. Project B: Sandbar and Sediment Storage Monitoring and Research

A. Campsites

1. This project chapter reports that high flow experiments benefit campsites by causing temporary increases in campsite area. At the same time, vegetation encroachment causes campsite declines. While the primary goal of this project is to monitor sediment and sandbars (as I understand it), "this project also contributes to the goals for recreational experience."
2. I do not see campsites mentioned anywhere else. Is there a recommendation or conclusion? Do larger campsites allow for more visitors or larger individual campsites? How does this effect the economic value of the recreational experience?
3. What are the recommendations as they relate to recreational experience? This is missing from the entire report, not just in project B.

B. Citizen Science

1. See above on moving to the more inclusive term "Community Science."

II. Project C: Riparian Vegetation Monitoring and Research

A. Campsites

1. Goals and Objectives are missing. There is a section, but it does not list the goals and objectives, only the list of accomplishments.
2. This project aims to monitor changes to riparian vegetation which can reduce camping area (negative in economic value), add beauty to the landscape (positive) and create shades and windbreaks (positive). All of these things affect the socio-economics. Is there a summary or recommendations as related to Project J?

III. Project H: Salmonid Research and Monitoring

There is significant overlap in topic, if not work, with this project and Project J.

A. Recreational Fishery

This project focuses on protection of the endangered humpback chub and maintaining a healthy recreational rainbow trout fisheries. The goal is to maintain a balance between the sport fishery and the downstream humpback chub. Experimental flows proposed in the

LTEMP were designed for this purpose. Simultaneously, there is an effort to slow the increase in brown trout populations. According to the report "The primary objective of this Project Element is to assess the effectiveness of GCDAMP policy actions that influence abundance, survival, recruitment, and movement for two distinctly different trout species."

1. There is reference to an angler survey, but it appears this is a different angler survey than the one used to measure economic value? The economic value (contingent valuation survey) looks to be from 2016. Was there any attempt to collect additional socio-economic data via the survey that was conducted in 2020? Has the data that was collected in terms of numbers of anglers and catch rates compared to the 2016 survey?
2. I assume the recreational fishery is extremely valuable, but there is no reference to the economics or which flow regime could improve the recreational experience (value).
3. Jan Boyer's presentation also covered catch rates and angler satisfaction. Catch rates and satisfaction both went down this year. The significant drop in 2020 is curious. Does this drop have to do with covid-related travel conditions? Or is it simply that different people are fishing this year? There was certainly increased visitation at all federal recreational areas and national parks in 2020 and 2021. Since the number of anglers did indeed go up, is there a way to connect or examine the differences in demographics? Does congestion play a role with increased visitation?[1]

B. Incentive program

1. There is brief mention of an incentive program put together by the National Park Service and the Arizona Department of Fish and Game aimed at reducing brown trout populations. The goal is to incentivize anglers (through payments) to harvest brown trout. This is the only time I saw this program mentioned, though it was mentioned in one of the video presentations. From a socio-economic perspective, incentives can be very powerful tools. Is it working? Is there any data on participation? What is the recommendation?
2. This incentive program was discussed in more detail in Jan Boyer's presentation. From my notes from that presentation, apparently 58% of survey respondents said they would participate in an incentivized harvest of brown trout. The survey also asked about the amount of money that would incentivize the respondent to participate. It sounds like this incentive program was started in November? With a $25? Incentive? This was followed by a survey asking anglers if they were aware of this program. This seems to be extremely important information, but it is missing from the report.

C. Citizen Science

1. I recommend moving from "Citizen Science" to the more inclusive "Community Science."

[1] Jan Boyer's presentation covered items that overlap Projects H and J.

IV. Project J: Socioeconomics

This project addresses the Tribal Resources, Humpback Chub (*Gila cypha*), Hydropower and Energy, and Rainbow Trout Fishery Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement resource goals by addressing the LTEMP Record Of Decision (U.S. Department of Interior 2016a, 2016b) objective to respect the "interests and perspectives of American Indian Tribes" and "determine the appropriate experimental framework that allows for a range of programs and actions, including ongoing and necessary research, monitoring, studies, and management actions in keeping with the adaptive management process." These studies also attempt to "maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term stability of downstream resources."

Summarizing the socio-economics is tricky since pieces are covered or mentioned in several other projects. This project only reports on two of the resource goals. Since socio-economics permeates several of the projects, the authors might want to discuss how to incorporate a summary of the socio-economics in each project?

A. Tribal Resources

1. Tribal Values: I have read Project J on Tribal values and reviewed the slides that were presented. This section is difficult to review since the reports are currently confidential as I understand it and the audio that accompanied the slides was not released. Within my area of expertise, both the report and the slides mention a tribal survey that included a contingent valuation question. I was interested in learning more about this since in my experience, many indigenous groups have balked at the idea of monetizing cultural resources.

2. After a series of questions about preferences for environmental and management outcomes, the contingent valuation question reads:

   > "What is the most you would be willing to pay per month in order to have the river management tools you approve of used to manage the Colorado River ecosystem? Please keep in mind your financial situation and the fact that you may prefer to use the money for other purposes including alternative environmental conservation programs." (Incorporating Tribal Knowledge and Preferences slides, January 9, 2021)

   I have two concerns with the phrasing of this question. The first is about *what* is being valued. Contingent valuation results suffer from biased responses when respondents are not clear on what is being valued, but also when different respondents are valuing different things. In this case, the respondent needs to presumably remember what management tools they said they preferred, but also might be making a payment choice based on something entirely different from

another respondent. My preferred management goal might be different from yours; in which case, we cannot compare or average our individual willingness to pay (WTP) since we are "bidding" on different goods. What are they valuing? If each respondent is simply valuing their own choices, these data cannot be used to measure the economic value and I urge extreme caution with use of these responses, unless they are grouped by management tool.

Second, the last phrase seems like it could easily induce bias. "Please keep in mind your financial situation and the fact that you may prefer to use the money for other purposes including alternative environmental conservation programs." This reads a bit like a caution that perhaps I should say no to the willingness to pay question? Did this language come from focus groups or survey pre-testing?

Again, without more context and information, I can only make these general comments and cautions.

Finally, the slide that shows the responses to the WTP question does indeed show a larger percentage of $0s. The data on why respondents chose "no" or $0 could be very informative on whether they protest the scenario, cannot afford it, prefer the opt out given in the question, or something else. Best practice suggests protest bids should be removed.

The simple average of willingness to pay is okay, but a rather crude measure when using this payment card method.

B. Recreational Use

1. There is no mention in Project J about the economic value of the recreational fishery.
2. Lucas Bair's presentation, however, presented two performance metrics: recreation and visitor use and experience as it relates to fishing, boating and camping. The impact topics include recreational use values and employment and income.

   Glen Canyon rafting metrics were presented, including the statistic that 50,000 people participate in day use rafting. The presentation also examined whether or not high flow scenarios impacted the number of visitors. They also examined inundation of recreation sites.

C. Whitewater rafting (a subset of B above)

1. Whitewater rafting was also not mentioned in Project J although rafting plays a large role in socio-economic value. The presentation did cover whitewater rafting extensively comparing the more recent data with the original Bishop study. In high demand months, the economic value is significant. I did review the two published papers by this team on the value of the whitewater rafting. Those studies are based on a contingent valuation survey that was then compared to the original 1995 Bishop survey.
2. The decision about which model to apply to WTP data is not neutral, which is why sensitivity analysis is so important. The parametric approaches are fairly

straightforward and deliver good estimates with good statistical properties provided the specification of the distribution is correct. If the proposed distribution family is incorrect, however, the estimated mean WTP can have a systematic upward or downward bias. Non-parametric techniques are appealing, in part, because they do not rely on an assumption about the underlying distribution of WTP values. Since we do not know what this distribution looks like, a linear or logistic function may or may not be appropriate. In fact, the authors state that the pooled model suggests possible differences in the underlying WTP distribution functions between the two studies suggesting a non-parametric approach would be most appropriate for comparison. It would be interesting to use some of the more commonly used approaches such as the non-parametric Turnbull with this data. The Turnbull is easy to calculate by hand and the data from Table 3 in the Neher et al (2017) article would allow for a comparison using a non-parametric technique. Another appeal for using the Turnbull with this particular data is that the Turnbull does not rely on covariates which clearly are changing over time for demographics. As such I recommend including sensitivity analysis of WTP estimates including the use of non-parametric models for the next iteration with this data. It would certainly be an interesting test of whether these values are stable over time using a different technique.

3. Using a price index more representative of recreation is recommended (rather than the CPI for all urban consumers).

Neher, C., Duffield, J., Bair, L., Patterson, D., & Neher, K. (2017). Testing the limits of temporal stability: willingness to pay values among Grand Canyon whitewater boaters across decades. *Water Resources Research*, *53*(12): 10108-10120.

D. Humpback Chub and Rainbow Trout

1. "Donovan and others (2019) published an updated bioeconomic model to estimate the most cost-effective approach to managing rainbow trout removal at the confluence of the LCR and the Colorado River to meet long-term adult humpback chub survival goals." The report gives a relatively short description of the bioeconomic dynamic programming model that evaluates that tradeoffs between protecting humpback chub and rainbow trout abundance.
2. Where is a summary of the findings? Who are the decision-makers?
3. Both of these species have considerably large economic value I presume, so how are the tradeoffs measured? Endangered species and other non-use values can be quite large. Has the economic value of the humpback chub been estimated?

E. Rainbow Trout Fishery

1. Recreational fishing is covered above, but the rainbow trout fishery is also discussed in several of the other projects. There needs to be some summary material in this report that weaves these similar topics together. I am still not clear on the economic value of this fishery although it is extremely valuable.

2. How have the change in numbers and types of recreational fishers influenced these values?
3. Has the incentivized catch program for brown trout impacted satisfaction and economic value of the rainbow trout fishery?
4. 2016 report on the economic value of the recreational fishery. Is this survey going to be repeated to get a more current assessment of recreational fishing that can be used with the 2020 fish and angler counts?

F. Hydropower and Energy

1. Why is there no summary of the socioeconomics of hydropower?

G. Climate Change

1. There is no mention of the on-going severe drought or climate change. Will new low-flow scenarios be tested? Are there recommendations going forward related to climate change? And how does the renegotiation of the Colorado River Compact impact this report.
2. The report does include: "The Donovan and others (2019) model will also allow research into the impact of nonstationary climate impacts (e.g., changes in flood frequency) on humpback chub recruitment in the Little Colorado River and how that may inform effective and efficient management and research." This will be important for continued inclusion.

V. Project N: Hydropower Monitoring and Research

A. Lack of detail

1. Goals and objectives could be clearer.
2. One of the goals is " The operation of [Glen Canyon Dam] GCD to meet hydropower and energy resource objectives, as the integration of renewables and a greater recognition of the social cost associated with power system emissions occurs, is an important consideration when attempting to maintain and improve resources downstream of GCD."
3. There is no detailed report on the economic value of hydropower outside of the slides, and it isn't clearly laid out in the Annual Report. What is the total value of hydropower? The report states "The total value of hydropower generated at GCD includes costs associated with energy generation, greenhouse gas emissions, human health, and other regional impacts. These impacts are dependent on the price of fuel (e.g., natural gas) and the integration of additional generation, including renewable energy, into the electricity sector. Scenarios incorporating these factors were used to assess total economic costs associated with a proxy experimental flow at GCD." Where are these results?

4. "We demonstrated the change in production and emissions costs in the Western Interconnect by reoperation of GCD has the potential to be significant and could potentially result in offsetting costs." (p 156). A table with numbers and results from different scenarios would be extremely helpful. I would like to see what these external social costs are. I agree that they are very important, but having some details or a summary table is necessary.
5. There is a link in the document "for more detail and preliminary results…" but that link simply takes me to a powerpoint presentation from February 2020. There are 3 slides on hydropower (slides 30-32), but those have very little detail without knowing what the speaker said. I do not know how the various scenarios were calculated. For example, how are emissions costs measured? Which experimental flow scenario results in which costs? What are the recommendations?
6. Project N needs more detail.
7. From the presentations I learned that the value of hydropower generation is $millions/year was estimated over 20 years discounted at 3.375% and the value of hydropower capacity was calculated by finding the 90% exceedance value for daily minimum generation in August. A table of these results would be extremely helpful. Was any sensitivity analysis performed? Is the choice of a 3.375% discount rate mandated or chosen by analysts?

   From the presentations I understand they estimated capacity and energy for various flow? scenarios which can then be used to estimate economic value and changes in rates for rate payers. Then they look at how this impacts emissions. This seems really important? Are the results posted anywhere?

Other Comments

How do the references on total economic value tie in with the other items in socio economics (The Bair/Duffield/Nehere references)

Covid-19 impacted data collection in 2020. It also significantly impacted the numbers and types of visitors. How are these changes influencing the monitoring efforts and decision-making?

Finally, there is no mention of the on-going severe drought or climate change. Will new low-flow scenarios be tested? Are there recommendations going forward related to climate change? And how does the renegotiation of the Colorado River Compact impact this report?

Peer Review

AGENCY:	US Bureau of Reclamation, Glen Canyon Dam Adaptive Management Program (GCDAMP)
MATERIAL REVIEWED:	2020 Grand Canyon Monitoring and Research Center (GCMRC) Annual Report
REVIEWED BY:	Ben Livneh, PhD, University of Colorado - Boulder
DATE:	July 29, 2021

I. Project A: Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem

Commentary

This project is focused on making and interpreting basic measurements of streamflow, water quality, and sediment budgeting, with relevance for management. Impacts of dam operations on sand budgets have implications for nearly all of the LTEMP goals. Overall, progress has been made in terms of collating, analyzing, and modeling the Colorado River ecosystem (CRe) to identify drivers of sand and to articulate limitations in historical monitoring. A large number of data products, reports, and presentations indicate good progress, generally sound methods, and potential applications for further high flow analysis.

Sustainability of sand resources

The authors report reductions in sand concentrations in the river, i.e., those needed to maintain sand bars. This appears to be both a robust and an important result, which raises the question of the sustainability of sand resources within the system. In their companion manuscript (Topping et al. 2021), the authors contend that sand concentrations need to be measured continuously in order to effectively monitor sand availability, given the episodic nature of sand loading in relation to high flows. For example, sand loads in different reaches are largely uncorrelated based on the available data, which is due to irregular sampling relative to high and low flows. Normal flows appear to result in losses in sand, i.e., erosion, such that only high flow events can contribute net gains to the sand budget.

Recommendations for this project element include:

(i) Continue monitoring and evaluation of sand resources to support the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) sediment goal. If feasible to implement and maintain, the continuous monitoring of sand will support greater understanding of the sustainability of current and future sand resources and critical connections between sand concentrations and high flows and other concomitant factors such as changes to the channel bed and flood deposits.

(ii) To mitigate the continued loss of sand, the timing of HFEs need to be coordinated during periods of high availability of fine sand, as a way to support a net contribution of sand and minimize erosion of sand.

Reconstruction of flood flows

The authors indicate that flood peaks in the Little Colorado River Basin have decreased through time, citing Dean and Topping (2019). This assertion is based partially on the authors reconstruction of flood flows using linear regression methods between different stream gage data sources. This method inherently contains uncertainty. It would be valuable if the authors could estimate the magnitude of this uncertainty either as a function of the mean flows or the flood flows in question, so that a clearer interpretability of the potential impact of the uncertainty could be made. The flood peak attenuation associated with within-channel vegetation (e.g., tamarisk) has the potential to minimize the benefit of upstream large flood peaks to propagate into the Little Colorado River.

Recommendations for this project element include:

(i) Explicitly report uncertainties in the reconstruction.

(ii) Where long-term precipitation gage data exist, consider incorporating these into the regressions, and/or expanding stream gaging to improve understanding of within-basin variability, inter-gauge relationships and reduction of uncertainty.

(iii) Given the high interannual variability in sand mass (i.e., reported in the table for years 2018-2020), it would be useful if the authors can report long-term rates of change and their uncertainties for overall planning, as well as to put individual years into clearer context.

(iv) Ensure all tables include a descriptive caption.

(v) Consider management options of riparian vegetation to minimize increased roughness and flood-peak attenuation associated with vegetation encroachment.

II. Project B: Sandbar and Sediment Storage Monitoring and Research

Commentary

This project seeks to connect high flow experiments and dam operations with impacts on sandbar dynamics, with relevance for management. Predictive tools for sand transport and behavior are contributed, as well as analysis of campsite areas together with citizen science. This project addresses the LTEMP sediment goal. Numerous data products, publications, and presentations indicate good progress, generally sound methods, and potential applications linking high-flow events with sand and camping impacts. Monitoring and data sharing are important continued activities from this project.

B.1. Sandbar Monitoring Using Topographic Surveys and Remote Cameras

The authors report that while some significant fraction (greater than or equal to 25%) of the sand comes from pre-dam sources, High Flow Experiments (HFEs) contribute to new sand deposition. This new sand is eroded in many places, but it does persist in other places. In the context of campsite areas, vegetation encroachment is an ongoing problem which is largely independent of HFE activity. The authors, as well as Chapman et al. (2020) clearly show that even the largest controlled floods from the past 20 years are much smaller than the pre-dam peak annual flows. In addition, the volume released by HFEs is small enough not to affect the annual water volumes released, such that HFEs can continue to occur without impacting the needs of the large number of reliant stakeholders

Recommendations for this project element include:

(i) The importance of Paria River inputs for sand budgets is underscored by the authors analyses. Given that trends in the Paria River sediment delivery and flood frequency are affected primarily by climatic changes rather than by human development activities (as noted by Chapman et al. 2020), it is therefore recommended that the authors expand their future work to diagnose the roles of historical temperature and precipitation more directly within their sand analysis. In this way, in the future it may be possible to more clearly understand the implications of projected temperature and precipitation on the long-term sustainability of sand resources within the domains of interest.

(ii) The authors have the capability to report uncertainties in the sand attribution analysis using their mixing model approach. It would therefore be helpful if they can present their relative confidence in magnitudes of the sources of sand as a way to put the current knowledge base into context. For example, to understand

the likelihood that the erosion of pre-dam sand presents an existential crisis for the system.

(iii) The viability of replanting native vegetation or manual removal of specific vegetation (e.g., tamarisk) should be analyzed as part of future analyses to understand the cost-benefit analysis of such an activity.

(iv) Remote camera images provide invaluable information on the status of sandbars within the system and their continued deployment is recommended. However, it would be of potentially greater impact to explore the use of existing high-resolution (<10 m) spaceborne visible satellite imagery as a way to complement and extend the knowledge base gained from existing satellite imagery.

(v) The public sandbar data base is a positive and important development. Consideration should be given as to whether MySQL is the appropriate database tool in the event that data volume becomes an issue.

(vi) It would be helpful to see a map of the points in the figure to understand their position within the system.

B.2. Bathymetric and Topographic Mapping for Monitoring Long-Term Trends in Sediment Storage

Recommendations for this project element include:

(i) Repeated mapping of the riverbed in LMC should be continued, given the demonstrated value of this effort in determining the sand budget and high signal to noise ratio.

(ii) Further exploration is warranted into potential applications of the Bayesian framework (e.g., Ashley et al. 2019) as a tool for quantifying reach-scale sediment deficits and surplus relevant for future studies.

B.3. Control Network and Survey Support

Recommendations for this project element include:

(i) The FY2020 expansion into un-surveyed reaches represents an important development that could offer new insights into mapping the system and key fluxes within it.

(ii) Regional geodetic improvements may serve a longer-term benefit of connecting local imagery with spaceborne remote sensing capabilities.

(iii) Mapping of the riverbed in LMC should be continued, given the demonstrated value of this activity.

III. Project C: Riparian Vegetation Monitoring and Research

The authors have compiled a useful set of monitoring data and methods that connect vegetation with flow, environmental variables, and management.

C.1. Ground-based Vegetation Monitoring

Recommendations for this project element include:

(i) It would be helpful to report what criteria are included in the 'error checking' of the ground-based monitoring data and to consider including stakeholders in the ideation process, so as to ensure that important criteria are not being screened or missed.

(ii) The percent cover reported in Figure 1 appears to be very small, i.e., less than 1.2% of the area, such that a clearer explanation for why such a small coverage is of significance is needed.

(iii) The website is very nice and provides good overview information. The authors should consider posting data directly to the webpage.

C.2. Imagery-based Riparian Vegetation Monitoring at the Landscape Scale

Recommendations for this project element include:

(i) It would be helpful to report the fraction of woody riparian vegetation as a function of total vegetation and as a function of total riparian area. Further, understanding changes in woody vegetation through time will be an important reference point in terms of data management strategies. It looks like some of this is covered in Kasprak et al. (2020).

(ii) Given the imperfect land-cover classification process (e.g., described by Bedford et al. 2018), it would be helpful for the authors to report the uncertainty in their estimates of various species composition, fractional coverage, etc., so as to more clearly articulate the state-of-the-knowledge of riparian vegetation species composition.

(iii) Given the recent advances in high-resolution spaceborne remote sensing, the authors should consider incorporating this technology as part of future work, at a

minimum comparing their results with viewable scenes from satellite remote sensing.

C.3. Vegetation Responses to LTEMP Flow Scenarios

Recommendations for this project element include:

(i) The analysis relating climate variables with vegetation patterns (Butterfield et al. 2018) is interesting and should continue to be pursued. For example, considering the diurnal temperature range, i.e., the difference between maximum daily temperature (T_{max}) and minimum daily temperature (T_{min}) for two reasons. First, the diurnal temperature range has been shown to be closely related to the daily downwelling shortwave radiation which is an important predictor variable for vegetation, and second the maximum and minimum temperatures are widely reported and are much simpler to observe than radiation.

(ii) The climate analysis in conjunction with the HFEs highlights an interesting avenue to pursue for future vegetation control with warming affecting inundation tolerance.

C.4. Vegetation Management Decision Support

Recommendations for this project element include:

(i) Given the challenges brought about by riparian vegetation for campsites and other uses, it would be helpful for the authors to report the typical depth of roots for each of the species, as well as the density of the roots at different depths, since these will be valuable in determining management strategies and to inform decision making regarding long-term treatment options of replanting, removal, etc.

IV. Project D: Geomorphic Effects of Dam Operations and Vegetation Management for Archaeological Sites

Recommendations for this project element include:

(i) The meteorological monitoring and data collection described by Caster et al. (2018) is extremely valuable and its continuation should be prioritized. The potential linkages between climate and riparian and riverine conditions offer unique insights into monitoring and management.

(ii) There appears to be a grammatical issue on Page 41 of the report, under the third-to-last sub-bullet of FY 2019.

(iii) Consideration should be given to exploring the use of high-resolution spaceborne remote sensing to complement existing aerial (e.g., LiDar methods) given the semi-continuous availability of spaceborne datasets, which would supply a valuable time-evolution of variables of interest.

V. Project E: Nutrients and Temperature as Ecosystem Drivers: Understanding Patterns, Establishing Links and Developing Predictive Tools for an Uncertain Future

Recommendations for this project element include:

(i) The authors report improvements in their predictive model on the basis of including solar radiation as a predictor. Details of the radiation data were entirely missing, such that it is not possible to evaluate the utility and appropriateness of the observations. However, effort should be made to utilize radiation observations reflective of conditions *in situ*, rather than relying upon radiation observations from distant locations, i.e., from gridded datasets. Further, where radiation is not readily observed—acknowledging the challenges in widespread radiation observations—the authors should consider using the diurnal air temperature range as a proxy for solar radiation in their model.

(ii) Many of the figures in Project E are low-resolution, making their evaluation challenging. This may simply be a typesetting issue.

(iii) Clearer justification of the water temperatures chosen, i.e., 10C, 15C, 20C, should be provided in the context of existing pool temperatures and temperatures relevant for other project components.

(iv) Overall, establishing connections between water temperature and taxa and species of interest is a viable area of investigation that should be continued going forward.

VI. Project J: Socioeconomic Research in the Colorado River Ecosystem

This integrative project plays in important role in connecting physical science with stakeholder needs, incorporating tribal perspectives within the context of dam operations.

Recommendations for this project element include:

(i) Overall, this project is an important component of the CRe, GCMRC, and GCDAMP, because it allows for a broad assessment of the connections of ongoing activities with needs and economics downstream. Therefore, it is recommended to continue prioritizing this area of analysis.

(ii) The proposal to evaluate nonstationary climate impacts using the Donovan et al. (2019) model appears to be an important idea and its prioritization is recommended. However, the authors need to be careful that such a modeling approach is implemented with realistic constraints dictated by the physical system, since there appears to be a chain of models proposed which can lead to solutions that are not realistic or feasible. For example, connections between the biogeomorphic (Dean and Topping 2019) and humpback chub recruitment (Van Haverbeke et al. 2013) conditions need to be mapped at the outset to identify linkages, constraints and outcomes of interest to stakeholders, while also ensuring that physically infeasible solutions are eliminated.

VII. Project K: Geospatial Science and Technology

Recommendations for this project element include:

(i) The migration of datasets away from traditional ‘flat-files’ into databases and within cloud computing resources (USGS Cloud Hosting Services and Amazon Web Services) is an important cross-cutting innovation that will continue to payoff throughout and beyond the life of the project. It is therefore recommended to be prioritized going forward.

(ii) The GIS toolkits provided by ESRI Desktop ArcGIS are effective and generally comprehensive for small processing and analysis jobs, but can become

overwhelmed with larger, multi-site analyses. Therefore, it is recommended that consideration be given to more powerful and efficient tools capable of handling larger datasets and analyses (e.g., Python-based tools), in the event that data sizes and ArcGIS-latency become an issue. The reliance upon ArcGIS may be suitable for the short-term, but as data volume and analysis-scope grows, there may be a need to expand towards more big-data-capable tools. There may be transition-relevant tools like ArcPy that could serve as a bridge. There appears to already be some project work being done on the project in Python; for example, the geoprocessing done for the lake elevations (Figure 1).

(iii) Tableau is a sleek visualization software that is generally easy to use and has a good community and forum. However, drawbacks of Tableau are its high-cost, security issues, and limited product support. Therefore, consideration should be given to the cost-benefit of this product in the context of other comparable visualization products.

(iv) Consideration should be given to whether the streamlining of multiple desktop applications (ArcGIS, ArcMap, GGIS) would improve workflows.

(v) It is important that migration continues for software development to follow version control protocols. For example those provided by Github.

(vi) The transition towards IoT sensors will have numerous benefits. However, consideration should be given to security issues surrounding such a transition.

VIII. Project L: Overflight Remote Sensing in Support of GCDAMP and LTEMP

Recommendations for this project element include:

(i) Although the details of the overflight are not clearly articulated, the value of additional remote sensing seems high and worthwhile. One recommendation would be to evaluate opportunities for integrating remote sensing imagery with publicly available spaceborne imagery as a way to potentially extend the investment.

IX. Project M: Administration

No major comments. However, one minor comment is that the citizen science programs, e.g., Adopt-a-Beach, seem like an excellent way to extend budgets, while also elevating the awareness of visitors to issues within the region.

X. Project N: Hydropower Monitoring and Research

Recommendations for this project element include:

(i) Continue to coordinate with partners to identify opportunities to improve hydropower and energy resources. For example, the impact of HFEs on total outflows, the sensitivity of GHG emissions to reservoir levels, etc.

XI. Appendix 1: Lake Powell Water Quality Monitoring

Recommendations for this project element include:

(i) The collaboration with EPA to support floating chamber-based measurements of carbon dioxide and methane should continue to be prioritized to advance understanding of GHG emissions from Lake Powell.

Peer Review

AGENCY:	US Bureau of Reclamation, Glen Canyon Dam Adaptive Management Program (GCDAMP)
MATERIAL(S) REVIEWED:	2020 Grand Canyon Monitoring and Research Center (GCMRC) Annual Report
REVIEWED BY:	John C. Stella, SUNY College of Environmental Science and Forestry
DATE:	October 3, 2021

I. Project A: Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem

A. Goals and objectives, and science questions

1. The statement of goals and objectives are clear. The physical monitoring of streamflow, water quality and sediment are critical to designing flow releases from Glen Canyon Dam, as well as supporting other ecological research.
2. The two key hypotheses, sustainable operation of sand resources and other CRe resources, are clear, if a bit basic. It would be helpful to know what constitutes a "sustainable" system in this context. How does annual and seasonal variability of sediment storage and transport, water quality, and discharge factor into whether the system is sustainable, and over what timeframes? How does current variability in these metrics compare to pre-dam variability, and to projected change in the future?

B. Results and deliverables

1. The physical monitoring program is very productive, with 12 presentations, 6 peer-review papers, and five USGS reports, data releases, and web applications developed. The papers are published in high-impact journals such as JGR Earth Sciences, ESPL, HESS and Geomorphology.
2. The bullet-point summary of results is informative, clear, and geared appropriately toward management. The negative feedback interactions between water discharge and sand supply highlight the importance of coordinating dam release levels with the timing of Paria River floods, which provide the primary sand supply to Marble and Grand Canyons. These insights provide clear sideboards for management, and highlight the true narrowness of the decision space available for dam management. The reduction of sand supply from the Little Colorado River basin only further constrains the management options available.

3. A small point, but it would be helpful to show a figure or two to illustrate the sediment budget in different reaches of the system. Some of the figures from Topping et al. 2021 (JGR – ES) could be appropriate.

II. Project C: Riparian Vegetation Monitoring and Research

A. Overall program productivity and quality

1. In general, the riparian vegetation monitoring and research is comprehensive, informative, and productive.
2. The project team has produced numerous deliverables including >20 presentations, six published peer-reviewed papers, and a USGS Techniques and Methods report. I have read or skimmed many of the papers and the report, and their quality is high, with several in high-impact journals.
3. The vegetation science program consists of complementary components including ground-based monitoring (C.1), remote sensing approaches (C.2), modeling of vegetation response to LTEMP flow scenarios (C.3), and management decision support (C.4).

B. Better articulation of overarching scientific and management questions

1. Despite the strength of the overall riparian vegetation program, the scientific questions that undergird the specific activities are not clearly articulated. For example, the section "Goals and Objectives" in Project C refers to the TWP FY2018-2020 deliverables, but no overall goals and objectives are stated. Similarly, the Science Questions Addressed only lists research questions for section C.2, the imagery-based vegetation monitoring project. The four components (C.1 to C.4) and their deliverables need to be tied more directly to overarching scientific and management questions that relate to how the system operates as a whole and to the LTEMP resource goals. Many of these larger questions are implied within the individual studies, but how they tie together is less clear.
2. For example, the interactions between exposed sandbar area, vegetation and hydrology modeled in Kasprak et al. (2021) suggest that climate change and river management will result in greater vegetation encroachment and less exposed sediment within the system. In the Butterfield et al. papers, associations between vegetation guilds and environmental conditions suggest that channel position and vegetation structure interact to influence the rate and pattern of sediment trapping. But what do these interactions predict for the future in terms of how the system functions currently and in the past? Will the hotter and drier conditions result in more vegetation encroachment due to a reduced disturbance regime, or conversely a narrowing of the vegetated zone? Will these changes favor non-native species, and if so, what are options for reducing this risk?

3. In the next phase of this research (e.g., the 2021-2023 work plan), it would be helpful to focus on integration and synthesis, to understand how these interactions between plants and the fluvial system either support or undermine the multiple LTEMP goals.

C. Relationship between restoration actions and management goals

1. Similar to the comment #2 above, it would be helpful to understand how the various implemented and planned restoration actions connect to reinforce the management goals. There are several examples of restoration-relevant studies conducted in the triennial work plan, including the arrowweed flood trials (Fig. 5), the genetic population analysis of riparian trees (Fig. 6), and the monitoring of tamarisk beetle impacts (Bedford et al. 2018).
2. However, the overall need and goals for restoration are not clear. Restoration of what processes and/or vegetation structure, and to what ends? What are the most likely restoration actions (e.g., flow prescriptions, biological control, physical removal, horticultural plantings), how do they support the LTEMP goals, and what scientific questions still need to be answered?

D. Conceptual model to tie science activities and restoration actions to management goals

1. One way to proceed for the next phase of the research is to develop a conceptual model of the primary interactions between biotic and abiotic components of the system based on the excellent work to date (if this hasn't been done explicitly yet), and to use it to identify the key knowledge gaps needed to advise dam operations and restoration actions.

E. Environmental niche modeling approach

1. The ground-based vegetation monitoring data (section C.1) has been analyzed primarily via a niche-based modeling approach (Butterfield et al. 2018, 2021). These two papers use innovative applications of niche modeling to understand associations of riparian species presence with environmental hydrological variables at the site and river scale (2018 paper) and regional scale (2021 paper).
2. Though investigating these plant-environment associations using niche models is common and informative, it is unclear how useful they will be for predicting the effects of environmental change. For one thing, there are lag effects in recruitment and establishment that do not get captured in niche models based on static measurements in time, especially for perennial and woody species. Niche models are less useful for understanding relationships when environmental variables are changing faster than the plants can adapt or disperse.
3. The topographic change detection approach in Butterfield et al. 2020 does address this issue through the effects of plants on sedimentation. However, the influences going the opposite way, of investigating how the changing environment will influence plant response, can only be inferred indirectly from the niche models. In the next phase of research, the niche model results can be used to inform and

design field experiments and lab manipulations (e.g., in flumes) to directly investigate the mechanisms governing plant distribution and diversity in the Grand Canyon.

APPENDIX B: REVIEWER'S CURRICULA VITAE

Michael E. Colvin, PhD, Associate Professor at Mississippi State University

Stefanie A. Kroll, PhD, Assistant Research Professor at Academy of Sciences of Drexel University

Lynne Y. Lewis, PhD, Professor at Bates College

Ben Livneh, PhD, Assistant Professor at University of Colorado – Boulder

John C. Stella, PhD, Professor at State University of New York

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Education

2012-2014 Postdoctoral Scholar Oregon State University
Research focus: *Causes and management of prespawn mortality in spring Chinooksalmon, structured decision making of natural resources*

2012 Ph.D. Iowa State UniversityMajor: Fisheries Biology
Dissertation: *Impacts of non-native species in a shallow lake: A simulation modeling approach for restoration and management*

2005 M.S. University of Idaho Major: Fisheries Resources
Thesis*: Ecology of Myxobolus cerebralis in the Pahsimeroi drainage, Idaho*

2000 B.S. Unity College Major: Aquaculture
Thesis: *Inventory of pathogenic bacteria of Maine baitfish*

Employment

2020-pres. Mississippi State University, Department of Wildlife, Fisheries, and Aquaculture Associate Professor
Starkville, Mississippi, USA

2012-2020 Mississippi State University, Department of Wildlife, Fisheries, and Aquaculture Associate Professor
Starkville, Mississippi, USA

2012-2014 Oregon State University, Department of Fisheries and WildlifePostdoctoral Scholar
Corvallis, Oregon, USA

2007- 2012 Iowa State University, Natural Resource Ecology and Management DepartmentResearch Assistant
Ames, Iowa, USA

2005- 2007 United States Environmental Protection Agency, Western Ecology DivisionStudent Contractor
Corvallis, Oregon, USA

2002- 2005 University of Idaho, Department of Fish and WildlifeResearch Assistant
Moscow, Idaho, USA

2002 Idaho Department of Fish and Game
Fisheries Technician
Nampa, Idaho, USA

2002 Utah Division of Wildlife ResourcesWildlife Technician
Logan, Utah, USA

2001- 2002 Idaho Department of Fish and GameFisheries Technician
Nampa, Idaho, USA

Teaching, mentoring, and workshops

2021 WFA 4313/6313: Fisheries Management 3 Credits (Instructor) WFA 4133/6133: Fisheries science 3 Credits (Instructor)
WFA 8433: Natural resource and conservation decision making 3 Credits (Instructor)

2020 WFA 4133/6133: Fisheries science 3 Credits (Instructor)
WFA 7000: Directed independent study. Fish and fisheries of shallow impoundments (Instructor)
WFA 4000: Directed independent study. Inland fisheries exploitation 3 Credits (Instructor)
WFA 4800: Directed independent study. Evaluating occurrence of migratory riverine fish species 3 Credits (Instructor)
WFA 4000: Directed independent study. Fisheries research and management studydesign 1 Credits (*Instructor*)
WFA 4000: Directed independent study. Fish tagging for management andconservation 3 Credits (*Instructor*)
WFA 7000: Directed independent study. R for biologists (*Instructor*)WFA 4313/6313: Fisheries Management 3 Credits (*Instructor*)

2019 WFA 4133/6133: Fisheries science 3 Credits (*Instructor*) WFA 4313/6313: Fisheries management 3 Credits (*Instructor*)
WFA 8433: Natural resource and conservation decision making 3 Credits (*Instructor*)
Undergraduate Research Scholar Program: Using boat mounted RFID to estimateexploitation. (Mentor to undergraduate researcher)

2018 WFA 4133/6133: Fisheries science 3 Credits (*Instructor*) WFA 4313/6313: Fisheries management 3 Credits (*Instructor*)
WFA 7000: Directed independent study: Using R for biology (*Instructor; 2 students*)
Undergraduate Research Scholar Program: Southern brook lamprey abundance and lifehistory (Mentor to undergraduate researcher)

2017 WFA 4133/6133: Fisheries Science 3 Credits (*Instructor*)
WFA 8433: Natural resource and conservation decision making 3 Credits (*Instructor*)WFA 4313/6133: Fisheries management 3 Credits (*Instructor*)
Undergraduate Research Scholar Program: Do fishing forecasts work? (Mentor toundergraduate researcher)

2016 WFA 4133/6133: Fisheries science 3 Credits (*Instructor*)
WFA 4313/6313: Fisheries management 3 Credits (*Instructor*)

2015 WFA 4313/6313: Fisheries management 3 Credits (*Instructor*)
Undergraduate Research Scholar Program: Adaptive harvest of crappie in Lake
WFA 4133/6133: Fisheries science 3 Credits (*Instructor*)
WFA 8990: Ecological theory and applications 3 Credits (*Instructor and co-developer*)

2014 MS Access for fish and wildlife application: Workshop at Research Advances inFisheries and Wildlife Ecology Symposium (*Instructor*)
R for fisheries applications: Continuing education course for Oregon Chapter of theAmerican fisheries society

2013 FW599: Introduction to R and data management for Fisheries and Wildlife applications – Oregon State University (*Instructor and co-developer with J.T. Peterson*)
FW537: Structured Decision Making in Natural Resources – Oregon State University (*Ecampus Instructor*)
FW538: Structured Decision Making in Natural Resources Laboratory – Oregon State

University (Ecampus Instructor)
Making scientific graphics with R – Workshop at Research Advances in Fisheries and Wildlife Ecology Symposium (Instructor)

2012 FW537: Structured Decision Making in Natural Resources – Oregon State University (Ecampus Instructor)
FW538: Structured Decision Making in Natural Resources Laboratory – Oregon State University (Ecampus Instructor)

2011 Clear Lake Ecosystem Model Technology Transfer – Iowa State University (Instructor for a 1 day workshop)
AEcl 420/520: Fisheries science – Iowa State University (Guest Lecturer on fisheries models)
Iowa Chapter AFS Continuing Education Course Age and Growth (Workshop Assistant)

2010 Science with Practice: Benthic invertebrate assemblages in Clear Lake, Iowa: Spatiotemporal variation due to habitat and the zebra mussel invasion – Iowa StateUniversity (Mentor for undergraduate student)

2009 AFS Continuing education course: R for routine fisheries analysis (Workshop Instructor for a 1.5 day workshop)
AEcl 420/520: Fisheries science – Iowa State University (Guest Lecturer on fisheries models)
AEcl 490: Independent study: Analysis of Sampling Methods for Dreissena polymorpha veligers – Iowa State University (Mentor for undergraduate student)
Ent 525: Aquatic Insects – Iowa State University (Guest Lecturer)

2008 AEcl 575x: Quantitative methods in field ecology – Iowa State University (Teaching Assistant, developed laboratory component of class)

2004 Fish 424: Fish diseases – University of Idaho (Teaching Assistant)

Peer reviewed articles ([†]graduate student, [††]undergraduate student, [†††]postdoc)

Aldridge, C.A., D.M. Norris, M.E. Colvin, L.E. Miranda, G. Coppola, H. Hatcher. *Accepted.* Structural Persistence of Brush Piles within a Southeastern Flood Control Reservoir. Submitted to the Journal of Fish and Wildlife Management.

Braaten, P.J., D.B. Fuller, T.M. Haddix, J.R. Hunziker, M.E. Colvin, L.M. Holmquist, R.H. Wilson. *Accepted.* Catch rates for sturgeon and sicklefin chubs in the upper Missouri River 2004-2016, and Correlations with Biotic and Abiotic Variables. Journal of Fish and Wildlife Management.

Coppola, G., L.E. Miranda, M.E. Colvin, H. Hatcher, and M.A. Lashley. 2021. Selection of habitat enhancing plants depends on predator-prey interactions. Journal of Fish and Wildlife Management.

Shirley, C.A., M.E. Colvin, and P.J. Allen. 2021. Evaluation of methods for cryopreservation of black-stripe Black Crappie (*Pomoxis nigromaculatus*) sperm and subsequent use in egg fertilization. Journal of the World Aquaculture Society. http://dx.doi.org/10.1111/jwas.12763.

Schumann[†††], D.A., M.E. Colvin, Campbell, R.[††], M.D. Wagner, and D. Schwartz. 2021. Suitability of passive integrated transponder (PIT) tags and enhanced madtom traps to monitor a cryptic species (*Noturus munitus*). Endangered species research. Endangered Species Research 44, 1-10. https://doi.org/10.3354/esr01086.

Aldridge, C.A.[†], L.E. Miranda, and M.E. Colvin. 2021. Themes of Contemporary Inland Fisheries Goals. Fisheries. https://doi.org/10.1002/fsh.10507.

Richardson, B.M.[†], M.J. Griffin, M.E. Colvin, T.E. Greenway, C. Ware, C.C. Mischke, T.S. Byars, D.J. Wise, and M.L. Lawrence. 2020. Using quantitative Polymerase Chain Reaction (qPCR) and occupancy models to estimate atypical *Aeromonas hydrophila* (aAh) prevalence in catfish. Aquaculture. 530: 735687. https://doi.org/10.1016/j.aquaculture.2020.735687.

Norris, D.M.[†], H.R. Hatcher[†], M.E. Colvin, G. Coppola[†], M.A. Lashley, and L.E. Miranda. 2020. Assessing establishment and growth of agricultural plantings on reservoir mudflats. North American Journal of Fisheries Management. 40: 394-405. https://doi.org/10.1002/nafm.10419

Kroboth, P., D. Hann, M.E. Colvin, P. Hartfield, and H. Schramm. 2020. Pallid sturgeon *Scaphirhynchus albus* seasonal habitat selection in a large river free-flowing river, the lower Mississippi River. Journal of Applied Ichthyology. 36: 131-141. https://doi.org/10.1111/jai.14000.

Schumann, D.A.[†††], M.E. Colvin, L.E. Miranda, and D.T. Jones-Farrand. 2020. Occurrence and co-occurrence patterns of gar in river-floodplain habitats: leveraging species interactions to benefit distributional models. North American Journal of Fisheries Management. 40: 622-637. https://doi.org/10.1002/nafm.10402.

Jargowsky, M., P.T. Cooper, M.J. Ajemian, M.E. Colvin, and J.M. Drymon. 2019. Discerning the dietary habits of the smooth butterfly ray *Gymnura lessae* using two distinct methods, otolith identification and metagenetics. Journal of Fish Biology. 96 (2), 434-443. https://doi.org/10.1111/jfb.14221.

Coppola, G.[†], H. Hatcher[†], S. Miranda, M.E. Colvin, and M.A. Lashley. 2019. Submergence responses of cool-season annual plants and potential for fish habitat. North American Journal of Fisheries Management. 39: 1269-1276. https://doi.org/10.1002/nafm.10359.

Kramer, N., Q.E. Phelps, C.L. Pierce, and M.E. Colvin. 2019. A Food Web Modelling Assessment of Asian Carp Impacts in the Middle and Upper Mississippi River. Food Webs. 21: e00120. https://doi.org/10.1016/j.fooweb.2019.e00120.

Shaw, S.B., J.O. Beslity, and M.E. Colvin. 2019. Working Toward a More Holistic Set of Hydrologic Principles to Teach Non-Hydrologists: Five Simple Concepts Within Catchment Hydrology. Hydrological Processes. 33: 2258-2262.

Ivey, M.R., M.E. Colvin, B.K. Strickland, and M.A. Lashley. 2019. The effects of vertebrate biological invasions on species-area relationships are not scale-dependent. Ecology andEvolution. 9: 7761-7767.

Hatcher[†], H.R., L.E. Miranda, M.E. Colvin, G. Coppola[†], and M.A. Lashley. 2019. Fish assemblages in reservoir mudflats with low structural complexity. Hydrobiologia. 841: 163-175

Guy, E.L., C.C. Mischke, M.E. Colvin, and P.J. Allen. 2019. Zooplankton selectivity and commercial feed consumption of Black Buffalo *Ictiobus niger.* North American Journal of Aquaculture. 81: 215-221.

Katzenmeyer, E., M.E. Colvin, T.W. Stewart, C.L. Pierce, and S. Grummer. 2019. Fish growth changes over time in a Midwestern USA lake. Transactions of the American Fisheries Society. 148: 493-506.

Gallardo, J.C., F.J. Vilella, and M.E. Colvin. 2019. A periodic population matrix model of the Caribbean Red-tailed Hawk *Buteo jamaicensis jamaicensis* in eastern Puerto Rico. Ibis. 161: 459-466. https://doi.org/10.1111/ibi.12703

Colvin, M.E., J.T. Peterson, C. Sharpe, M.L. Kent. and C.B. Schreck. 2018. Identifying optimal

hauling densities for adult Chinook Salmon trap and haul operations. River Research and Applications. 34: 1158-1167.

Miranda, L.E., L. Bull, M.E. Colvin, W.D. Hubbard, and L.L. Pugh. 2018. Segmentation of Mississippi Lakes. Lake and Reservoir Management. 34: 376-391

Gilliland†, C.R., M.E. Colvin, S.A. Rush, and S. Reagan. 2018. American alligators are predators of Paddlefish: An undocumented predator-prey linkage affecting Paddlefish population dynamics. Foodwebs. 16: 1-4.

Keretz, K.R., C.P. Dinken, P.J. Allen, M.E. Colvin, and H.L. Schramm Jr. 2018. The effect of water temperature, angling time, and dissolved oxygen on the survival of angled and tournament-handled Largemouth Bass. North American Journal of Fisheries Management. 38: 606-622.

Mangipane, L.A., J.L. Belant, D.J.R. Lafferty, D.D. Gustine, T.L. Hiller, M.E. Colvin, B.A. Mangipane, and G.V. Hilderbrand. 2018. Dietary plasticity in a nutrient-rich system does not influence brown bear body condition or denning. Polar Biology. 41: 763-772.

Mangipane, L.A., J.L. Belant, T.L. Hiller, M.E. Colvin, D.D. Gustine, B.A. Mangipane, and G.V. Hilderbrand. 2017. Influences of landscape heterogeneity on home-range sizes of brown bears in a salmon subsidized system. Mammalian Biology. 88: 1-7.

Miranda, L.E., and M.E. Colvin. 2017. Sampling for age and growth estimation. Chapter 5 in Age and Growth of Fishes. Quist, M.C., and D. Isserman editors. American Fisheries Society. Bethesda, MD.

Miranda, L.E., M.E. Colvin, A.C. Shamaskin, L.A. Bull, T. Holman, and R. Jones. 2017. Length-limits fail to restructure a Largemouth Bass population: A 27-year case history. North American Journal of Fisheries Management. 37: 624-632.

DeWeber, J.T., J.T. Peterson, C.S. Sharpe, M.L. Kent, M.E. Colvin, and C.B. Schreck. 2017. Prespawn mortality in outplanted Chinook Salmon is highly variable and associated with outplant date. North American Journal of Fisheries Management. 1: 162-175.

Colvin, M.E. and J.T. Peterson. 2017. Preparing future fisheries professionals to make good decisions. Fisheries 41(8): 473-474.

Neely, B.C., J.D. Koch, and M.E. Colvin. 2016. Utility of reservoir characteristics on collection of representative and precise fish samples: implications for determining minimum sampling effort. North American Journal of Fisheries Management. 36: 285-293.

Howell, P.J., M.E. Colvin, P.M. Sankovich, D.V. Buchanan, and A.R. Hemmingsen. 2016. Life Histories, Demography, and Distribution of Bull Trout from Mill Creek, a Tributary of the Walla Walla River. Transactions of the American Fisheries Society. 145: 173-194.

Dolan, B.P., K.M. Fisher, M.E. Colvin, S.E. Benda, J.T. Peterson, M.L. Kent, and C.B. Schreck. 2016. Innate and adaptive immune responses in migrating spring-run adult chinook salmon, *Oncorhynchus tshawytscha*. Fish & Shellfish Immunology 48:136-144.

Dolan, B., K. Fisher, M.E. Colvin, S. Benda, C. Danley, J.T. Peterson, M. Kent, P. Zwollo, and C.B. Schreck. 2015. Diminished innate, but not adaptive, immune responses in migrating adult Chinook salmon, *Oncorhynchus tshawytscha*. The Journal of Immunology 194 (1 Supplement): 146.15-146.15.

Colvin, M.E., T.W. Stewart, and C.L. Pierce. 2015. A food web modelling analysis of a Midwestern, USA eutrophic lake dominated by non-native Common Carp and Zebra Mussels. Ecological Modelling. 32: 26-40.

Colvin, M.E., J.T. Peterson, M. Kent, C.S. Sharpe, and C.B. Schreck. 2015. Using occupancy modeling to estimate detection probabilities and prevalence from hierarchically structured pathogen detection data. PLOS ONE. 10: e0116605.

Carlson, A.K., J.R. Fischer, D.J. Dembkowski, L.L. Pierce, M.E. Colvin, J.A. Kerns. 2015.

Purpose, History, and Importance of the "Student Angle". Fisheries. 40: 81-83.

Collymore, C., V. Watral, J.R. White, M.E. Colvin, S. Rasmussen, R.J. Tolwani, M.L. Kent. 2014. Tolerance and Efficacy of Emamectin Benzoate and Ivermectin for the Treatment of *Pseudocapillaria tomentosa* in laboratory Zebrafish (*Danio rerio*). Zebrafish. 11: 490-497.

Koch, J.D., B.C. Neely, and M.E. Colvin. 2014. Evaluation of precision and sample sizes using standardized sampling in Kansas Reservoirs. North American Journal of Fisheries Management. 34: 1211-1220.

Mayfield, M.P., L.D. Schultz, L.A. Wyss, M.E. Colvin, and C.B. Schreck. 2014. Using spatial resampling to assess survey length requirements to detect and estimate spawner abundance from redd counts: an example using Pacific lamprey. North American Journal of Fisheries Management. 34: 923-931.

Colvin, M.E. G.D. Scholten, and P.W. Bettoli. 2013. Predicting paddlefish roe yields using an extension of the Beverton-Holt equilibrium yield model. North American Journal of Fisheries Management. 33: 940-949.

Colvin, M.E., Pierce, C.L., T.W. Stewart, and S.E. Grummer. 2012. Strategies to control a common carp population by pulsed commercial harvest. North American Journal of Fisheries Management. 32: 1251-1264.

Colvin, M.E., C.L. Pierce, and T.W. Stewart. 2012. Semi-discrete biomass dynamic modeling: an improved approach for assessing fish stock responses to pulsed harvest events. Canadian Journal of Fisheries and Aquatic Sciences. 69: 1710-1721.

Ebersole, J.L., M.E. Colvin, P.J. Wigington, S.G. Leibowitz, J.P. Baker, M.R. Church, J.E. Compton, and M.A. Cairns. 2009. Hierarchical modeling of late-summer weight and summer abundance of juvenile coho salmon across a stream network. Transactions of theAmerican Fisheries Society. 138: 1138-1156.

Colvin, M.E. and J. Kopaska. 2009. The role of the student member in the American Fisheries Society Fisheries Information and Technology Section. Fisheries. 34(6): 305-306.

Ebersole, J.L., M.E. Colvin, P.J. Wigington, S.G. Leibowitz, J.P. Baker, M.R. Church, J.E. Compton, B.A., Miller, M.A. Cairns, B.P. Hansen, and H.R. Lavigne. 2009. Modeling stream network-scale variation in coho salmon overwinter survival and smolt size. Transactions of the American Fisheries Society. 138: 564-580.

Colvin, M.E., and C.M. Moffitt. 2009. Evaluation of irrigation canal networks to assess stream connectivity in a watershed. River Research and Applications. 25: 486-496.

Wigington, P.J., J.E. Ebersole, M.E. Colvin, S.G. Leibowitz, B. Miller, B. Hansen, H.R. Lavigne, D. White, J.P. Baker, M.R. Church, J.R. Brooks, M.A. Cairns, and J.E. Compton. 2006. Salmon dependent on intermittent streams. Frontiers in Ecology and the Environment. 4: 513-518.

Technical reports († denotes graduate student, ††denotes undergraduate student)

Peer-reviewed

Bonneau, J., M.E. Colvin, T. Gemeinhardt, N. Gosch, S. Reynolds†††, and T. Welker. 2020. Appendix D. Monitoring Plan for the Pallid Sturgeon to the Missouri River Strategic and Adaptive Management Plan (SAMP). 167 pg.

Reynolds, S. ††† and M.E. Colvin. 2020. Modeling Long-Term Population Growth Rate of Pallid Sturgeon in the Upper Missouri River Below Fort Peck Dam. DRAFT Report to the US Army Corps of Engineers. 55 pages.

Reynolds, S.††† and M.E. Colvin. 2019. Modeling Long-Term Population Growth Rate of Pallid

Sturgeon in the Upper Missouri River Below Fort Peck Dam. Report to the U.S. Army Corps of Engineers for model certification. 38 p.

Colvin, M.E., S. Reynolds[†††], R.B. Jacobson, LL. Pierce, K.D. Steffensen, and T.L. Welker. 2018. PSPAP v.2.0 redesign process: Overview of Pallid Sturgeon Assessment Framework Redesign Process. Open-file Report 2018-1166. 87 p., https://doi.org/10.3133/ofr20181166

Jacobson, R.B., Colvin, M., Bulliner, E.A., Pickard, D., and Elliott, C.M., 2018, Bend-scale geomorphic classification and assessment of the Lower Missouri River from Sioux City, Iowa, to the Mississippi River for application to pallid sturgeon management: U.S. Geological Survey Scientific Investigations Report 2018–5069, 35 p., https://doi.org/10.3133/sir20185069.

Randall, M., M.E. Colvin, K. Steffensen, T. Welker, L. Pierce, and R. Jacobson. 2017. Assessment of Adult Pallid Sturgeon Fish Condition, Lower Missouri River: Application of New Information to the Missouri River Recovery Program. U.S. Geological Survey Open-file Report 2017- 1121.

Jacobson, R. B., M.L. Annis, M.E. Colvin, D.A. James, T.L. Welker, and M.J. Parsley. 2016. Missouri River *Scaphirhynchus albus* (pallid sturgeon) effects analysis—Integrative report 2016. Report 2016-5064, Reston, VA.

Jacobson, R.B., M.J. Parsley, M.L. Annis, M.E. Colvin, T.L. Welker, and D.A. James. 2016. Development of working hypotheses linking management of the Missouri River to population dynamics of *Scaphirhynchus albus* (pallid sturgeon): U.S. Geological Survey,Open-file Report 2015-1236, 36 p. 10.3133/ofr20151236.

Jacobson, R.B., M.J. Parsley, M.A. Annis, M.E. Colvin, T.L. Welker, and D.A. James, D. 2015. Development of conceptual ecological models linking management of the Missouri River to pallid sturgeon population dynamics: U.S. Geological Survey, Open-File Report 2015-1038, 47 p. 10.3133/ofr20151038.

Jacobson, R.B., M.L. Annis, M.J. Parsley, D.A. James, M.E. Colvin, and T.L. Welker. 2015. Scientific information to support the Missouri River pallid sturgeon effects analysis: U.S. Geological Survey, Open-file Report 2015-1226, 78 p. 10.3133/ofr20151226.

Non-peer reviewed

Dunn, C.D. [†††], M.E. Colvin, D.A. Schumann, and K. Evans, 2020. Integrating conservation planning tools to develop a transparent conservation blueprint for southeastern aquatic species. Interim annual report to the USFWS. 15 pages.

Starnes, V.[†] and M.E. Colvin. 2020. A structured approach to water level management for a multiuse reservoir at Sam D. Hamilton Noxubee National Wildlife Refuge. Interim report to the US Fish and Wildlife Service. 63 pages.

Colvin, M.E. 2020. Pallid sturgeon Population Assessment Program Progress Report. Report to the USACE. 115 pages.

Colvin, M.E., and S. Reynolds[†††]. 2020. High-level planning process related to recovery of the endangered Pallid Sturgeon as part of the Missouri River Recovery Program. Final completion report to the USGS. 173 pages.

Aldridge, C.A. [†], M.E. Colvin, and L.E. Miranda. 2020. FRASps: a planning support tool for inland fisheries management. Annual report to Mississippi Department of Wildlife Fisheries and Parks. 37 pages.

Colvin, M.E. 2020. Estimating adult and subadult pallid sturgeon and shovelnose sturgeon in the Yellowstone River. Report to Montana Fish Wildlife and Parks. 44 pages.

Miranda, L.E., M.E. Colvin, G. Coppola[†], H. Hatcher[†], M. Lashley, D. Norris[†]. 2020.

Establishing Ground Cover in Reservoir Mudflats to Foster Fish Assemblages. Final report to Mississippi Department of Wildlife Fisheries and Parks. 133 pages.

Starnes, V.[†], and M.E. Colvin. A structured approach to water level management for a multiple use shallow eutrophic reservoir at Sam D. Hamilton Noxubee National Wildlife Refuge. Interim report to the U.S. Fish and Wildlife Service. 27 pages.

Schumann, D.A.[†††] and M.E. Colvin. 2019. Multi-objective conservation planning: prototyping a strategic decision framework for aquatic species conservation (phase 1). Completion Report to the U.S. Fish and Wildlife Service. 150 pages.

Miranda, L.E., M.E. Colvin, A. Shamaskin[†], and C. Aldridge[†]. 2019. Review, revision and development of new monitoring protocols to facilitate the meeting of goals and objectives of freshwater fisheries management in Mississippi. Final report to Mississippi Department of Wildlife Fisheries and Parks. 88 pages.

Colvin, M.E., and S. Reynolds[†††]. 2019. High-level planning process related to recovery of the endangered Pallid Sturgeon as part of the Missouri River Recovery Program. Completion Report to the U.S. Geological Survey. 22 pages.

Schumann, D.A.[†††], and M.E. Colvin. 2018. Multi-objective conservation planning: prototyping a strategic decision framework for aquatic species conservation (Phase 1). Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative, Annual Report, Columbia, Missouri.

Gilliland, C.R.[†], M.E. Colvin, P.J. Allen, and J.W. Neal. 2017. Paddlefish *Polyodon spathula* spawning and migratory habitat use in the Noxubee River System with focus on the Noxubee National Wildlife Refuge Management. Interim report to the U.S. Fish and Wildlife Service. 47 pages.

Gilliland, C.R.[†], M.E. Colvin, P.J. Allen, and J.W. Neal. 2016. Paddlefish *Polyodon spathula* spawning and migratory habitat use in the Noxubee River System with focus on the Noxubee National Wildlife Refuge Management. Interim report to the U.S. Fish and Wildlife Service. 27 pages.

Miranda, L.E., M.E. Colvin, and A.C. Shamaskin[†]. 2016. Review, revision and development of new monitoring protocols to facilitate the meeting of goals and objectives of freshwater fisheries management in Mississippi. Progress report to Mississippi Department of Wildlife, Fisheries, and Parks. 9 pages.

Peterson, J.T., K. McDonnell, and M.E. Colvin. 2014. Coarse Resolution Planning Tools for Prioritizing Central Valley Project Improvement Act Fisheries Activities. Final Report to Central Valley Project Improvement Act Fisheries Program, Sacramento, CA.

Colvin, M.E. 2013. Mill Creek Bull Trout Survival Analysis. Completion report to the U.S. Forest Service.

Schreck, C.B., M.L. Kent, M.E. Colvin, S. Benda, C. Sharpe, J.T. Peterson, and B. Dolan. 2013. Potential causes and management of prespawn mortality in adult upper Willamette River spring Chinook salmon. Annual report to the U.S. Army Corps of Engineers.

Colvin, M.E. 2012. Impacts of nuisance species in a shallow lake: A systems modeling approach for evaluating restoration and management policies. Final Report to the Iowa Department of Natural Resources.

Colvin, M.E., C.L. Pierce, and L. Beck. 2012. Age structure and growth of invasive common carp populations in the Malheur National Wildlife Refuge. Final Report to the U.S. Fish and Wildlife Service Malheur National Wildlife Refuge.

Colvin, M.E., E.D. Katzenmeyer, T.W. Stewart, and C.L. Pierce. 2010. The Clear Lake ecosystem simulation model (CLESM) project. Annual Progress Report to the Iowa

Department of Natural Resources.

Colvin, M.E., E.D. Katzenmeyer, T.W. Stewart, and C.L. Pierce. 2009. The Clear Lake ecosystem simulation model (CLESM) project. Annual Progress Report to the Iowa Department of Natural Resources.

Colvin, M.E., E.D. Katzenmeyer, T.W. Stewart, and C.L. Pierce. 2008. The Clear Lake ecosystem simulation model (CLESM) Project. Annual Progress Report to the Iowa Department of Natural Resources.

Munson, A.D., M.E. Colvin, and K.A. Johnson. 2005. *Ceratomyxa shasta* exposure trials at Oxbow fish hatchery. Idaho Department of Fish and Game Fishery Research Report 04-48. Boise, ID.

Grants and contracts received

Dunn, C.G., and M.E. Colvin. 2021. Using conservation genomics, morphometrics, and occupancy modeling to support Species Status Assessments of rivulet crayfishes (*Hobbseus* spp.). U.S. Fish and Wildlife Service. ($230,240)

Dunn, C.G., L.E. Miranda, and M.E. Colvin. 2021. TNCR data management application. U.S. Fish and Wildlife Service. ($148,112)

Dunn, C.G., and M.E. Colvin. 2021. Using a Bayesian belief network to structure Species Status Assessments of data-deficient species: a case study with Piebald Madtom (*Noturus gladiator*). U.S. Fish and Wildlife Service. ($69,034)

Colvin, M.E., and C.G. Dunn. 2021 Developing a cooperative post stocking conservation framework to evaluate stocking effectiveness and inform restoration efforts. U.S. Fish and Wildlife Service. ($26,194)

Dunn, C.G., and M.E. Colvin. 2021. Development of quantitative tools to support Species Status Assessments of freshwater mussels. U.S. Fish and Wildlife Service. ($234,912)

Dunn, C.G., L.E. Miranda, and M.E. Colvin. 2021. Developing an adaptive framework based on connectivity for evaluating management actions that limit bigheaded carps access to floodplain lakes. U.S. Fish and Wildlife Service. ($263,547)

Colvin, M.E. and C.G. Dunn. 2021. Use of machine learning to quantify habitat for the Oktibbeha Rivulet Crayfish. College of Forest Resources Undergraduate Research Scholars Program. ($3,000)

Colvin, M.E. and C.G. Dunn. 2020. Evaluating occurrence of migratory riverine fish species. College of Forest Resources Undergraduate Research Scholars Program. ($3,000)

Colvin, M.E. 2020. Application of quantitative methods supporting Pallid Sturgeon Adaptive Management Project. U.S. Army Corps of Engineers. ($174,584)

Miranda, L.E. and M.E. Colvin. 2020. Intrusion of bigheaded carps into major oxbow lakes. U.S. Fish and Wildlife Service. ($100,000)

Allen, P.J., M.E. Colvin, and B. Pracheil. 2020. River origins of juvenile Gulf Sturgeon: investigating the Pearl/Bogue Chitto Rivers and the Pascagoula River. U.S. Fish and Wildlife Service. ($250,000)

Colvin, M.E. and D.A. Schumann. 2019. Using boat mounted RFID readers to monitor the effectiveness of conservation stocking efforts of aquatic species. College of Forest Resources Undergraduate Research Scholars Program. ($3,000)

Strickland, B.K., G.M. Street, and M.E. Colvin. 2019. Maximizing the effectiveness of feral swine removal programs to mitigate agricultural damages and recover native species richness. USDA-APHIS. ($80,000)

Colvin, M.E., D.A. Schumann, and K. Evans 2019. Integrating conservation planning tools to

develop a transparent conservation blueprint for southeastern aquatic species. U.S. Fish and Wildlife Service. ($181,878)

Miranda, L.E. and M.E. Colvin. 2019. FRASps: a planning support tool for inland fisheries management. Mississippi Department of Wildlife Fisheries and Parks. ($109,526)

Colvin, M.E. 2019. High-level planning process related to recovery of the endangered Pallid Sturgeon as part of the Missouri River Recovery Program. U.S. Geological Survey. ($137,589)

Lashley, M.A., G. Street, B. Strickland and M.E. Colvin. 2018. Continuation of using island biogeography to decrease agricultural damage and systematically eradicate feral swine from agricultural landscapes. USDA-APHIS. ($136,000)

Colvin, M.E., D. Schumann, J.B. Davis, and L.E. Miranda. 2018. Evaluating the fish assemblage and fishery of Bluff Lake and integrating fishery objectives with Paddlefish and bird management objectives to evaluate water level management decisions. US Fish and Wildlife Service. ($117,346)

Schumann, D. and M.E. Colvin. 2018. Evaluating Southern Brook Lamprey Movement and Biology. College of Forest Resources Undergraduate Research Scholars Program. ($3,000)

Colvin, M.E. 2018. High-level planning process related to recovery of the endangered Pallid Sturgeon as part of the Missouri River Recovery Program. U.S. Geological Survey. ($128,279)

Colvin, M.E. and K. Evans (2018). Multi-objective Conservation Planning: Prototyping a strategic decision framework for aquatic species conservation. U.S. Fish and Wildlife Service. ($85,159)

Colvin, M.E. 2017. Evaluating Fishing Forecasts with Real Data. College of Forest Resources Undergraduate Research Scholars Program. ($3,000)

Lawrence, M.L., M. Griffin, D. Wise, A. Karsi, T. Greenway, M. Colvin, and C. Mischke. 2017. Control strategies for virulent *Aeromonas hydrophila* in catfish aquaculture by vaccination and informing pond management. USDA-National Institute of Food and Agriculture. ($500,000)

Colvin, M.E. 2017. High-level planning process related to recovery of the endangered Pallid Sturgeon as part of the Missouri River Recovery Program. U.S. Geological Survey. ($123,731)

Colvin, M.E. and K. Evans. 2017. Multi-objective Conservation Planning: Prototyping a strategic decision framework for aquatic species conservation. U.S. Fish and Wildlife Service. ($75,281)

Miranda, L.E., M.E. Colvin, and M.A. Lashley. 2016. Establishing ground cover in reservoir mudflats to foster fish assemblages, Mississippi Wildlife, Fisheries, and Parks. ($194,911)

Miranda, L.E., M.E. Colvin, and M.A. Lashley. 2016. Establishing ground cover in reservoir mudflats to foster fish assemblages, Reservoir Fisheries Habitat Partnership. ($27,570)

Rush, S., M.E. Colvin, and C. Ayers. 2016. Investigation of bat roost characteristics, senescence and use on Sam D. Hamilton Noxubee National Wildlife Refuge. College of Forest Resources Undergraduate Research Scholars Program. ($5,000)

Colvin, M.E. 2016. Development of Structured Decision Framework, Missouri River Pallid Sturgeon Effects Analysis. U.S. Geological Survey. ($77,281)

Colvin, M.E., P.J. Allen, J.W. Neal, and F. Vilella. 2015. Paddlefish *Polyodon spathula* spawning and migratory habitat use in the Noxubee River System. US Geological

Survey Quick Response Program. ($8,000)

Colvin, M.E., P.J. Allen, and J.W. Neal. 2015. Paddlefish *Polyodon spathula* spawning and migratory habitat use in the Noxubee River System. US Fish and Wildlife Service Inventory and Monitoring. ($60,000)

Colvin, M.E. 2015. Adaptive fishery management of Black Crappie fisheries. College of Forest Resources Undergraduate Research Scholars Program. ($5,000)

Colvin, M.E. 2015. Development of Structured Decision Framework, Missouri River Pallid Sturgeon Effects Analysis. U.S. Geological Survey. ($52,274)

Miranda, L.E. and M.E. Colvin. 2014. Review, revision and development of new monitoring protocols to facilitate the meeting of goals and objectives of freshwater fisheries. Mississippi Department of Wildlife Fisheries and Parks. ($110,867)

Colvin, M.E. and J.T. Peterson. 2013. Development of Structured Decision Framework, Missouri River Pallid Sturgeon Effects Analysis. U.S. Geological Survey. ($37,193)

Colvin, M.E. and J.T. Peterson. 2012. Mill Creek Bull Trout Survival Analysis. U.S. Forest Service. ($5,743)

Schreck, C.B. M. Kent, J. Peterson, B. Dolan, C. Sharpe, and M.E. Colvin. 2012. Potential causes of prespawn mortality in adult UWR Chinook, Middle Fork Basin of the Willamette River. U.S. Army Corps of Engineers. ($361,000)

Colvin, M.E. 2005-2007. Student Contractor. U.S. Environmental Protection Agency. ($86,120)

Invited presentations († denotes graduate student, †† denotes undergraduate student)

Colvin, M.E., and D. Schumann. 2018. Decision making process and tools for aquatic systems. Management Action Team Meeting. Weeks Bay Reserve Tonsmeire Resource Center, Fairhope, AL.

Gilliland, C.R. †, M.E. Colvin, J.W. Neal, and P.J. Allen. 2017. Residents, Migrants, or Both? Evaluating Movement of Paddlefish *Polyodon spathula* in a Regulated System. Presentation to the Friends of the Noxubee National Wildlife Refuge. Oktoc Community Center, September 8th.

Colvin, M.E., R. Jacobson, D. James, L. Pierce, M. Randall, and T. Welker. 2017. Missouri River Pallid Sturgeon Effects Analysis. Lower Basin Pallid Sturgeon Workgroup Meeting. January 10th.

Gilliland, C.R. † and M.E. Colvin. 2016. Paddlefish *Polyodon spathula* spawning and migratory habitat use in the Noxubee River System with focus on the Noxubee National Wildlife Refuge. Presentation to the Audubon Society. Mississippi State, September 8th.

M.E. Colvin. 2016. Challenges and potential solutions to integrating fisheries research, management, and monitoring—emerging patterns from a national perspective. 42nd annual meeting of the Mississippi Chapter of the American Fisheries Society, Tara Lodge, MS. March 9-11th.

Colvin, M.E., R. Jacobson, D. James, L. Pierce, M. Randall, and T. Welker. 2016. Pallid Sturgeon population modeling update. Middle Basin Pallid Sturgeon Recovery Meeting. Kansas City. February 18th -19th.

Jacobson, R., M.E. Colvin, M. Randall, D. James, and T. Welker. 2016. Effects Analysis. Lower Basin Pallid Sturgeon Recovery Meeting. Middle Basin Pallid Sturgeon Recovery Meeting. Kansas City. February 18th -19th.

Colvin, M.E., R. Jacobson, D. James, L. Pierce, M. Randall, and T. Welker. 2016. Pallid Sturgeon population modeling update. Lower Basin Pallid Sturgeon Recovery Meeting.

Cape Girardeau. January 11th-13th.

Jacobson, R., M.E. Colvin, M. Randall, D. James, and T. Welker. 2016. Effects Analysis. Lower Basin Pallid Sturgeon Recovery Meeting. Cape Girardeau. January 11th-13th.

Colvin, M.E. 2015. Integrating management, monitoring and research in aquatic systems. University of Southern Mississippi Gulf Coast Research Laboratory. April 9th.

Colvin, M.E. 2015. Integrating management, monitoring and research with structured decision making and adaptive management. Mississippi Research Summit. February 5th.

Colvin, M.E., J.T. Peterson, M. Kent, and C.B. Schreck. 2014. Estimating sensitivity and prevalence from hierarchically structured pathogen sampling data using occupancy modeling. Oregon State University Microbiology Department Colloquium.

Colvin, M.E., P.W. Bettoli, G.D. Scholten, C.L. Pierce, and T.W. Stewart. 2012. Caviar and carp: increasing fisheries model realism and management applications. University of Idaho 501 Seminar Series.

Colvin, M.E., C.L. Pierce, and T.W. Stewart. 2012. Minimizing impacts of carp in a shallow lake: A simulation modeling approach for restoration and management. 142nd Annual Meeting American Fisheries Society, St. Paul, Minnesota.

Colvin, M.E. 2011. Clear Lake Ecosystem simulation model overview and managing populations experiencing pulsed harvest. Iowa Department of Natural Resources Wildlife Bureau Meeting. Ames, IA.

Colvin, M.E., T. Stewart, and C. Pierce. 2011. Monitoring and modeling the Clear Lake ecosystem: Native and invasive species in the context of lake restoration. Iowa Water Center Conference. Ames, IA.

Colvin, M.E. 2010. Application of carp control strategies into a model for Malheur NWR. Malheur National Wildlife Refuge Invasive Carp Control Workshop. Burns, OR.

Colvin, M.E., S. Grummer, J. Wahl, T.W. Stewart, and C.L. Pierce. 2010. Carp and water quality research, a Midwest case study. Malheur National Wildlife Refuge Invasive Carp Control Workshop. Burns, OR.

Colvin, M.E., S. Grummer, J. Wahl, T. Stewart, and C. Pierce. 2010. Real and potential impacts of common carp and zebra mussel impacts on water quality in the context of ongoing shallow lake restoration. 71st Midwest Fish and Wildlife Conference. Minneapolis, MN.

Colvin, M.E., T. Stewart and C. Pierce. 2009. Towards ecosystem management of an inland freshwater fishery in the context of invasive species. Iowa State University Student Subunit of the American Fisheries Society, Ames, IA.

Ebersole, J.L., M.E. Colvin, P.J. Wigington, Jr., and S.G. Leibowitz. 2009. Patterns of coho salmon size and survival within a stream network. International Environmetrics Society, Corvallis, OR.

Colvin, M.E., J.L. Ebersole and P.J. Wigington. 2007. A life-history based strategy for restoring juvenile salmon habitat across a stream network. Iowa State University Departmental Seminar Series, Ames, IA.

Technical presentations († denotes graduate student, †† denotes undergraduate student)

Blische, H., M.E. Colvin, and C.G. Dunn. 2021Distribution and detection of American eels *Anguilla rostrata* in Mississippi. Annual meeting of the Southern Division of the American Fisheries Society. (Virtual Presentation)

Besson, J., M.E. Colvin, L.E. Miranda, and C.G. Dunn. 2021. A framework for evaluating Silver

Carp movement in a floodplain system Annual meeting of the Southern Division of the American Fisheries Society. (Virtual Poster)

Aldridge, C.A., L.E. Miranda, and M.E. Colvin. 2021. Towards standardized fisheries management plans. Annual meeting of the Southern Division of the American Fisheries Society. (Virtual Presentation)

Blische, H., M.E. Colvin, and C.G. Dunn. 2021. Distribution and detection of American eels *Anguilla rostrata* in Mississippi. Annual meeting of the Mississippi Chapter of the American Fisheries Society. (Virtual Presentation)

Besson, J., M.E. Colvin, L.E. Miranda, and C.G. Dunn. 2021. A framework for evaluating Silver Carp movement in a floodplain system Annual meeting of the Mississippi Chapter of the American Fisheries Society. (Virtual Poster)

Aldridge, C.A., L.E. Miranda, and M.E. Colvin. 2021. Towards standardized fisheries management plans. Annual meeting of the Mississippi Chapter of the American Fisheries Society. (Virtual Presentation)

Reynolds, S.A.[†††], M.E. Colvin, C.R. Fischenich, G. Long, and D. Marmorek. 2020. Examining Long-Term Pallid Sturgeon, *Scaphirhynchus albus*, Population Growth with Respect to Alternative Management Operations Under Environmental Stochasticity. Annual Meeting of the North American Surgeon and Paddlefish Society. Virtual.

Reynolds, S.A.[†††], M.E. Colvin, C.R. Fischenich, G. Long, and D. Marmorek. 2020. Examining Long-Term Pallid Sturgeon, *Scaphirhynchus albus*, Population Growth with Respect to Alternative Management Operations Under Environmental Stochasticity. 150th Annual Meeting of the American Fisheries Society. Virtual.

Aldridge, C.A.[†], L.E. Miranda, and M.E. Colvin. 2020. Standardized Management Plans: A Glance into the Future. 150th Annual Meeting of the American Fisheries Society. Virtual.

Starnes, V.R.[†], M.E. Colvin, J.B. Davis, and L.E. Miranda. 2020. A Decision Support Tool for Evaluating Water Level Management in a Multiple Use Reservoir. 150th Annual Meeting of the American Fisheries Society. Virtual.

Starnes, V.R.[†], M.E. Colvin, J.B. Davis, and L.E. Miranda. 2020. A prototype decision support tool for evaluating water level management to achieve competing objectives in a multiple use reservoir. Annual Meeting of the Southern Division of the American Fisheries Society. Little Rock, AR.

Richardson, B.M.[†], Colvin, M.E., Griffin, M.J., Mischke, C.C., Greenway, T.E. and D.J. Wise. 2020. Leaving Nothing on the Table: Using structured decision-making to evaluate management decisions in catfish aquaculture. Annual Meeting of the Southern Division of the American Fisheries Society. Little Rock, AR.

VanderBloemen, S, L.E. Miranda, M.E. Colvin and G. Sass. 2020. Asian Carp Population Dynamics and Movement Ecology within the Tennessee-Tombigbee Waterway. Annual Meeting of the Southern Division of the American Fisheries Society. Little Rock, AR.

Richardson, B.M.[†], Griffin, M.J., Mischke, C.C., Greenway, T.E., Wise, D.J., Colvin, M.E., Lawrence, M.L., and Liles, M. 2020. They are the same but different: Comparative genomics of two atypical *Aeromonas hydrophila* pathotypes found in catfish aquaculture of the southeast. Annual Meeting of the Southern Division of the American Fisheries Society. Little Rock, AR.

Starnes, V.R.[†], M.E. Colvin, B.A. Jones, W.R. Whittington, B.A. Clarke, J.E. Coleman, J.T. Gandy, W.P. Johnson, W.R. Horne, R.J. Hurt, R. W. King, R. M. Savoie, B.C. Wilkinson. 2020. Development of an affordable autonomous four-dimensional water quality monitoring network. Annual Meeting of the Southern Division of the American

Fisheries Society. Little Rock, AR.

Wilmoth, B.M.[††], M.E. Colvin, and C. Dunn[†††]. 2020. Using boat-mounted Radio Frequency Identification to estimate stocking exploitation and estimate efficiency of Passive Integrated Transponders. Annual Meeting of the Southern Division of the American Fisheries Society. Little Rock, AR.

Wilmoth, B.M.[††], M.E. Colvin, N. Temple, and E. Sparks. 2020. Evaluating Accuracy of Inexpensive Acoustic Water Level Sensors. Annual Meeting of the Southern Division of the American Fisheries Society. Little Rock, AR. (Poster)

Aldridge, C.A.[†], L.E. Miranda, and M.E. Colvin. 2020. For management plans, consult a computer? Annual Meeting of the Southern Division of the American Fisheries Society. Little Rock, AR. (Poster)

Norris, D.M.[†], M.E. Colvin, L.E. Miranda, and M.A. Lashley. 2020. To plant or not to plant? A decision support tool to minimize risk associated with uncertainty in reservoir habitat management. Annual Meeting of the Southern Division of the American Fisheries Society. Little Rock, AR.

Aldridge, C.A.[†], L.E. Miranda, and M.E. Colvin. 2020. Same profession different jobs — fisheries goals across the US. Annual Meeting of the Southern Division of the American Fisheries Society. Little Rock, AR.

Aldridge, C.A.[†], D.M. Norris[†], H. Hatcher[†], G. Coppola[†], M.E. Colvin, and L.E. Miranda. 2020. Brush piles: Understanding structural dynamics to help plan habitat management. Annual Meeting of the Southern Division of the American Fisheries Society. Little Rock, AR.

Wilmoth, B.M.[††], M.E. Colvin, N. Temple, and E. Sparks. 2020. Evaluating accuracy of inexpensive acoustic water level sensors. Annual Meeting of the Mississippi Chapter of the American Fisheries Society. Gulfport, MS.

Starnes, V.R.[†], M.E. Colvin, J.B. Davis, and L.E. Miranda. 2020. A prototype decision support tool for evaluating water level management to achieve competing objectives in a multiple use reservoir. Annual Meeting of the Mississippi Chapter of the American Fisheries Society. Gulfport, MS. (Poster)

Richardson, B.M.[†], Griffin, M.J., Mischke, C.C., Greenway, T.E., Wise, D.J., Colvin, M.E., Lawrence, M.L., and Liles, M. 2020. They are the same but different: Comparative genomics of two atypical *Aeromonas hydrophila* pathotypes found in catfish aquaculture of the southeast. Annual Meeting of the Mississippi Chapter of the American Fisheries Society. Gulfport, MS.

Starnes, V.R.[†], M.E. Colvin, B.A. Jones, W.R. Whittington, B.A. Clarke, J.E. Coleman, J.T. Gandy, W.P. Johnson, W.R. Horne, R.J. Hurt, R. W. King, R. M. Savoie, B.C. Wilkinson. 2020. Development of an affordable autonomous four-dimensional water quality monitoring network. Annual Meeting of the Mississippi Chapter of the American Fisheries Society. Gulfport, MS.

Wilmoth, B.M.[††], M.E. Colvin, and C. Dunn[†††]. 2020. Using boat-mounted Radio Frequency Identification to estimate stocking exploitation and estimate efficiency of Passive Integrated Transponders. Annual Meeting of the Mississippi Chapter of the American Fisheries Society. Gulfport, MS.

Aldridge, C.A.[†], L.E. Miranda, and M.E. Colvin. 2020. For management plans, consult a computer? Annual Meeting of the Mississippi Chapter of the American Fisheries Society. Gulfport, MS. (Poster)

Aldridge, C.A.[†], D.M. Norris, H.R. Hatcher, G. Coppola, M.E. Colvin and L.E. Miranda. 2020. Brush piles: Understanding structural dynamics to help plan habitat management. Annual

Meeting of the Mississippi Chapter of the American Fisheries Society. Gulfport, MS. (Poster)

Norris, D.M.[†], M.E. Colvin, L.E. Miranda, and M.A. Lashley. 2020. To plant or not to plant? A decision support tool to minimize risk associated with uncertainty in reservoir habitat management. Annual Meeting of the Mississippi Chapter of the American Fisheries Society. Gulfport, MS.

Reynolds, S.A.[†††], M.E. Colvin, C.R. Fischenich, G. Long, and D. Marmorek. 2020. Coupling hydrodynamic, spawning, and larval settling models with a pallid sturgeon, *Scaphirhynchus albus*, population model to evaluate alternative management operations. Annual Meeting of the Mississippi Chapter of the American Fisheries Society. Gulfport, MS.

Aldridge, C.A.[†], L.E. Miranda, and M.E. Colvin. 2020. Same profession different jobs — fisheries goals across the US. Annual Meeting of the Mississippi Chapter of the American Fisheries Society. Gulfport, MS.

Richardson, B., M. Griffin, C. Mischke, T. Greenway, M.E. Colvin, and D. Wise. 2019. Modeling atypical *Aeromonas hydrophila* (aAh) dynamics in catfish aquaculture ponds of the southeastern United States. Conference of research workers in animal diseases. Chicago, IL.

Lawrence, M. T. Hasan, M. Griffin, D. Wise, K. Attila, T. Greenway, M. Colvin, and C. Mischke. 2019. Control strategies for virulent *Aeromonas hydrophila* in catfish aquaculture by vaccination and informing pond management. Conference of research workers in animal diseases. Chicago, IL.

Schumann, D.A.[†††], M.E. Colvin, and D.T. Jones-Farrand. 2019. Occurrence & Co-Occurrence Patterns of Gar in River-Floodplain Habitats: Leveraging Species Interactions to Benefit Distributional Models. American Fisheries Society & The Wildlife Society 2019 Joint Annual Conference. Reno, NV. (*Poster*)

Dykstra, Adrienne, D.J. Steakley, G. Street, B. Strickland, K VerCauteren, M. Colvin, M. Lashley. 2019 Biological Invasions Disrupt Activity Patterns of Native Wildlife: An Example from Invasive Wild Pigs. American Fisheries Society & The Wildlife Society 2019 Joint Annual Conference. Reno, NV.

Colvin, M. V. Starnes[†], D. Schumann[†††], S. Shaw, C. Gilliland[††], S. Reagan, L.E. Miranda, and J.B. Davis. 2019 Evaluating Water Level Management to Satisfy Competing Management Objectives for Fish, Fishery, and Birds in a Reservoir American Fisheries Society & The Wildlife Society 2019 Joint Annual Conference. Reno, NV.

Campbell, R.L.[††], M.E. Colvin, D.A. Schumann[†††], M.D. Wagner, and D.E. Schwarz. 2019. An overview of passive integrated transponder (PIT) tag feasibility and a new monitoring technique for Frecklebelly Madtom, *Noturus munitus*. Mississippi Chapter of the American Fisheries Society annual meeting, Jackson, MS.

L.E. Miranda, L.A. Bull, M.E. Colvin, W.D. Hubbard, L.L. Pugh. 2019. Segmentation of Mississippi's natural and artificial lakes. Mississippi Chapter of the American Fisheries Society annual meeting, Jackson, MS.

Richardson, B.M.[†], M.J. Griffin, C.C. Mischke, T.E. Greenway, M.E. Colvin, and D.J. Wise. 2019. State boundaries draw hard lines in *Aeromonas hydrophila* disease strains of farm-raised Channel Catfish, *Ictalurus punctatus*. Mississippi Chapter of the American Fisheries Society annual meeting, Jackson, MS.

Wilmoth, B.M.[††], D.A. Schumann[†††], B.M. Richardson[†], C.A. Aldridge[†], and M.E. Colvin. 2019. Ontogeny of Southern Brook Lamprey, *Ichthyomyzon gagei*, with emphasis on abundance, distribution, and morphology in a small watershed. Mississippi Chapter of the

American Fisheries Society annual meeting, Jackson, MS.

Aldridge[†], C.A., M.E. Colvin, and L.E. Miranda. 2019. Early look: Performance of machine learning to classify age from age-length data. Mississippi Chapter of the American Fisheries Society annual meeting, Jackson, MS. (*Poster*)

Norris, D.M.[†], G. Coppola[†], H. Hatcher[†], M.A. Lashley, M.E. Colvin, and L.E. Miranda. 2019. Establishing Ground Cover in Reservoir Mudflats to Foster Fish Assemblages. Mississippi Chapter of the American Fisheries Society annual meeting, Jackson, MS.

Dykstra, A., Steakley, D., Street, G., Strickland, B., Vercauteren, K., Colvin, M., and M. Lashley. Native Wildlife Adjust Activity Patterns to Temporally Avoid Wild Pigs. Wildlife Damage Management Conference. Starkville, MS. March 26, 2019.

Steakley, D., A. Dykstra, G. Street, B. Strickland, K. Vercauteren, M. Colvin, and M. Lashley. Vertebrate Community Response to Wild Pig Control in an Agroecosystem. Wildlife Damage Management Conference. Starkville, MS. March 26, 2019.

Aldridge, C.A.[†], B. Richardson[†], D.A. Schumann[†††], and M.E. Colvin. 2018. Identifying barriers to the use and detection of passive integrated transponder (PIT) tags in Southern Brook Lamprey ammocoetes (*Ichthyomyzon gagei*, Hubbs & Trautman, 1937). Presentation at Southeastern Fishes Council 44th Annual Meeting. Hickory Knob State Park Resort, McCormick, SC.

Reynolds, S.A.[†††], M.E. Colvin, M. Miller, T.L. Welker, T. Gemeinhardt, K. Steffensen, L. Pierce and R.B. Jacobson. 2018. Estimating Abundance and Capture Probabilities of a Rare, Endangered Species—Pallid Sturgeon (*Scaphirhynchus albus*)—in the Lower Missouri River. Annual Meeting of the North American Sturgeon and Paddlefish Society. Columbia, MO. (Poster).

Reynolds, S.A.[†††], M.E. Colvin, R.B. Jacobson, T.L. Welker, L. Pierce, K. Steffensen and D.R. Marmorek. 2018. A structured decision making approach to redesigning the Pallid Sturgeon population assessment program. Annual Meeting of the North American Sturgeon and Paddlefish Society. Columbia, MO.

Gilliland, C.R.[†], M.E. Colvin, P.J. Allen, J.W. Neal, and S. Reagan. 2018. Evaluating site fidelity of translocated Paddlefish in a regulated system. Annual Meeting of the North American Sturgeon and Paddlefish Society. Columbia, MO.

Kroboth, P.K., D.A. Hann, M.E. Colvin, P.D. Hartfield, and H.L. Schramm, Jr. 2018. Pallid Sturgeon Seasonal Habitat Selection in a Large Free-flowing River, the Lower Mississippi River. Annual Meeting of the North American Sturgeon and Paddlefish Society. Columbia, MO.

Jacobson, R.B., M.E. Colvin, and D. Marmorek. 2018. Engaging Science to Manage a Very Rare Fish in a Very Large River – Pallid Sturgeon in the Missouri River. Annual Meeting of the North American Sturgeon and Paddlefish Society. Columbia, MO.

Schumann, D.A.[†††], and M.E. Colvin. 2018. A Bayesian Belief Network to Estimate Conservation Need for Understudied Aquatic Taxa. 148th Annual Meeting of the American Fisheries Society. Atlantic City, NJ.

Reynolds, S.A.[†††], M.E. Colvin, R.B. Jacobson, T.L. Welker, L. Pierce, K. Steffensen and D.R. Marmorek. 2018. A structured decision making approach to redesigning the Pallid Sturgeon population assessment program. 148th Annual Meeting of the American Fisheries Society. Atlantic City, NJ.

Coppola, G.[††], H. Hatcher[††], M.E. Colvin, L.E. Miranda and M. Lashley. 2018. Persistence of agricultural plants as potential fish habitat. 148th Annual Meeting of the American Fisheries Society. Atlantic City, NJ.

Richardson, B.R.[††], M.E. Colvin, D. Wise, M. Griffin, C. Mischke and T. Greenway. 2018. Status of Atypical *Aeromonas Hydrophila* (aAh) in Mississippi. 148th Annual Meeting of the American Fisheries Society. Atlantic City, NJ.

Reynolds, S.A.[†††], M.E. Colvin, M. Miller, T.L. Welker, T. Gemeinhardt, K. Steffensen, L. Pierce and R.B. Jacobson. 2018. Estimating Abundance and Capture Probabilities of a Rare, Endangered Species—Pallid Sturgeon (*Scaphirhynchus albus*)—in the Lower Missouri River. 148th Annual Meeting of the American Fisheries Society. Atlantic City, NJ. (Poster).

Schumann, D.A.[†††], M.E. Colvin, K. Koupal, and C. Wessel. 2018. A Bayesian Decision Network to Identify Optimal Management Practice to Support Plains Topminnow Persistence in Nebraska. 148th Annual Meeting of the American Fisheries Society. Atlantic City, NJ. (Poster).

Richardson, B.[†] C.A. Aldridge[†], D.A. Schumann[†††] and M.E. Colvin. 2018. Assessing Viability of Passive Integrated Transponder (PIT) Tags for Ecological Studies of Lamprey Ammocoetes. 148th Annual Meeting of the American Fisheries Society. Atlantic City, NJ. (Poster).

Gilliland, C.R.[†], M.E. Colvin, P.J. Allen, J.W. Neal, and S. Reagan. 2018. Residents, Migrants, or Both? Evaluating Population Dynamics and Movement of Paddlefish *Polyodon spathula* in a Regulated System. Mississippi Chapter of the American Fisheries Society annual meeting, Oxford, Mississippi.

Shannon, A.N. [††], D.A. Schumann[†††], and M.E. Colvin. 2018. Debunking angler lore: can the Farmer's Almanac really forecast catch rates? Mississippi State University Undergraduate Research Symposium, Mississippi State, Mississippi.

Schumann, D.A.[†††], and M.E. Colvin. 2018. A Bayesian belief network to prioritize conservation need among diverse aquatic taxa in a speciose and understudied region. Mississippi Chapter of the American Fisheries Society annual meeting, Oxford, Mississippi.

Shannon, A.N.[††], D.A. Schumann[†††], and M.E. Colvin. 2018. Debunking angler lore: can the Farmer's Almanac really forecast catch rates? Mississippi Chapter of the American Fisheries Society annual meeting, Oxford, Mississippi.

Richardson, B.R.[†], M.E. Colvin, D. Wise, M. Griffin, C. Mischke and T. Greenway. 2018. Assessing Atypical *Aeromonas hydrophila* (aAh) Prevalence in Farm-raised Catfish Using Occupancy. Mississippi Chapter of the American Fisheries Society annual meeting, Oxford, Mississippi.

Coppola, G.[†], H. R. Hatcher[†], M. Lashley, M.E. Colvin, L.E. Miranda. 2018. Persistence of agricultural plants as potential habitat for fish. Mississippi State University Graduate Student Research Symposium. February 17, 2018. Starkville, Mississippi.

Coppola, G.[†], H. R. Hatcher, M. Lashley, M.E. Colvin, L.E. Miranda. 2018. Persistence of agricultural plants as potential habitat for fish. Mississippi American Fisheries Society Chapter Meeting. February 8, 2018. Oxford, Mississippi.

Hatcher, H.R.[†], G. Coppola, M. Lashley, M.E. Colvin, L.E. Miranda. 2018. Assessing Growth and Establishment of Agricultural Plantings on Reservoir Mudflats. . Mississippi American Fisheries Society Chapter Meeting. February 8, 2018. Oxford, Mississippi.

Ivey, M.R., M.A. Lashley, B.K. Strickland, and M.E. Colvin. 2017. Do Feral Swine Alter the Island Biogeography of Native Wildlife in Agro-Ecosystem Forest Patches? Annual Meeting of the Wildlife Society. Albuquerque, NM.

Ivey, M.R., M.A. Lashley, B.K. Strickland, and M.E. Colvin. 2017. Do Feral Swine Alter the Island Biogeography of Native Wildlife in Agro-Ecosystem Forest Patches? Joint

Meeting of the Mississippi and Alabama Wildlife Society. Meridian, MA.

Jacobson, R.J., M.E. Colvin, D. Marmorek, and M. Randall. 2017. Science to manage a very rare fish in a very large river – Pallid sturgeon in the Missouri River. American Geophysical Union Fall Meeting. New Orleans, LA.

Pugh, L., L.E. Miranda, and M.E. Colvin. 2017. Thirty Years of Standardized Sampling in Mississippi Lakes and Reservoirs. Southeastern Association of Fish & Wildlife Agencies 71st Annual Conference. Louisville, KY.

Colvin, M.E., S. Reynolds, R.B. Jacobson, T.L. Welker, L. Pierce, K. Steffensen, and M. Randall. 2017. Evaluating Potential Population Monitoring Programs for Endangered Pallid Sturgeon in the Context of Agency Objectives and Adaptive Management. 147th Annual Meeting of the American Fisheries Society. Tampa, FL.

Richardson, B.R. †, M.E. Colvin, C. Mischke, T. Greenway, M. Griffin, and D. Wise. 2017. Virulent *Aeromonas hydrophila* (vAh) – Not Just Another "Hole-in-the-Head". 147th Annual Meeting of the American Fisheries Society. Tampa, FL.

Gilliland†. 2017. Residents, Migrants, or Both? Evaluating Population Dynamics and Movement of *Paddlefish Polyodon* Spathula in a Regulated System. 147th Annual Meeting of the American Fisheries Society. Tampa, FL.

Gilliland, C.R. †, M.E. Colvin, P.J. Allen, and J.W. Neal. Paddlefish *Polyodon Spathula* Passage Potential in a Regulated Stream. 147th Annual Meeting of the American Fisheries Society. Tampa, FL. (Poster)

Hatcher, H. †, G. Coppola†, L.E. Miranda, M.E. Colvin, and M.A. Lashley. 2017. Cover in the Mudflats of a Reservoir Structures Fish Assemblages. 147th Annual Meeting of the American Fisheries Society. Tampa, FL.

Coppola, G. †, H. Hatcher†, M.A. Lashley, L.E. Miranda, and M.E. Colvin. 2017. Performance of Agricultural Plantings on Reservoir Mudflats. 147th Annual Meeting of the American Fisheries Society. Tampa, FL.

Shamaskin, A.C.†, M.E. Colvin, and L.E. Miranda. 2017. Evaluating Multisystem Scale Length Limits. 147th Annual Meeting of the American Fisheries Society. Tampa, FL.

Shamaskin, A.C.†, M.E. Colvin, and L.E. Miranda. 2017. Evaluating Multisystem Scale Length Limits. World Recreational Fisheries Conference. Victoria, Canada. July

Shirley, C.†, M.E. Colvin, C. Mischke, T. Holman, and P. Allen. 2017. Development of techniques for spawning, sperm cryopreservation, and feed-training of crappie (*Pomoxis* spp.). Annual Meeting of the Southern Division American Fisheries Society. MS-AL Chapter of the American Fisheries Society Annual Meeting. Biloxi, MS.

Gilliland, C.†, M.E. Colvin, W. Neal, and P. Allen. 2017. Potential Paddlefish (*Polyodon spathula*) passage in a regulated stream. Annual Meeting of the Southern Division American Fisheries Society. MS-AL Chapter of the American Fisheries Society Annual Meeting. Biloxi, MS.

Coppola G.†, H.R. Hatcher†, M.A. Lashley, L.E. Miranda, and M.E. Colvin. Performance of agricultural plantings on reservoir mudflats. MS-AL Chapter of the American Fisheries Society Annual Meeting. Biloxi, MS.

Hatcher, H.R.†, G. Coppola†, L.E. Miranda, M.E. Colvin, M.A. Lashley. 2017. Fish Assemblages Associated with Cover in the Mudflats of a Reservoir. MS-AL Chapter of the American Fisheries Society Annual Meeting. Biloxi, MS.

Shamaskin, A.C.†, M.E. Colvin and L.E. Miranda. 2017. Multisystem scale length limits: making it easy. MS-AL Chapter of the American Fisheries Society Annual Meeting. Biloxi, MS.

Gilliland, C.†, M.E. Colvin, W. Neal, and P. Allen. 2017. Potential Paddlefish (*Polyodon spathula*) passage in a regulated stream. Annual Meeting of the Southern Division American Fisheries Society. Oklahoma City, OK. February 5th. (Platform)

Coppola G.†, H.R. Hatcher†, M.A. Lashley, L.E. Miranda, and M.E. Colvin. Performance of agricultural plantings on reservoir mudflats. Southern Division American Fisheries Society. February 3, 2017. Oklahoma City, OK.

Hatcher, H.R.†, G. Coppola†, L.E. Miranda, M.E. Colvin, M.A. Lashley. 2017. Fish Assemblages Associated with Cover in the Mudflats of a Reservoir. Annual Meeting of the Southern Division American Fisheries Society. Oklahoma City, OK. February 4th.

Shamaskin, A.†, M.E. Colvin and L.E. Miranda. 2017. Sensitivity of a Multisystem Length Limit Model. Annual Meeting of the Southern Division American Fisheries Society. Oklahoma City, OK. February 4th.

Hann, D.†, P. Kroboth, M.E. Colvin, P. Hartfield, and H. Schramm. 2017. Seasonal habitat use of adult Pallid Sturgeon in the Lower Mississippi River. Annual Meeting of the Southern Division of the American Fisheries Society. February 5th. Oklahoma City, OK.

Hann, D.†, P. Kroboth, M.E. Colvin, P. Hartfield, and H. Schramm. 2017. Seasonal habitat use of adult Pallid Sturgeon in the Lower Mississippi River. Lower Basin Pallid Sturgeon Workgroup Meeting. January 10th.

Shamaskin, A.†, M.E. Colvin and L.E. Miranda. 2016. Sensitivity of a Multisystem Length Limit Model. 147th Annual Meeting of the American Fisheries Society, Kansas City, MO. August 21-25th.

Colvin, M.E., R. Jacobson, D. James, L. Pierce, M. Randall, and T. Welker. 2016. Model development to support Pallid Sturgeon recovery. 147th Annual Meeting of the American Fisheries Society, Kansas City, MO. August 21-25th.

Jacobson, R., M.E. Colvin, D. James, L. Pierce, M. Randall, and T. Welker. Missouri River Pallid Sturgeon Effects Analysis. 147th Annual Meeting of the American Fisheries Society, Kansas City, MO. August 21-25th.

Miranda, L.E., A. Shamaskin†, and M.E. Colvin. 2016. Long-term population changes in relation to harvest regulations at Ross Barnett Reservoir, Mississippi. 147th Annual Meeting of the American Fisheries Society, Kansas City, MO. August 21-25th.

Kramer, N.W., Q.E. Phelps, C.L. Pierce, and M.E. Colvin 2016. Using Food Web Modeling To Determine Effects of Increased Exploitation on Invasive Carps In The Middle Mississippi River. 76th annual Midwest Fish and Wildlife Conference. Grand Rapids, MI. January 27th.

Shirley, C.††, N. Aycock, and M.E. Colvin. 2016. Effects of proposed length limit changes and '5 under rule' on Lake Washington crappie yield. Mississippi State University undergraduate Research Symposium. Mississippi State, MS. April 15th. (Poster)

Kramer, N.W., Q.E. Phelps, C.L. Pierce, and M.E. Colvin 2016. Using Food Web Modeling To Determine Effects of Increased Exploitation on Invasive Carps In The Middle Mississippi River. 76th annual Midwest Fish and Wildlife Conference. Grand Rapids, MI. January 27th.

Jacobson, R., M.E. Colvin, D. James, L. Pierce, M. Randall, and T. Welker. 2016. Missouri River Pallid Sturgeon Effects Analysis: Progress and What's Next. Missouri River Natural Resources Conference. March 22nd-25th. Great Falls, MT.

Colvin, M.E., R. Jacobson, D. James, L. Pierce, M. Randall, and T. Welker. 2016. Model development to support Pallid Sturgeon effects analysis and adaptive management. Missouri River Natural Resources Conference. March 22nd-25th. Great Falls, MT.

Shirley, C.[††], N. Aycock, and M.E. Colvin. 2016. Effects of proposed length limit changes and '5 under rule' on Lake Washington crappie yield. 42nd annual meeting of the Mississippi Chapter of the American Fisheries Society, Tara Lodge, MS. March 9-11th.

Shamaskin, A.[†], M.E. Colvin, L.E. Miranda, L. Bull, and T. Holman. 2016. Long-term population changes in relation to harvest regulations at Ross Barnett Reservoir, Mississippi. 42nd annual meeting of the Mississippi Chapter of the American Fisheries Society, Tara Lodge, MS. March 9-11th.

Veum, S., S.A. Rush, M.E. Colvin, and S.R. Reagan. 2016. Habitat use and niche partitioning of bats in the central gulf coastal plains of Mississippi. 21st Annual Meeting of the Southeastern Bat Diversity Network & 26th Annual Colloquium on the Conservation of Mammals in the Southeastern U.S. February 18th -19th.

Kneece, M.R., J.C. Shipes, J.B. Davis, E.P. Wiggers, R.M. Kaminski, and M.E. Colvin. 2016. Nesting Ecology of Mottled Ducks in Coastal South Carolina. North American Duck Symposium and Workshop. Annapolis, February 1-5.

Kramer, N.W., Q. Phelps, C.L. Pierce, and M.E. Colvin. 2016. Using Food Web Modeling To Determine Effects of Increased Exploitation on Invasive Carps In The Middle Mississippi River. 76th Midwest Fish and Wildlife Conference, Grand Rapids, MI. January 24-27th.

James, D.A., L.L. Pierce, M.L. Annis, M.E. Colvin, R.B. Jacobson, M. Randall, and T.L. Welker. 2015. Association of Native Prey-fish Abundance to Pallid Sturgeon Condition. 145th Annual Meeting of the American Fisheries Society, Portland, OR. August 16-20th.

Neely, B.C., J.D. Koch, and M.E. Colvin. 2015. Influence of Reservoir Characteristics on Collection of Representative and Precise Fish Samples: Implications for Determining Minimum Sampling Effort. 145th Annual Meeting of the American Fisheries Society, Portland, OR. August 16-20.

Colvin, M.E. and L.E. Miranda. 2015. Summary and synthesis of standardized electrofishing efforts from 1986 to present. 41st Annual meeting of the Mississippi Chapter of the American Fisheries Society, Tara Lodge, MS. March 22-25th.

Colvin, M.E., M.L. Annis, D.A. James, R.B. Jacobson, M.R. Randall, and T.L. Welker. 2015. A Framework for Integrating the Pallid Sturgeon Effects Analysis to Evaluate Management and Restoration Alternatives. Missouri River Natural Resource Conference, Nebraska City, NE. March 10-12th.

Jacobson, R. M.L. Annis, M.E. Colvin, D.A. James, M.R. Randall, and T.L. Welker. 2015. Missouri River Pallid Sturgeon Effects Analysis: Progress and Prospects. Missouri River Natural Resource Conference, Nebraska City, NE. March 10-12th.

James, D.A., L.L. Pierce, M.L. Annis, M.E. Colvin, R.B. Jacobson, M. Randall, and T.L. Welker. 2015. Association of Native Prey-fish Abundance to Pallid Sturgeon Condition. Missouri River Natural Resource Conference, Nebraska City, NE. March 10-12th.

Colvin, M.E., J.T. Peterson, C. Sharpe, S. Benda, M. Kent and C. Schreck. 2015. Upper Willamette River spring Chinook prespawn mortality: data synthesis and prediction of optimal management actions. Southern Division of the American Fisheries Society Annual Meeting. Savanah, GA. January 28-February 1.

Koch, J.D., B.C. Neely, and M.E. Colvin. 2015. Evaluation of precision and sample sizes using standardized sampling in Kansas Reservoirs. Kansas Natural Resource Conference. Wichita, KS. January 29-30.

Colvin, M.E., J.T. Peterson, M.L. Kent, and C.B. Schreck. 2014. Evaluating of the influence of interspecific interactions on the structure of pathogen metacommunities in spring Chinook salmon. Joint Aquatic Sciences Meeting. Portland, OR.

Herron, C.[††], M.E. Colvin, M. Kent, C. Caudill and C. Schreck. 2014. *Nanophyetus*

salminocola burdens in Chinook salmon (*Onchorhynchus tshawystscha*) in the Upper Willamette Basin. 50th Annual Meeting Oregon Chapter of the American Fisheries Society, Eugene, OR

Colvin, M.E., J.T. Peterson, C. Sharpe, S. Benda, M. Kent, B. Dolan, C. Caudill and C. Schreck. 2014. Upper Willamette River spring Chinook prespawn mortality: data synthesis and prediction of optimal management actions. 50th Annual Meeting Oregon Chapter of the American Fisheries Society, Eugene, OR.

Colvin, M.E., J.T. Peterson, C. Sharpe, S. Benda, M. Kent, B. Dolan, C. Caudill and C. Schreck,. 2014. Integrating science, management, and monitoring: A decision tool for optimizing annual spring Chinook outplanting strategies and prioritizing future research. Willamette River Science Review. Portland, OR.

Colvin, M.E., J.T. Peterson, C. Sharpe, S. Benda, C. Schreck, M. Kent, B. Dolan, C. Caudill. 2013. Development of a tool to evaluate outplanting strategies and prespawn mortality of Upper Willamette River spring Chinook. Annual Meeting of the Western Division of the American Fisheries Society. Boise, Idaho.

Kent, M.L., S.E. Benda, M.E. Colvin, J.T. Peterson, B. Dolan, C.B. Schreck. 2013. Pathogens, lesions and links to prespawning mortality in Chinook salmon from the Willamette River basin. 54th Joint Western Fish Disease Workshop and AFS Fish Health Section Meeting, Port Townsend, Washington.

Colvin, M.E., J.T. Peterson, C. Sharpe, S. Benda, C. Schreck, M. Kent, B. Dolan, C. Caudill. 2013. Upper Willamette River spring Chinook prespawn mortality synthesis and modeling. 49th Annual Meeting Oregon Chapter of the American Fisheries Society, Bend, OR.

Benda, S., M.L. Kent, J. Unrein, M.E. Colvin, R. Chitwood., C. Caudill, G. Naughton, C. Schreck. 2013. A closer look: stress and parasites in prespawn mortality. 49th Annual Meeting Oregon Chapter of the American Fisheries Society, Bend, OR.

Colvin, M.E. 2012. Willamette River spring Chinook prespawn mortality: probing the depth of knowledge. Oregon State University Department of Fish and Wildlife Monday Morning Meeting.

Colvin, M.E., S. Grummer, J. Wahl, T. Stewart, and C. Pierce. 2011. Setting harvest targets for a common carp stock undergoing pulsed harvest. 72nd Midwest Fish and Wildlife Conference. Des Moines, IA. (*Poster*)

Colvin, M.E., S. Grummer, J. Wahl, T. Stewart, and C. Pierce. 2010. Impacts of invasive species and restoration on recreational fisheries: Zebra mussels and common carp in a shallow hypereutrophic lake. 140th Annual Meeting American Fisheries Society, Pittsburgh, PA.

Colvin, M.E., S. Grummer, J. Wahl, T. Stewart, and C. Pierce. 2010. Impacts of invasive species and restoration on recreational fisheries: zebra mussels and common carp in a shallow hypereutrophic lake. Joint Annual Meeting of the North American Benthological Society and ASLO, Santa Fe, NM. (*Poster*)

Colvin, M.E., S. Grummer, J. Wahl, T. Stewart, and C. Pierce. 2010. Simulating food web interactions among nuisance common carp, invading zebra mussels, nutrient reduction and the recreational fishery of a shallow eutrophic lake. Iowa Chapter of the American Fisheries and Wildlife Society Annual Meeting. Ames, IA. (*Poster*)

Skiff, J.J.[††], M.E. Colvin, T. Stewart and C. Pierce. 2010. Analysis of sampling methods for *Dreissena polymorpha* veligers. Iowa Chapter of the American Fisheries and Wildlife Society Annual Meeting. Ames, IA. (*Poster*)

Colvin, M.E., E. Katzenmeyer, T. Stewart and C. Pierce. 2009. Simulating food web interactions among nuisance common carp, invading zebra mussels, and the native biological community in a shallow eutrophic lake. 70th Midwest Fish and Wildlife Conference, Springfield, IL. (*Poster*)

Colvin, M.E., J.L. Ebersole, P.J. Wigington, B. Miller, and B. Hansen. 2009. Using juvenile coho salmon demographics and movement to prioritize areas of focal restoration across a stream network. 138th Annual Meeting American Fisheries Society, Nashville, TN.

Colvin, M.E., E. Katzenmeyer, T. Stewart and C. Pierce. 2009. Simulating food web interactions among nuisance common carp, invading zebra mussels, and the native biological community in a shallow eutrophic lake. 139th Annual Meeting American Fisheries Society, Nashville, TN. (*Poster*)

Katzenmeyer, E., M.E. Colvin, C. Pierce and T. Stewart. 2009. Fish growth responses to changing conditions in Clear Lake: Effects of common carp (*Cyprinus carpio*) and zebra mussels (*Dreissena polymorpha*). 138th Annual Meeting American Fisheries Society, Nashville, TN.

Katzenmeyer, E., M.E. Colvin, C. Pierce and T. Stewart. 2009. Fish growth responses to changing conditions in Clear Lake: Effects of common carp (*Cyprinus carpio*) and zebra mussels (*Dreissena polymorpha*). Iowa Chapter of the American Fisheries and Wildlife Society Annual Meeting. Ames, IA.

Katzenmeyer, E., M.E. Colvin, C. Pierce and T. Stewart. 2009. Fish growth responses to changing conditions in Clear Lake: Effects of common carp (*Cyprinus carpio*) and zebra mussels (*Dreissena polymorpha*). 2nd Midwest Student Colloquium. Ames, IA.

Colvin, M.E., C.L. Pierce, and T.W. Stewart. 2008. A simulation model to evaluate common carp (*Cyprinus carpio*) removal as a tool to improve water quality. 137th Annual Meeting American Fisheries Society, Ottawa, CA.

Colvin, M.E., Ebersole, J.L., and P.J. Wigington. 2008. A demographic based strategy for prioritizing juvenile salmon habitat restoration across a stream network. 137th Annual Meeting American Fisheries Society, Ottawa, CA. (*Poster*)

Katzenmeyer, E., C.L. Pierce and M.E. Colvin. 2008. Growth responses of fish species of multiple trophic levels to a zebra mussel (*Dreissena polymorpha*) invasion in a shallow, eutrophic lake. 138th Annual Meeting American Fisheries Society, Ottawa, CA.

Colvin, M.E., C.L. Pierce, and T.W. Stewart. 2008. A simulation model to evaluate common carp (*Cyprinus carpio*) removal as a tool to improve water quality. North American Benthological Society Annual Meeting, Salt Lake City, UT.

Colvin, M.E., C.L. Pierce, and T.W. 2008. Stewart. A simulation model to evaluate common carp (*Cyprinus carpio*) removal as a tool to improve water quality. 1st Midwest Student Colloquium. Lincoln, NE.

Colvin, M.E., C.L. Pierce, and T.W. Stewart. 2008. A proposed ecosystem simulation model to predict the effects of common carp and zebra mussels in shallow lake ecosystems. 8th Annual Water Monitoring Conference, Ames, IA. (*Poster*)

Colvin, M.E., C.L. Pierce, and T.W. Stewart. 2008. A simulation model to evaluate common carp (*Cyprinus carpio*) removal as a tool to improve water quality. Joint Iowa and Dakota Chapter AFS Annual Meeting, Sioux City, IA.

Colvin, M.E., C.L. Pierce, and T.W. Stewart. 2008. A proposed ecosystem simulation model to predict the effects of common carp and zebra mussels in shallow lake ecosystems. Joint Iowa and Dakota Chapter AFS Annual Meeting, Sioux City, IA. (*Poster*)

Ebersole, J.L., Colvin, M.E. Colvin, P.J. Wigington, S.G. Leibowitz, and K. Burnett. 2008. Application of restoration scenarios to basin-scale demographics of coho salmon inferred from pit-tags. Tag Conference, Auckland, NZ.

Colvin, M.E., C.L. Pierce, and T.W. Stewart. 2008. A proposed ecosystem simulation model to predict the effects of common carp and zebra mussels in shallow lake ecosystems. 2nd USGS Modeling Conference, Orange Beach, AL. (*Poster*)

Colvin, M.E., C.L. Pierce, and T.W. Stewart. 2007. Carp removal strategies: a simulation model to identify effective carp removal strategies for Clear Lake, IA. 68th Midwest Fish and Wildlife Conference, Madison, WI.

Ebersole, J.L., M.E. Colvin, P.J. Wigington, J.P. Baker, M.R. Church, J. Compton, M. Cairns, and H.R. LaVigne. 2007. Variation in juvenile coho salmon end-of-summer size and abundance: Hierarchical analysis of habitat effects. American Fisheries Society Annual Meeting, San Francisco, CA.

Wigington, P.J., M.E. Colvin, B. Miller, B. Hansen, H.R. LaVigne, J.P. Baker, and M.R. Church. 2007. Over-winter juvenile coho salmon growth and survival in a coastal Oregon stream network. American Fisheries Society Annual Meeting, San Francisco, CA.

Ebersole, J.L., M.E. Colvin, P.J. Wigington Jr., M.R. Church, J. Compton, J.P. Baker, M.A. Cairns, S.G. Leibowitz, and D. White. 2007. Variation in juvenile coho salmon end-of-summer size: hierarchical analysis of habitat effects. 43rd Annual Meeting Oregon Chapter of the American Fisheries Society, Eugene, OR.

Colvin, M.E., J. L. Ebersole, P.J. Wigington Jr., and K. Rodnick. Influence of summer temperature spatial variability on distribution and condition of juvenile coho salmon. 136th Annual Meeting American Fisheries Society, Lake Placid, NY.

Colvin, M.E., J.L. Ebersole, P.J. Wigington Jr., J.P. Baker, M.A. Cairns, H.R. LaVigne, B. Hansen, and B. Miller. 2006. Factors associated with the timing of coho salmon smolts. 42nd Annual Meeting Oregon Chapter of the American Fisheries Society, Sun River, OR.

Colvin, M.E., K.J. Anlauf, and C.M. Moffitt. 2005. The ecology of *Myxobolus cerebralis* in the Pahsimeroi River drainage, Idaho: factors affecting the distribution and intensity. Idaho State Chapter of the American Fisheries Society Annual Meeting, Boise, ID.

Anlauf, K.J., C.M. Moffitt, and M.E. Colvin. 2005. The influence of landscape, stream, and microhabitat parameters on Tubificid habitat and population abundances. Idaho Chapter of the American Fisheries Society Annual Meeting, Boise, ID.

Moffitt, C.M., M.E. Colvin, and B. Sun. 2005. Microbial profiles from rainbow trout intestines, New Zealand mudsnails, and hatchery inflow and outflow at Hagerman State Fish Hatchery, Idaho. American Fisheries Society Fish Health Section 46th Western Fish Disease Workshop, Boise, ID.

Colvin, M.E., K.J. Anlauf, C.M. Moffitt, and K. Johnson. 2005. Addressing risks of reconnection in watersheds of the Salmon and Pahsimeroi River. 11th Annual Whirling Disease Symposium, Denver, CO. (*Poster*)

Colvin, M.E., K.J. Anlauf, C.M. Moffitt, and K. Johnson. 2005. Ecology of *Myxobolus cerebralis* in the Pahsimeroi River drainage, Idaho: factors affecting the distribution. 11th Annual Whirling Disease Symposium, Denver, CO. (*Poster*)

Anlauf, K.J., C.M. Moffitt, and M.E. Colvin. 2005. The Influence of landscape, stream, and microhabitat parameters on Tubificid habitat and population abundance. 11th Annual Whirling Disease Symposium, Denver, CO. (*Poster*)

Colvin, M.E., and C.M. Moffitt. 2004. Piecing together the Pahsimeroi puzzle. Idaho Chapter of the American Fisheries Society Annual Meeting, Moscow, ID.

Anlauf, K.J., C.M. Moffitt, M.E. Colvin, and B.E. Reiman. 2004. Understanding the ecology of whirling disease through modeling of Tubificid habitat. Idaho Chapter of the American Fisheries Society Annual Meeting, Moscow, ID.

Colvin, M.E., K.J. Anlauf, K. Johnson, and C.M. Moffitt. 2004. Effects of fish distributions on whirling disease in the Pahsimeroi River drainage, Idaho. Joint Western Division of the American Fisheries Society and 10th Annual Whirling Disease Foundation Annual Meeting, Salt Lake City, UT.

Colvin, M.E., K.J. Anlauf, K. Johnson, and C.M. Moffitt. 2003. Prevalence of *Myxobolus cerebralis* in the Pahsimeroi watershed, Idaho: associations between landscape and fine scale habitat characteristics. 9th Annual Whirling Disease Symposium, Seattle, WA.

Anlauf, K.J., C.M. Moffitt, M.E. Colvin, A.H. Haukenes,and B.E. Reiman. 2003. Progress in using GIS based landscape parameters to model the likely influence of *Myxobolus cerebralis* in Idaho. 9th Annual Whirling Disease Symposium, Seattle, WA.

Moffitt, C.M., M.K. Santora, C.J. Williams, K.J. Anlauf, M.E. Colvin, and K.A. Johnson. 2003. Using parameters from landscape and population based models to understand the dynamics of *Myxobolus cerebralis* infections. 9th Annual Whirling Disease Symposium, Seattle, WA.

Colvin, M.E., K.J. Anlauf, K. Johnson, and C.M. Moffitt. 2003. Prevalence of *Myxobolus cerebralis* in the Pahsimeroi watershed, Idaho: Associations between landscape and fine scale habitat characteristics. Idaho Chapter of the American Fisheries Society Annual Meeting, Boise, ID.

Colvin, M.E. and C.M. Moffitt. 2003. Modeling of *Myxobolus cerebralis* infections in a landscape altered by irrigation. 4th Annual USGS Conference on Science in Oregon and Washington, Troutdale, OR. (*Poster*)

Outreach & other creative work

Colvin, M.E., 2015. The legacy of Missouri Mike Colvin. Fisheries Management Newsletter (March).

Colvin, M.E., E.K. Katzenmeyer, T.W. Stewart and C.L. Pierce. 2009. Zebra mussels: overview, preliminary trends and implications for the future of Clear Lake. Project Clear Newsletter.

Colvin, M.E., E.K. Katzenmeyer, T.W. Stewart and C.L. Pierce. 2010. Clear Lake project overview. Clear Lake Association Annual Picnic. Clear Lake, IA.

Colvin, M.E., E.K. Katzenmeyer, T.W. Stewart and C.L. Pierce. 2009. Zebra mussel biology and potential impacts in Clear Lake. Clear Lake Association Annual Picnic. Clear Lake, IA (*Poster*).

Colvin, M.E., E.K. Katzenmeyer, T.W. Stewart and C.L. Pierce. 2008. Clear Lake project overview. Clear Lake Association Annual Picnic. 2008. Clear Lake, IA.

Colvin, M.E., C.L. Pierce, and T.W. Stewart. 2008. Impacts of nuisance species in a shallow lake: A simulation modeling approach for restoration and management. Ames Anglers, Ames, IA.

Honors and awards

2016 College of Forest Resources Early Career Achievement Award
2011 Certificate of Appreciation: Education Section of the American Fisheries Society Kenneth Carlander Award
USEPA Scientific and Technological Achievement Award (Honorablemention for innovative research quantifying the effects of multi-level factors on fish populations across entire watersheds)
2010 American Fisheries Society Skinner Award
Iowa Natural Heritage Foundation J.N. "Ding" Darling Scholarship Sherry Fisher Award
2009 Fenske Award Finalist
Kenneth Carlander Award
2007 Level II EPA Scientific and Technology Achievement Award
2005 University of Idaho Fisheries Graduate Student of the Year
Idaho Chapter of the American Fisheries Society Graduate Student of the Year
University of Idaho Alumni Award for Excellence
2004 Adams Scholarship for Academic Achievement
2003 Idaho Chapter American Fisheries Scholarship Recipient
2000 Certificate of Merit from Unity College for Outstanding Undergraduate Research in Aquaculture
NSCAA Academic All American
1999 NSCAA Academic All American
1997-2000
Phi Theta Kappa

University service

2021-pres. Masters co-advisor: Josh Stafford
2021-pres. Masters committee member: Brad Thorton
2020-pres. Masters co-advisor: Jordan Besson
2020-pres. Masters committee member: Josh Neary
2020-pres. Ph.D. committee member: Wenteo Song
2019-pres. Masters committee member: Spencer VanderBloemen
2019-pres. Ph.D. committee member: Rebecca Bracken
2018-pres. Masters committee member: Victoria Starnes
2018-pres. PhD co-advisor: Caleb Aldridge
2018-2020 Masters committee member: T.J. Arnoult
2018-2019 Masters committee member: D.J. Steakley
2018-2019 Masters committee member: Matthew Jargawsky
2017-2019 Masters committee member: Daniel Firth
2016-2019 Masters committee member: Britney Chesser
2016-2018 Masters co-advisor: Giancarlo Coppolla
2016-2018 Masters co-advisor: Hunter Hatcher
2016-2018 Masters committee member: Matthew Ivey
2016-2018 Masters committee member: Christian Shirley
2016-pres. PhD co-advisor: Bradley Richardson
2016-2018 Masters committee member: Emmett Guy
2015-2018 Masters advisor: Chelsea Gilliland
2015-2018 Masters co-advisor: Andrew Shamaskin

2015-2017 Masters committee member: Scott Veum
2015-pres. Ph.D. committee member: Brian Ott
2015-pres. Ph.D. committee member: Rob DeVries
2015-2017 Masters committee member: Lindsey Stutzman
2015-2018 Masters committee member: Kevin Keretz
2015-2017 Masters committee member: Clayton Raines
2014- pres. Ph.D. committee member: Cynthia Fox

Departmental committees and service

2020-pres. Faculty Search Committee – Fish Nutritionist, Mississippi State University
2019 Departmental Seminar Committee
2018 Faculty Search Committee – Vertebrate Ecologist, Mississippi State University
2017 Faculty Search Committee – Aquatic Ecologist, Mississippi State University
2016-2017 Faculty Search Committee – Coastal Fisheries Extension, Mississippi State University
2016-pres. DAFVM Awards Committee – WFA representative
2015-pres. WFA Communications Committee
2015 Faculty Search Committee – DRAC Aquaculture Economist, Mississippi State University
2014-Pres. Wildlife, Fisheries and Aquaculture Library Representative
2012 Faculty Research Assistant Search Committee – Department of Fish and Wildlife, Oregon State University
2011-2012 Faculty Search Committee – Graduate Student Representative Department of Natural Resource Ecology and Management, Iowa State University

Professional service

2017-pres. Mississippi Chapter of the American Fisheries Society: Webmaster
2017-pres. American Fisheries Society Certification Committee: Committee Chair
2015-pres. American Fisheries Society Certification Committee: Southeastern Division Representative for the Education Section
2015-2018. Education Section of the American Fisheries Society: Southeastern Division Representative
2014- 2018. Fisheries Management Section of the American Fisheries Society: Western Division Representative
2012-pres. Education Section of the American Fisheries Society: New initiatives committee chair
2011 Symposium chair "Control Strategies Nonnative and Native Nuisance Aquatic Species" 72nd Midwest Fish and Wildlife Conference
2010-2012 Malheur National Wildlife Refuge: Carp Suppression Research and Assessment Working Group
2009-2010 American Fisheries Society Student Subsection: President
2008-2012 Iowa Chapter of the American Fisheries Society: Webmaster
2007-2008 Iowa State University Student Unit of the American Fisheries Society: Webmaster
2008-2009 Iowa State University Graduate Student Organization: Seminar Committee Chair
2005-2007 Oregon Chapter of The American Fisheries Society: Webmaster
2004-2005 Palouse Unit American Fisheries Society: Fund Raising Chair
2003-2004 Palouse Unit American Fisheries Society: President
2002-2003 Palouse Unit American Fisheries Society: Education Committee Chair

Reviewer for: *Aquatic Conservation, Fisheries Ecology and Management, Ecological Application, Fisheries, Ecology of Freshwater Fish, Ohio Sea Grant, Fisheries Research, Environmental Monitoring and Assessment, North American Journal of Fish Management, Transactions of the American Fisheries Society, Inland Fisheries Management (Third Edition), Hydrobiologia, Journal of Fish and Wildlife Management, Springer Online, Canadian Journal of Fisheries and Aquatic Sciences, Turkish Journal of Fisheries and Aquatic Sciences, PLOS One, Fish and Fisheries, Nature Science Communications.*

Professional affiliations

American Fisheries Society (2002- present)
- Education Section (2007-present)
- Student Section (2007-2012)
- Fisheries Information and Technology Section (2007-2012)
- Western Division (2002-2007)
- Oregon Chapter (2005-present)
- Idaho Chapter (2002-2005)
- Palouse Student Unit (2002-2005)
- North Central Division (2007-2012)
- Iowa Chapter (2007-2012)
- Iowa State University Student Unit (2007-2012)

North American Benthological Society (2008-2010)

Ecological Society of America (2010-pres.)
- Aquatic Ecology Section (2010-pres.)
- Student Section (2010-2010)

Continuing Education, training, and certifications

- Hazardous Waste (Completed September 2016)
- Classroom Strategy Series: Active Participation Strategies (Completed September 2016)
- Teaching Online: Alternatives to the Fifty-Minute Lecture in Online Classes (Completed September 2016)
- RCR for PIs via myCourses (Completed September 2016)
- Responsible Conduct of Research via CITI (Completed September 2016)
- Working With Fish in Research Settings - Lab Animal Research (Completed September 2016)
- Title IX and Haven Part I (Completed September 2016)
- Perception, Visualization, Cognition, Learning in Sciences (Completed January 2016)
- Information Security Privacy Training (Completed January 2016)
- Financial Conflict of Interest (Completed October 2015)
- Instructors Tool Kit Developing a Good Syllabus (Completed January 2015)
- Occupational Health and Safety (Completed October 2014)
- Animal User Certification (Completed October 2014)
- RCR Live Session - Data Management (Completed October 2014)
- First Aid with CPR/AED adult and child (Completed June 2013)
- Open water SCUBA diver (Completed December 2008)
- Department of the Interior Motorboat Operator Certification Course (Completed June 2008)

LYNNE Y. LEWIS

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ACADEMIC POSITIONS

Current:
Elmer W. Campbell Professor of Economics, 2015-
Department of Economics, Bates College

Professor of Economics and Department Chair 2007-2015
Department of Economics, Bates College

Associate Professor of Economics 2000-2007
Department of Economics, Bates College

Assistant Professor of Natural Resource Economics
Yale University School of Forestry and Environmental Studies, 1994-2000

AWARDS & ACADEMIC HONORS

Association of Environmental and Resource Economists Board of Directors, Nov 2018-Dec 2021..
Named the Elmer W. Campbell '27 Chair of Economics, April 2012
Friend of UCOWR Award, July 2005
Board of Directors of Universities Council on Water Resources, 1999-2005
NSF/Lucent Technologies Research Fellowship Award, 1997-1999
Association of Environmental and Resource Economists Travel Fellowship Award, 1998
Universities Council on Water Resources Outstanding Dissertation Award, 1995
National Center for Atmospheric Research Dissertation Fellowship, 1992-1994
Morris E. Garnsey Fellowship, 1992

EDUCATION

Ph.D in Economics. University of Colorado at Boulder, 1994

B.A. in International Affairs, University of Colorado at Boulder

FUNDED PI RESEARCH AND TEACHING DEVELOPMENT SUPPORT

Water Resources Research Institute Grant "20 years of River Restoration in Maine." $26,402. June 2020-March 2021.

Faculty Development Grant for conference presentations: $4,400, May 2018.

Phillips Fellowship – sabbatical fellowship awarded for Academic Year 2014-15, "Estimating the Socio-Economic Impacts of Climate Change: Mapping Vulnerabilities and Building Community Resilience in the Face of Rapid Glacier Melt and Glacial Lake Outburst Floods."

EPSCoR/NSF Award #EPS-0904155 YR5 (September 2013-July 2014) project for *"Ecological and Economic Recovery and Sustainability of the Kennebec and Androscoggin Rivers"* $63,725 with Bev Johnson.

EPSCoR/NSF Award #EPS-0904155 year 4, $52,225, with Bev Johnson.

EPSCoR/NSF Award #EPS-0904155, $165,000 for years 1-3 Maine's Sustainability Science Initiative. September 2009-September 2013 – with Bev Johnson. **(year 3: 2011-2012 grant = $54,974,

National Science Foundation, Participating as Senior Personnel on Collaborative Research Award to Philip Brown, Colby College ($162,641), Darin Magee, Hobart and William Smith Colleges ($90,470), and Desiree Tullos, Oregon State University ($494,967), *Interdisciplinary Research and Methods for Assessing Dams as Agents of Change in China*. 2008-2011.

Incoporating Stakeholder Values into River Restoration Decisions, PI, Co-PI: Kathleen Bell. Water Resources Research Institute, USGS, $26,000. March 2008 – July 2010.

Bates Faculty Development Award, January 2010, $2,350.

Harward Center Publically Engaged Academic Projects, PI, $6,000. 2009.

"The Androscoggin River: A Living Laboratory. Renewal," with Faculty at Colby, Bates and Bowdoin, August 2008-August 2009, $7,200.

Faculty Development Grant, Bates, College, $2,150. 2008.

Capacity Building for Sustainable Governance in the GEF International Waters Portfolio PIMS no.3799.

The Androscoggin River: A Socio-Economic Inventory, PI, Harward Center for Community Partnerships Grant, 2006-2007, $7000.

Faculty Development Grants, Bates College, 2006-2007.

Valuing Environmental Changes for Decision Making: Dam Removal and Restoration on the Penobscot and Kennebec Rivers, PI, Water Resources Research Institute, Mitchell Center for Environmental and Watershed Research, Funded for 2005-2006, $23,452.

Pearson Education, Inc. Authored Instructor's Manuals for Tom Tietenberg's *Environmental and Natural Resource Economics* and *Environmental Economics and Policy*. Also assisted with revisions for new textbook edition. Have signed contract to phase-in as co-author of upcoming editions.

Karl Mills Grant for participating in the Seminar on Reflections in the Liberal Arts, 2003-2004, $1,000.

Karl Mills Grant to design new interdisciplinary course on Environmental Valuation. $10,000. With Frank Chessa.

"Management of River Basins Through Decentralization, "Consultancy with the World Bank, 2001.

LADD Grant, Bates College, with Maggie Maurer-Fazio and Francesco Duina, $5,000, 2001.

"Connecting Ecological and Social Systems: Watershed Research Relating Ecosystem Structure and Function to Human Values and Socioeconomic Behaviors," Co-PI with Stephen Kellert, Gaboury Benoit, Mark Ashton, David Skelly and Paul Barten (NSF/EPA: $795,000), 1997-1999.

"Connecting Ecological and Social Systems: Watershed Research Relating Ecosystem Structure and Function to Human Values and Socioeconomic Behaviors," Co-PI with Stephen Kellert (CT Sea Grant: $97,439), 1997-1999.

"Modeling the Industrial Ecosystem," Co-PI with Thomas Graedel and Oswald Schmitz, (NSF and Lucent Technologies: $100,000), 1997-1999.

"Effects of the Clean Air Act Amendments on Water Quality—812 Project," consultancy with Industrial Economics, Inc, 1998.

"Effluent Trading in the Quinnipiac River Watershed: An Experimental Market," Principal Investigator (The Geoffrey C. Hughes Foundation: $19,550), 1997.

"Estimating the Effects of Water Rate Increases on Residential Customers," Principal Investigator (S. Connecticut Regional Water Authority ($10,000), 1995-1996.

"Urban Water Supply Reliability: Planning Procedures and Survey Techniques. Charles W. Howe, Principal Investigator, Environment and Behavior Program and Department of Economics, University of Colorado, 1989-1991.

RESEARCH & PUBLICATIONS

Books and Edited Volumes

Tietenberg, Tom and Lynne Lewis. *Environmental and Natural Resource Economics,* 12th Edition, Taylor and Francis, *forthcoming winter 2022.*

Lynne Lewis and Tom Tietenberg. *Environmental Economics and Policy,* 7th Edition. Routledge, *January 2020*.

Tietenberg, Tom and Lynne Lewis. *Environmental Economics: The Essentials.,* Routledge, Taylor and Francis Group, *2020.*

Tietenberg, Tom and Lynne Lewis. *Natural Resource Economics: The Essentials.,* Routledge, Taylor and Francis Group, *2020.*

Tietenberg, Tom and Lynne Lewis. *Environmental and Natural Resource Economics,* 11th Edition, Taylor and Francis, *February 2018*

Tietenberg, Tom and Lynne Lewis. *Environmental and Natural Resource Economics,* 10th Edition, Pearson, *2014*.

Tietenberg, Tom and Lynne Lewis. *Environmental and Natural Resource Economics,* 9th Edition, Pearson, 2012.

Tietenberg, Tom and Lynne Lewis. *Environmental and Natural Resource Economics,* 8th Edition, Addison-Wesley Publishers, 2009

Tietenberg, Tom and Lynne Lewis. *Environmental Economics and Policy,* 6th Edition. Addison-Wesley Publishers, 2010.

"River and Lake Restoration: Changing Landscapes," *Journal of Contemporary Water Research and Education,* Issue 134, July 2006. Issue Editor.

Refereed Articles and Book Chapters – published and submitted

"Diversity in Environmental and Resource Economics" with Nicolai V. Kuminoff, Katherine Ciaramello, Hanna M. Dooley, Martin Heintzelman, Neha Khanna, Lea-Rachel Kosnik, Lynne Lewis, and Eric Trimble. Under review at *Review of Environmental Economics and Policy.*

"What *should* we be teaching students about the economics of climate change: Is there a consensus?"with Casey Wichman. Under review at *Int Rev of Environmental and Resource Economics*"

Preservation Values for an Individual Animal: Does Webcam Viewing Influence Willingness to Pay for Conservation? With Leslie Richardson. *Under Revision for AJAE*

"Rethinking Hydropower:: The Economics and Politics of Privately Owned Hydropower in the United States" 2020., *Oxford Encyclopedia of Water Resources Management and Policy.*

Timothy C. Haab, Lynne Y. Lewis and John C. Whitehead, "State of the Art of Contingent Valuation," Revision *Oxford Research Encyclopedia of Environmental Science* Haab, T., Lewis, L., & Whitehead, J. (2020). State of the Art of Contingent Valuation. In *Oxford Research Encyclopedia of Environmental Science*.

"Aligning economic and ecological priorities: conflicts, complementarities, and regulatory frictions," with Guillermo Hererra and Keith Evans, *Agriculture and Resource Economics Review*. August2017.

"River Restoration and Hedonic Property Value Analyses: Guidance for Effective Benefit Transfer." With Craig Landry. *Water Resources and Economics*. Vol 85. 13-Apr-2017
DOI information: 10.1016/j.wre.2017.02.001

"The Cost of Revenue Stability: Water Pricing During Severe Drought" with Amy Schmidt. *Journal of Contemporary Water Research and Education*, special issue highlighting undergraduate research. Issue 160. April 2017.

"The Disappearing Environmental Kuznets Curve: A Study of Water Quality in the Lower Mekong Basin," with Yoon Loon (Andrew) Wong (Bates Economics '12), in *Journal of Environmental Management* October 2012.

"Environmental and Natural Resource Economics: Teaching the Major and Non-Majors Simultaneously" *January 2012* in International Handbook on Teaching and Learning Economics (Hoyt and McGoldrick, Editors), Elgar Press.

"A "Virtual" Field Trip to the Real World of Cap and Trade: Environmental Economics and the EPA SO_2 Allowance Auction" *Journal of Economic Education*, 42:4, Fall 2011.

"Examining the Economic Impacts of Hydropower Dams on Property Values Using GIS," (with Curtis Bohlen) *Journal of Environmental Management*. December 2009.

"Demolish it and They will Come: Dam Removal and the *Ex-post* measurement of Fisheries Benefits," (with Jesse Robbins (Bates '06. *Journal of the American Water Resources Association* 44(6) December 2008.

"Dams, Dam Removal and River Restoration: A Hedonic Property Value Analysis," (with Curtis Bohlen and Sarah Wilson (Bates '06)). *Contemporary Economic Policy.* April 2008.

"Environmental Quality and Housing Market: Does Lot Size Matter?" (with G. Acharya), *Marine Resource Economics,* 21, 317-330. 2006.

"River and Lake Restoration: Changing Landscapes – An Introduction," *Journal of Contemporary Water Research and Education,* Issue 134, July 2006.

"Interstate River Compacts of the West?" *Water Allocation in the Southeast: New Issues, New Methods, New Models*, (Jordan and Wolf, Eds.) University Press of Florida, 2006.

"The Value of Water Supply Reliability in Urban Water Systems," (with Charles W. Howe, Mark G. Smith, et al.) *Economics of Water Resources: Institutions, Instruments and Policies for Managing Scarcity*,(K. William Easter and Mary Renwick, Editors), Ashgate, February 2004.
reprinted from *Journal of Environmental Economics and Management*, 26, 19-30, 1994.

"Valuing Open Space and Land Use Chaos in Urban Watersheds: An Hedonic Property Value Analysis," (with G. Acharya) *Journal of Real Estate Economics and Finance*.22:2/3, 221-237. 2001.

"Interstate River Compacts: Incentives for Noncompliance," (with C.W. Howe) *Conflict Prevention and Resolution in Water Systems* (Aaron Wolf, Ed), Edward Elgar, November 2001, reprinted from *Water Resources Research*, 34(3), 485-495, March 1998.

"Complexities with Transboundary Water Resource Management: Progress and Stumbling Blocks," (Editor) *Water Resources Update*, 2001.

"The Integration of Water Quality into Transboundary Allocation Agreements: Lessons from the Southwestern United States," *Agricultural Economics* 24, 113-125, 2000.

"Cost-Effective Control of Nitrogen Loadings in Long Island Sound," (with S. Thorpe and A.J. Guse) *Water Resources Research* 36(12), 3711-3720, December 2000.

"The Interstate River Compact as a Water Allocation Mechanism: Efficiency Aspects," (with C.W. Howe and J.S. Shope) *American Journal of Agricultural Economics*, November 2000.

"The Cost of Noncompliance: The Economic Value of Water in the Middle Arkansas Valley," (with R. Naeser) *Natural Resources Journal*, 38(3), 445-463, Summer 1998.

"Interstate River Compacts: Incentives for Noncompliance," (with C.W. Howe) *Water Resources Research*, 34(3), 485-495, March 1998.

"The Impact of Global Warming on Water Systems: Theoretical Issues," (with R. Mendelsohn) *Climatic Change* 37, 271-290, 1997.

Also reprinted in "Climate Change and Water Resources Planning Criteria" (Frederick, Major, and Stakhiv, Eds.), Kluwer, 1997.

"Facilitating International Agreements Through an Interconnected Game Approach: The Case of River Basins," (with S. Ragland and P. Yolles) *Conflict and Cooperation on Trans-Boundary Water Resources* (Just and Netanyahu, Eds.), Kluwer, 61-85, 1997.

"The Arkansas River Compact: Integrated Watershed Management as a Means of Conflict Prevention," (with R. Naeser) in *Water Resources Education, Training and Practice: Opportunities for the Next Century* (Warwick, Ed.), Symposium Proc. AWRA/UCOWR, 723-732, 1997.

"Design and Analysis of Contingent Valuation Surveys Using the Nested Tobit Model," (with C.W. Howe and B.J. Lee) *Review of Economics and Statistics*, 385-389, 1994.

"The Value of Water Supply Reliability in Urban Water Systems," (with Charles W. Howe, Mark G. Smith, et al.) *Journal of Environmental Economics and Management*, 26, 19-30, 1994.

In Prep/Working papers/Current Projects

Big Solutions Contributor at Anything but Dismal at https://www.anythingbutdismal.com/

"The Charisma Premium: Iconic Individuals and Wildlife Values" With Christoper Costello, John Lynham and Leslie Richardson.

"On-line wildlife cam viewing: the impact of the pandemic." With Leslie Richardson.

Special Issue Editor for IWREC on teaching environmental economics

"Dam Removal, Hedonic Analysis and Benefit Transfer: What have we learned" with Craig Landry and Ben Wilson.

"2nd Stage Hedonic Analysis" with Craig Landry.

"Spatial variation in stated willingness to pay for river restoration" Guillermo Herrera and BoRa Kim, *In prep*.

"Dynamic land use under uncertainty and constrained choice" with Jordan Suter and Sahan T. M.

Dissanayake *draft*

Who Gives a Dam?: Taking stock of public support for river restoration" with Kathleen Bell W*orking Paper*.

Other Publications

"Live Animal Cam Viewing: Survey of Katmai National Park Bearcam Viewers 2019 and 2020." With Mike Fitz, Jeffrey Skibins and Leslie Richardson." Final Report submitted to explore.or

"Water Quality," in *Environmental and Natural Resource Economics: An Enclyclopedia*. (Timothy Haab and John C. Whitehead, Editors), Greenwood Press, June 2014.

"Valuation in a bubble: hedonic modeling pre- and post-housing market collapse" (with Kevin Boyle, Jaren Pope and Jeffrey Zabel), *Association of Environmental and Resource Economists Fall Newsletter*, Novemer 2012.

"Environmental Economics: It's not an oxymoron anymore?" *Newsletter of the Committee on the Status of Women in the Economics Profession*, Spring/Summer 2010, p. 4-5.

Instructor's Manual to Accompany Environmental Economics and Policy, 5th Edition (T. Tietenberg 2006) http://www.aw-bc.com/catalog/academic/product/0,1144,0321348907-IS,00.html June 2006.

Instructor's Manual to Accompany Environmental and Natural Resource Economics, 7th Edition. (T. Tietenberg 2005), June 2005

Instructor's Manual to Accompany Environmental Economics and Policy, 4th Edition (T. Tietenberg 2004),

Instructor's Manual to Accompany Environmental and Natural Resource Economics (T. Tietenberg 2002), January 2003.

Instructor's Manual to Accompany Environmental Economics and Policy (T. Tietenberg 2000), January 2001. http://occ.awlonline.com/bookbind/pubbooks/tietenberg_eep3_awl/chapter98/deluxe.html.

"Land Use Diversity and Urban Watersheds: The Case of New Haven County," (with G. Acharya) Proceedings of the 1999 W-133 resource economics meetings.

"Economic Considerations of the Restoration of a Tidal Salt Marsh: The Case of the West River," (with M. Udziela) in *Restoration of an Urban Salt Marsh: An Interdisciplinary Approach* (David Casagrande, Ed.), Yale University School of Forestry and Environmental Studies Bulletin Series, No. 100, 1997.

"Unidirectional Problems with International River Basins: A Game Theoretic Approach," (with S. Ragland and P. Yolles) in Proceedings of *Water: A Trigger for Conflict/Reason for Cooperation,* 1996.

"The Economics of Interstate River Compacts: Efficiency, Compliance and Climate Change," National Center for Atmospheric Research, NCAR/CT-151, 1994.

"Foreign Threats and Domestic Actions: The Case of Sanctions Against South Africa," (with W. H. Kaempfer, A. D. Lowenberg and H. Naci) in *Justice Without Violence*, (Wehr, Burgess, and Burgess, Eds.), Lynne Rienner Publishers, 1993.

Completion Reports

"Valuing Environmental Changes for Decision Making: Dam Removal and Restoration on the Penboscot and Kennebec Rivers," Report Submitted to the George J. Mitchell Center for Environmental and Watershed Research, June 2006.

"Effluent Trading for Quinnipiac River Nitrogen Control: Simulation Analysis," completion report for the Geoffrey C. Hughes Foundation, Inc. 1999.

"Estimating the Benefits of Decreased Nitrogen Deposition into Estuaries in the United States Due to Air Quality Improvements Attributable to the CAAA: A Marginal Cost and Avoided Cost Analysis," completion report submitted to Industrial Economics, Inc., July 1998.

"Estimated Impacts of Proposed Rate Increases on Residential Water Demand for Customers Served by the South Central Connecticut Regional Water Authority," completion report for the South Central Regional Water Authority, June 1996.

"Incorporating Public Preferences in the Optimization of Urban Water Supply Reliability: Planning Procedures and Survey Techniques," (with Charles W. Howe, et al.), completion report for the U.S. Geological Survey, December 1991.

"Urban Water Supply Reliability: Preferences of Managers, Elected Officials, and Water Users in Boulder, Colorado," (with Charles W. Howe, et al.), Colorado Water Resources Research Institute Report No. 158, December 1990.

Book Review

Review of *Classic Papers In Natural Resource Economics* (Gopalakrishnan, Ed.), MacMillan Press.

Review of "Water Quantity/Quality Management and Conflict Resolution" (Dinar and Loehman, Eds.). In *The Forum.*

SELECTED CONFERENCE/SEMINAR PRESENTATIONS

Preservation Values for an Individual Animal: Does Webcam Viewing Influence Willingness to Pay for Conservation? With Leslie Richardson. *Presented at:*

Southern Economics Association AERE session, November 2019
W4133 Nonmarket Valuation Meeting, February 2020
AERE virtual conference June 2020

"Hedonic Analysis, the Second Stage," Presented at the Southern Economics Association Annual Meeting, November 2018.

"Dam Removal, Hedonic Analysis and Benefit Transfer: What have we learned" W4133 Nonmarket Valuation Workshop. February 2018. UNH Department of Economics Seminar. April 2018.

"Dam Removal, Hedonic Analysis and Benefit Transfer: What have we learned" W4133 Nonmarket Valuation Workshop. February 2018.

"The Cost of Revenue Stability: Water Pricing During Severe Drought" with Amy Schmidt (Bates '16). UCOWR annual meeting June 2017.

"River Restoration and Hedonic Property Value Analyses: Guidance for Effective Benefit Transfer and Environmental Policy." Invited Presentation. Southern Denmark University, June 2017.

"River Restoration and Hedonic Property Value Analyses: Guidance for Effective Benefit Transfer." Southern Economic Association, November 2016.

"Spatial variation in stated willingness to pay for river restoration." AERE annual conference. June 2015.

"Who Gives a Dam? When Environmental Economics and Economic Hydrology Collide" Presentation for Elmer W. Campbell Chair, February 2014.

Panel Presentation: Participant in "What Economists Think", Southern Economic Association Meetings 2013.

Willingness to Pay for Anadromous Fisheries Restoration: Distance Decay and River Reputation, with Lindsay Thompson (ES '12) and Guillermo Herrera, presented at the 3rd Annual AERE conference, June 2013.

Panel participation: "Hedonic Prices pre- and post- housing market bubble." 2nd Annual AERE conference, Asheville, NC, June 2012.

"Including the Public in Dam Removal Debates: Using Stated Preference Surveys," Presentation at the International Water Resource Economics Consortium, Banff, Canada, June 2011.

"Dam Removal and Benefits Transfer: If you've seen one, have you seen them all?" Presentation and

Session Organizer at the World Congress of Environmental and Resource Economists, Montreal, June 27-July2 2010.

Invited Speaker for "The Economics for Evaluating Water/Energy Interactions for Policy," Decision Center for a Desert City and Center for Environmental Economics and Sustainability, Arizona State University, April 2010.

Program Committee and Moderator, Northeast Association of Agricultural and Resource Economists, June 2010.

NAAFE Forum, Newport, RI, May 2009.

Invited Plenary Speaker for Goodwin-Niering Center on Conservation Biology and Environmental Studies Annual Environmental Symposium, "Water Scarcity and Conflict," April 2009. Connecticut College.

"A Field Trip to the Real World: Environmental Economics and the EPA SO_2Auction" Presented at the Southern Economics Association Meetings, November 2008.

"Do Benefits Really Transfer? A Fish Tale Across 3 Rivers," presented at the CU Environmental Economics Workshop, September 2008, and the Southern Economics Association Meetings, November 2008.

"Environmental Economics: Oxymoron or the New Reality?" Faculty Symposium, Parents Weekend, Bates College, October 2008.

"Hedonic Property Value Models and River Restoration, CSWEP session at the Southern Economics Association Annual Meetings November 2007.

Keynote Speaker for the Global Water Project's Annual Workshop, University of New Hampshire, May 2007.

"Dams, Dam Removal and River Restoration: A Socio-economic Analysis," Presentation at Dam Modeling Symposium, Washington, April 2007.

Invited Seminar Speaker. Water Resources Research Center Seminar Series, University of Hawaii. Presentation scheduled for March 15, 2007.

Harward Center for Community Partnerships' Public Works In Progress Seminar Series. Presentation Scheduled for February 13, 2007.

Invited Speaker at Women in Economics Forum, University of Colorado, October 2006.

Invited Participant for International Water Expert Consultation Workshop Vancouver, British Columbia, July 2006.

Invited Participant for Panel on Building Collaboratories, Campus Compact Conference, April 2006.

"Experimental Education for Undergraduates: Getting Non-science Students into the Field," Panel Discussion at the UCOWR Annual Conference, Portland, ME 2005.

Committee on the Status of Women in the Economics Profession, Invited Mentor for Workshop, Southern Economics Association, November, 2005.

Allocating Water: Economics and the Environment. Panel presentation on the Columbia River Treaty, July 2004.

Water Security in the 21st Century, UCOWR Annual Conference, Moderator for Plenary session, a breakout session and presented Warren Hall Medal award, July 2003

University of Maine at Orono, Department of Resource Economics and Policy Seminar Series, Presented, "Spatial Components of Environmental Quality: Watersheds and Housing Markets, April 2003.

Maine Rivers Conference: Invited Presentation, "The Value of Water," Bethel, Maine, May 2002

September 2002. Planning Committee for Integrated Transboundary Water Management, UCOWR sponsored, 2002.

Symposium on Climate, Water and Transboundary Challenges in the Americas, UCSB, Presented "Climate Variability and the Interstate River Compact: When will the Compact Fail?," July 2000.

University of Rhode Island, Department of Agricultural and Resource Economics Seminar Series. Presented "Understanding Environmental Preferences in the New Haven Watershed," September 1999.

Universities Council on Water Resources and International Water Economics Consortium annual meeting. Presented two papers and chaired two sessions, June 1999.

University of New Hampshire, Department of Economics Seminar Series. Presented "Valuing Open Space and Land Use Chaos in Urban Watersheds: An Hedonic Property Value Analysis," April 1999.

Committee on the Status of Women in the Economics Profession, CCOFFE workshop, Eastern Economics Association annual meeting, March 1999.

W-133 annual meeting. Presented "Land Use Diversity and Urban Watersheds: The Case of New Haven County," February 1999.

Connecticut State Legislature Opening Session. Moderated a panel on nitrogen trading programs for Long Island Sound. 1998

Southern Economics Association annual meeting. Chaired a SAPPCREE session on water quality and presented "Cross-Media Trading Possibilities for Water Quality," November 1998.

Organized, hosted, and conducted workshop on Permit Trading Possibilities for Long Island Sound. Presented computer simulation of permit market. Yale University School of Forestry and Environmental Studies, October 1998.

Universities Council on Water Resources annual meeting. Presented "The Design of Water Allocation Mechanisms: The Case of the Interstate River Compact," August, 1998.

World Congress of Environmental and Resource Economists. Joint meeting of European Association of Environmental and Resource Economists and Association of Environmental and Resource Economists. Presented, June 1998.

Southern Economics Association annual meeting. Invited panelist for SAPPCREE session on "Teaching Environmental and Natural Resource Economics," Atlanta, November, 1997.

AWRA/UCOWR annual meeting. Presented, June 1997.

University of Hawaii, Department of Economics Seminar Series. Presented, April 1997.

Fifth Annual International Water and Resource Economics Consortium, Annapolis. Presented, April 1997.

Twenty-eighth Annual Symposium on International Relations, *Troubled Water: An Impending Global Crisis*, Invited Panelist, League of Women Voters of Connecticut Education Fund and Yale University Center for International Area Studies, March 1997.

European Association of Environmental and Resource Economists annual meeting, Lisbon. Presented and discussed paper, June 1996.

University of Massachussetts, Department of Agriculture and Natural Resources Seminar Series, May 1996.

Water: A Trigger for Conflict/Reason for Cooperation, Indiana University. Presented, March 1996.

ASSA meetings, AERE session. Presented, January 1993.

TEACHING DEVELOPMENT

Short Term Course Redesign. Coastal Adaptation to Climate Change with Bev Johnson. 2018.

Faculty Commons Training on Learning Goals.

New course on the Economics of Tourism and Ecotourism, Short Term 2011.

Committee on the Status of Women in the Economics Profession (CSWEP) mentor for Junior Faculty in Economics, Nov. 2005.

Seminar on *Reflection in the Liberal Arts* participant, 2003-2004.

Received Karl Mills Grant for interdisciplinary course development. Course entitled, *Valuation: Ethics and Economics in Practice*, with Frank Chessa, Philosophy, Summer 2001.

CCOFFE Participant: NSF funded mentoring workshop for junior faculty. Participated as a mentee, 1999.

Invited panelist. *Teaching Environmental and Natural Resource Economics*. Southern Economics Association annual meeting, Atlanta, 1997.

PROFESSIONAL SERVICE

Bates College

Co-Chair, College Reaccreditation, Standard 6, Teaching Learning and Scholarship, 2018-2020
Faculty Governance Review Committee: 2019-2021
Faculty Advisor to WE@Bates (Women in Economics group)
Teaching and Learning Committee 2016-
Otis Committee 2016-
Environmental Studies Committee, 2000-present
Committee on Faculty Governance 2010-2015 (co-chair 2012-2014)
Chair, Department of Economics, 2007-2014
Athletics Committee, 2011-2012
Sustainable Foods Committee 2008-2009
College Lectures Committee, 2007-2008
Bates Education Committee, 2005-2006
Elected to Coordinating Committee for General Education Reform, 2004-2005
Educational Policy Committee 2002-2004
Mellon Fellow Faculty Sponsor, Winter 2002
Honors Committee, 2001-2004
Presidential Inauguration Committee, May 2002-October 2002.
Presentation to Trustees on new interdisciplinary course and Karl Mills Grant

Association of Environmental and Resource Economists (AERE)

Board of Directors, Elected Nov 2018: 2018-2021

Outside Bates for Other Colleges

External Reviewer – Clarement McKenna
External Reviewer – Tenure, Trinity University
External Reviewer – Promotion, University of Missouri
External Review - William and Mary, Environmental Policy Program, January 2019.
External Reviewer – Tenure review, Colorado State University.
External Review – Environmental Studies Program, Connecticut College. March 2017.
External Reviewer - Tenure case, Boston College, 2014
External reviewer - Tenure case at Oberlin, September 2012
External reviewer - Promotion case at Fairfield University, September 2012
Maine Water Conference, Chair of Student Poster Competition and Poster Judge, March 2012, 2018.
External reviewer - Tenure case at Pomona College, Summer 2011

Universities Council of Water Resources (UCOWR)

Board of Directors, 1999-2005
Guest Editor, *Journal of Contemporary Water Research and Education*, July 2006
2005 Annual Meeting Program Chair
2004 Annual Meeting Program Committee
2002 Annual Meeting Organizing Committee
Guest Editor, *Water Resources Bulletin,* spring 2000-2001
Editorial Board, *Water Resources Bulletin*
Lead delegate, 1996-present
Dissertation Awards Committee, 1999

Maine Audubon

Board of Directors, June 2010-2019

Natural Resources Council of Maine (NRCM)
Board of Directors, September 2003-October 2010

Senator George Mitchell Center for the Environment and Watershed Research, University of Maine
Research Advisory Board 2005-2011

Maine Ultimate
Board of Directors. Sept 2016-

Penobscot Science Steering Committtee
Human Dimensions Representative
2006-2010

Androscoggin River Valley Watershed Council
Steering Committee, 2002-2006

Have served as Referee for:

Land Economics
Review of Environmental Economics and Policy
Water Resources and Economics
Marine Resource Economics
National Science Foundation – review panel May 2013 and May 2014
Water Resources Research
Contemporary Economic Policy
Land Use Policy
Journal of Economic Education
Landscape and Urban Planning
Journal of the American Water Resources Association
Journal of Environmental Economics and Management
Journal of Environmental Management
American Journal of Agricultural Economics
Resource and Energy Economics
Environmental Management
South-Western Publishing
Dryden Press
Natural Resources Council
U.S. EPA
New Hampshire Sea Grant
Delaware Sea Grant
Industrial Economics, Inc.
Mountain Institute
NOAA

Professional Affiliations

Association of Environmental and Resource Economists (AERE)
Universities Council on Water Resources (UCOWR)
Committee on the Status of Women in the Economics Profession (CSWEP)
Natural Resources Council of Maine (NRCM)
Northeast Agriculture and Resource Economics Association (NAREA)
American Economic Association (AEA)

Community Service

Faculty Liaison/coach to Bates Women's Ultimate Frisbee Team 2005-present.
Faculty Liaison to Bates Men's Lacrosse. 2007-2015.
Volunteer for the Animal Refuge League of Greater Portland, September 2000-present.
Volunteer Business Manager for CoolestGame2002, video project fundraising for youth ultimate.

Ben Livneh, Ph.D.
Assistant Professor, Department of Civil, Environmental, and Architectural Engineering (CEAE)
Fellow, Cooperative Institute for Research in Environmental Sciences (CIRES)
University of Colorado, Boulder

EDUCATION

Ph.D. Civil and Environmental Engineering, University of Washington, 2012
Advisor: Dr. Dennis Lettenmaier
M.E.Sc. Civil and Environmental Engineering, University of Western Ontario, 2006
Advisor: Dr. M. Hesham El Naggar
B.E.Sc. Civil and Environmental Engineering, University of Western Ontario, 2004

POSITIONS HELD

2015-	Assistant Professor, CEAE and CIRES Fellow, CU-Boulder.
2014-2015	CIRES Research Scientist II, CU-Boulder.
2013, 2014	Lecturer, CEAE, CU-Boulder.
2013-2014	CIRES Research Scientist I, CU-Boulder.
2012-2013	CIRES Visiting Fellow, CU-Boulder.
2008,2010,2011	Adjunct Professor, Civil and Environmental Engineering, Seattle University.
2006-2012	Research Assistant, Land Surface Hydrology Group, University of Washington.
2006	Design and CAD Engineer, Lican Developments, Windsor, ON.
2003-2006	V.P. Sales and Engineering, Univercycle Recycling Co., Windsor, ON, Jiang Ying, China.
2004-2006	Graduate Teaching Assistant, Civil and Environmental Engineering, Univ. of Western Ontario
2002	Engineer Assistant, Quality Engineering Company, Southfield, MI, USA.
2001	Event Manager, Canada Summer Games, London, ON.

AWARDS

2020	Young Researcher Award, *Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder*
2018	New (Early Career) Investigator Award in Earth Sciences, *NASA*
2017	Ralph E. Power Junior Faculty Enhancement Award*, Oak Ridge Associated Universities*
2012	CIRES Visiting Postdoctoral Fellowship Award.

REFEREED JOURNAL PUBLICATIONS

Underline denotes a CU graduate student, *italicized underline* denotes a CU undergraduate student, and *asterisk denotes a CU postdoctoral scientist advised by B. Livneh.

In my field, the order of authorship reflects degree of contribution, with the exception that in some cases the last author often oversees the research or is the project PI.

As of Nov, 2019 an H-Index of 23 (Web of Knowledge), 27 (Google Scholar), with 2083 total citations (Web of Knowledge) and 3064 (Google Scholar).

Abolafia-Rosenzweig, R., M. Pan, *J.L. Zeng*, and **B. Livneh**, **2021**: A remotely sensed ensemble to observe the terrestrial water budget over major global river basins, *Remote Sensing of Environment*, 252, 112191, https://doi.org/10.1016/j.rse.2020.112191.

Abolafia-Rosenzweig, R., *A.M. Badger, E.E. Small, and **B. Livneh**, **2020**: A Continental-scale Soil Evaporation Dataset Derived from Soil Moisture Active Passive Satellite Drying Rates, *Scientific Data*, 7(1), 1-10, https://doi.org/10.1038/s41597-020-00748-z.

Barsugli, J. J., A. Ray, **B. Livneh**, C. Dewes, A. Heldmyer, I. Rangwala, J. Guinnotte, and S. Torbit, **2020**: Projections of mountain snowpack loss for wolverine denning elevations in the Rocky Mountains, *Earth's Future,* 8(10), https://doi.org/10.1029/2020EF001537.

Wang, G., C. Kirchhoff, A. Seth, J. T. Abatzoglou, **B. Livneh**, D. W. Pierce, L. Fomenko, and T. Ding, **2020**: Projected Changes of Precipitation Characteristics Depend on Downscaling Method and Training Data: the U.S. Northeast as an Example, *Journal of Hydrometeorology*, 1-55, https://doi.org/10.1175/JHM-D-19-0275.1.

Kumar, S., M.N. Newman, D.M., Lawrence, M-H. Lo, S. Akula, C-W., Lan, **B. Livneh**, and D. Lombardozzi, **2020**: The GLACE-Hydrology Experiment: Effects of Land-Atmosphere Coupling on Soil, *Journal of Climate,* 33(15), 6511–6529, https://doi.org/10.1175/JCLI-D-19-0598.1.

Kampf, S., B. Gannon, C. Wilson, F. Saavedra, M. E. Miller, A. Heldmyer, **B. Livneh**, P. Nelson, and L. MacDonald, **2020**: PEMIP: Post-fire Erosion Model Inter-comparison Project, *Journal of Environmental Management*, 268, https://doi.org/10.1016/j.jenvman.2020.110704.

Livneh, B., and *A.M. Badger, **2020**: Drought less predictable under declining future snowpack, *Nature Climate Change*, 10, 452–458, https://doi.org/10.1038/s41558-020-0754-8.

Williams, A.P., E.R. Cook, J.E. Smerdon, B.I. Cook, R. Seager, J.T. Abatzoglou, K. Bolles, S.H. Baek, *A. Badger, and **B. Livneh**, **2020**: Large contribution from anthropogenic warming to an emerging North American megadrought, *Science*, 368(6488), 314-318, https://doi.org/10.1126/science.aaz9600.

Steinberg, D., B.K. Mignone, J. Macknick, Y. Sun, K. Eurek, *Badger, A.M., **B. Livneh,** and K.B. Averyt, **2020:** Decomposing supply-side and demand-side impacts of climate change on the U.S. electricity system through 2050, *Climatic Change,* 158(2), 125-139, https://doi.org/10.1007/s10584-019-02506-6.

Abolafia-Rosenzweig, R., **Livneh, B.**, Small, E. E., & Kumar, S. V., **2019**: Soil moisture data assimilation to estimate irrigation water use. *Journal of Advances in Modeling Earth Systems*, 11, https://doi.org/10.1029/2019MS001797.

Hoerling, M.P., J.J. Barsugli, **B. Livneh**, J. Eischeid, X. Quan, and *A. M. Badger, **2019**: Causes for the Century-Long Decline in Colorado River Flow, *Journal of Climate*, 32, 8181-8203, https://doi.org/10.1175/JCLI-D-19-0207.1.

Kumar, S., Newman, M.N, Wang Y., and **B. Livneh**, **2019**: Potential Reemergence of Seasonal Soil Moisture Anomalies in North America, *Journal of Climate,* 32(8), https://doi.org/10.1175/JCLI-D-18-0540.1.

Morrill, C., E. Meador, **B. Livneh**, D.T. Liefert, B. N. Shuman, **2019**: Quantitative model-data comparison of Mid-Holocene lake level change in the central Rocky Mountains, *Climate Dynamics,* 1-18, https://doi.org/10.1007/s00382-019-04633-3.

Fan Y., M. Clark, D. M. Lawrence, S. Swenson, L. E. Band, S. L. Brantley, P. D. Brooks, W. E. Dietrich, A. Flores, G. Grant, J. W. Kirchner, D. S. Mackay, J. McDonnell, P. C. D. Milly, P. L. Sullivan, C. Tague, H. Ajami, N. Chaney, A. Hartmann, P. Hazenberg, J. McNamara, J. Pelletier, J. Perket, E. Rouholahnejad-Freund, T. Wagener, X. Zeng, E. Beighley, J. Buzan, M. Huang, **B Livneh**, B. P. Mohanty, B. Nijssen, M. Safeeq, C. Shen, W. van Verseveld, J. Volk, D. Yamazaki, **2019**: Hillslope Hydrology in Global Change Research and Earth System Modeling, *Water Resources Research*, AGU Centennial Volume on GRAND CHALLENGES IN THE EARTH AND SPACE SCIENCES, 55(2), 1737-1772, https://doi.org/10.1029/2018WR023903.

Small, E.E., *A.M. Badger., R. Abolafia-Rosenzweig and **B. Livneh**, **2018**: Estimating soil evaporation using drying rates determined from satellite-based soil moisture records, *Remote Sensing,* 10(12), 1945; https://doi.org/10.3390/rs10121945.

*Badger, A.M., **B. Livneh**, Hoerling, M.P., and J.K. Eischeid, **2018**: Understanding the 2011 Upper Missouri River Basin floods in the context of a changing climate, *Journal of Hydrology: Regional Studies,* 19, 110-123, https://doi.org/10.1016/j.ejrh.2018.08.004.

Hein C.J., S. Gopalakrishnan, J.E. Ten Hoeve, **B. Livneh**, H.D. Adams, E.L. Marino, and S.C. Weiler, **2018**: Overcoming Early Career Barriers to Interdisciplinary Climate Change Research, *Wiley Interdisciplinary Reviews Climate Change*, 9(5) e530, https://doi.org/10.1002/wcc.530.

Jennings, K.S., T. Winchell, **B. Livneh**, and N.P. Molotch, **2018**: Spatial variation of the rain-snow temperature threshold across the Northern Hemisphere, *Nature Communications*, 9(1), 1148, https://doi.org/10.1038/s41467-018-03629-7.

Friedrich, K., R. Grossman, J. Huntington, P. Blanken, J. Lenters, K. Holman, D. Gochis, **B. Livneh**, J. Prairie, E. Skeie, N. Healey, K. Dahm, C. Pearson, T. Finnessey, S. Hook, and T. Kowalski, **2018**: Reservoir Evaporation in the Western United States: Current Science, Challenges, and Future Needs, *Bulletin of the American Meteorological Society*, 99(1), 167-187, https://doi.org/10.1175/BAMS-D-15-00224.1.

Shellito, P., E. E. Small, and **B. Livneh**, **2018**: Controls on surface soil drying rates observed by SMAP and simulated by the Noah land surface model, *Hydrology and Earth System Sciences,* 22(3), 1649, https://doi.org/10.5194/hess-22-1649-2018.

Henn, B., A.J. Newman, **B. Livneh**, C. Daly, and J.D. Lundquist, **2018**: An assessment of differences in gridded precipitation datasets in complex terrain, *Journal of Hydrology*, 556, 1205-1219, https://doi.org/10.1016/j.jhydrol.2017.03.008.

Marlier, M.E., M. Xiao, R. Engel, **B. Livneh**, J.T. Abatsoglou, and D.P. Lettenmaier, **2017**: The 2015 drought in Washington State: A harbinger of things to come? *Environmental Research Letters*, 12 114008, https://doi.org/10.1088/1748-9326/aa8fde.

Stewart, J.S., **B. Livneh**, J.R. Kasprzyk, J.T. Minear, B. Rajagopalan, and W.J. Raseman, **2017**: A multi-algorithm approach to land surface modeling of suspended sediment in the Colorado Front Range, *Journal of Advances in Models Earth Systems*, 9(7), 2526-2544, https://doi.org/10.1002/2017MS001120.

Yanto, **B. Livneh**, and B. Rajagopalan, **2017**: Development of a gridded meteorological dataset over Java island, Indonesia 1985–2014, *Nature Scientific Data*, 4, 170072, https://doi.org/10.1038/sdata.2017.72.

Hallar, A.G., N.P. Molotch, J. Hand, **B. Livneh**, I.B. McCubbin, R. Petersen, J. Michalsky, D. Lowenthal, **2017**: Impacts of Increasing Aridity and Wildfires on Aerosol Loading in the Intermountain Western U.S., *Environmental Research Letters*, 12(1), 014006, http://dx.doi.org/10.1088/1748-9326/aa510a.

Houle, E.S., **B. Livneh**, and J.R. Kasprzyk, **2017**: Exploring Snow Model Parameter Sensitivity Using Sobol' Variance Decomposition, *Environmental Model and Software*, 89, 144–158, https://doi.org/10.1016/j.envsoft.2016.11.024.

Buma, B., and **B. Livneh**, **2017**: Key landscape and biotic indicators of watersheds sensitivity to forest disturbance identified using remote sensing and historical hydrography data. *Environmental Research Letters*, 12(7), 074028, https://doi.org/10.1088/1748-9326/aa7091.

Raseman, W. J., J.R. Kasprzyk, F.L. Rosario-Ortiz, J.R. Stewart, and **B. Livneh**, **2017**: Emerging investigators series: a critical review of decision support systems for water treatment: making the case for incorporating climate change and climate extremes. *Environmental Science: Water Research & Technology*, 3(1), 18-36, doi.org: https://doi.org/10.1039/C6EW00121A.

Yanto, **B. Livneh**, B. Rajagopalan, B., and J. R. Kasprzyk, **2017**: Hydrological model application under data scarcity for multiple watersheds, Java Island, Indonesia. *Journal of Hydrology: Regional Studies*, *9*, 127-139, https://doi.org/10.1016/j.ejrh.2016.09.007.

Barnhart, T.B., N.P. Molotch, **B. Livneh**, A.A. Harpold, J.F. Knowles, and D. Schneider, **2016**: Snowmelt Rate Dictates Streamflow, *Geophysical Research Letters*, 43, 8006–8016, https://doi.org/10.1002/2016GL069690.

Livneh B., and M.P. Hoerling, **2016**: The Physics of Drought in the U.S. Central Great Plains. *Journal of Climate*, 29, 6783-6804, https://doi.org/10.1175/JCLI-D-15-0697.1.

Cheng L., M.P. Hoerling, A. AghaKouchak, **B. Livneh**, and X-W. Qian, **2016**: How Has Human-Induced Climate Change Affected California Drought Risk?, *Journal of Climate,* 29, 111–120, https://doi.org/10.1175/JCLI-D-15-0260.1.

Raleigh, M.S., **B. Livneh**, K. Lapo and J.D. Lundquist, **2016**: How does availability of meteorological forcing data impact physically-based snowpack simulations in different climates? *Journal of Hydrometeorology*, 17, 99–120, https://doi.org/10.1175/JHM-D-14-0235.1.

Mizukami N., M.P. Clark, E.D. Gutmann, P.A. Mendoza, A.J. Newman, **B. Livneh**, B. Nijssen, L. Hay, L.D. Brekke and J.R. Arnold, **2016**: Implications of the methodological choices for hydrologic portrayals over the Contiguous United States: statistically downscaled forcing data and hydrologic models, *Journal of Hydrometeorology* 17, 73–98, https://doi.org/10.1175/JHM-D-14-0187.1.

Livneh B., R. Kumar, and L. Samaniego, **2015**: Influence of Soil Textural Properties on Hydrologic Fluxes in the Mississippi River Basin, *Hydrological Processes*, 29, 4638–4655, https://doi.org/10.1002/hyp.10601.

Lundquist J.D., M. Hughes, B. Henn, E. Gutmann, and **B. Livneh**, J. Dozier, and P. Neiman, **2015**: High-elevation precipitation patterns: using snow measurements to diagnose when and why gridded datasets succeed or fail across the Sierra Nevada, California, *Journal of Hydrometeorology* 16, 1773–1792, https://doi.org/10.1175/JHM-D-15-0019.1.

Livneh B., T.J. Bohn, D.S. Pierce, F. Munoz-Ariola, B. Nijssen, R. Vose, D. Cayan, and L.D. Brekke, **2015**: A spatially comprehensive, hydrometeorological data set for Mexico, the U.S., and southern Canada 1950-2013, *Nature Scientific Data*, 2, 150042, https://doi.org/10.1038/sdata.2015.42.

Funk, C., S. Shukla, A. Hoell, and **B. Livneh**, **2015**: Assessing the contributions of East African and west Pacific warming to the 2014 boreal spring East African drought, *Bulletin of the American Meteorological Society*, 96(12), S77-S82, https://doi.org/10.1175/BAMS-D-15-00106.1.

Buma B., and **B. Livneh**, **2015**: Potential effects of forest disturbances and management on water resources in a warmer climate, *Forest Science*, http://dx.doi.org/10.5849/forsci.14-164.

Livneh B., J.S. Deems, B. Buma, J.J. Barsugli, D. Schneider, N.P. Molotch, K. Wolter, and C.A. Wessman, **2015**: Catchment Response to Bark Beetle Outbreak and Dust-on-Snow in the Upper Colorado River Basin, *Journal of Hydrology* 523,196–210, https://doi.org/10.1016/j.jhydrol.2015.01.039.

Pal, I., E. Towler, and **B. Livneh, 2015**: How Can We Better Understand Low River Flows as Climate Changes?*, Eos Opinion, AGU,* 96, http://dx.doi.org/10.1029/2015EO033875. (**Editor-only reviewed*)

Livneh, B., J.S. Deems, D. Schneider, J.J. Barsugli, and N.P. Molotch, **2014**: Filling in the gaps: Inferring spatially distributed precipitation from gauge observations over complex terrain, *Water Resources Research*, 50, https://doi.org/10.1002/2014WR015442.

Chen F., M. Barlage , M. Tiwari , R. Rasmussen , J. Jin , D.P. Lettenmaier, **B. Livneh**, C. Lin , G. Michuez-Macho , G-Y. Niu , L. Wen , Z-L. Yang, **2014**: Modeling seasonal snowpack evolution in the complex terrain and forested Colorado Headwaters region: A model inter-comparison study, *Journal of Geophysical Research*, 119(13), 13,795-13,819, https://doi.org/10.1002/2014JD022167.

Kumar, S.V., C.D. Peters-Lidard, D. Mocko, Y. Liu, K. Arsenault, Y. Xia, M.B. Ek, G. Riggs, **B. Livneh**, and M., Cosh, **2014**: Assimilation of passive microwave-based soil moisture and snow depth retrievals for drought estimation, *Journal of Hydrometeorology*, *15*(6), 2446-2469 https://doi.org/10.1175/JHM-D-13-0132.1.

Livneh B., E.A. Rosenberg, C. Lin, B. Nijssen, V. Mishra, K.M. Andreadis, E.P. Maurer, and D.P. Lettenmaier, **2013**: A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States: Update and Extensions, *Journal of Climate*, 26, 9384–9392, https://doi.org/10.1175/JCLI-D-12-00508.1.

Kumar, R., **B. Livneh**, and L. Samaniego, **2013**: Towards computationally efficient large-scale hydrologic predictions with the multi-scale regionalization scheme, *Water Resources Research,* 49(9), 5700-5714, https://doi.org/10.1002/wrcr.20431.

Xia Y., M. B. Ek, J. Sheffield, **B. Livneh**, H. Wei, S. Feng, L. Luo, J. Meng, and E. Wood, **2013**: Validation of Noah-simulated Soil temperature in the North American Land Data Assimilation System Phase 2, *Journal of Applied Meteorology and Climatology*, 52, 455–471, https://doi.org/10.1175/JAMC-D-12-033.1.

Bohn, T. J., **B. Livneh**, J. W. Oyler, S. W. Running, B. Nijssen, and D. P. Lettenmaier, **2013**: Global evaluation of MTCLIM and related algorithms for forcing of ecological and hydrological models, *Agriculture Forest Meteorology*, 176, 38-49, https://doi.org/10.1016/j.agrformet.2013.03.003.

Livneh B., and D.P. Lettenmaier, **2013**: Regional parameter estimation for the Unified Land Model, *Water Resources Research*, 49(1), 100-114, https://doi.org/10.1029/2012WR012220.

Sheffield, J., **B. Livneh**, and E.F. Wood, **2012**: Representation of Terrestrial Hydrology and Large Scale Drought of the Continental US from the North American Regional Reanalysis, *Journal of Hydrometeorology,* 13, 856–876, https://doi.org/10.1175/JHM-D-11-065.1.

Livneh, B. and D.P. Lettenmaier, **2012**: Multi-criteria parameter estimation for the unified land model, *Hydrology and Earth System Sciences*, 16, 3029-3048, https://doi.org/10.5194/hess-16-3029-2012.

Mahanama, S.P., **B. Livneh**, R.D. Koster, D.P. Lettenmaier, and R.H. Reichle, **2012**: Soil Moisture, Snow, and Seasonal Streamflow Forecasts in the United States, *Journal of Hydrometeorology*, 13, 189-203, https://doi.org/10.1175/JHM-D-11-046.1.

Xia Y., K. Mitchell, M. Ek, J. Sheffield, B. Cosgrove, L. Luo, C. Alonge, H. Wei, J. Meng, **B. Livneh**, D.P. Lettenmaier, V. Koren, Q. Duan, K. Mo, Y. Fan, and D. Mocko, **2012**: Continental-scale water and energy flux analysis and validation for the North American Land Data Assimilation System Project Phase 2 (NLDAS-2), part 1: inter-comparison and application of model products, *Journal of Geophysical Research*, 117, https://doi.org/10.1029/2011JD016048.

Xia Y., K. Mitchell, M. Ek, B. Cosgrove, J. Sheffield, L. Luo, C. Alonge, H. Wei, J. Meng, **B. Livneh**, Q. Duan, and D. Lohmann, **2012**: Continental-scale water and energy flux analysis and validation for the North American Land Data Assimilation System Project Phase 2 (NLDAS-2), part 2: Validation of Model-simulated streamflow, *Journal of Geophysical Research,* 117, https://doi.org/10.1029/2011JD016051.

Livneh, B., P.J. Restrepo, and D.P. Lettenmaier, **2011**: Development of a Unified Land Model for prediction of surface hydrology and land-atmosphere interactions, *Journal of Hydrometeorology*, 12(6), 1299-1320, https://doi.org/10.1175/2011JHM1361.1.

Koster, R.D., S.P. Mahanama, **B. Livneh**, D.P. Lettenmaier, and R.H. Reichle, **2010**: Skill in Streamflow Forecasts Derived from Large-Scale Estimates of Soil Moisture and Snow, *Nature Geoscience*, 3(9), 613, https://doi.org/10.1038/ngeo944.

Livneh, B., Y. Xia, K.E. Mitchell, M.B. Ek, and D.P. Lettenmaier, **2010**: Noah LSM Snow Model Diagnostics and Enhancements, *Journal of Hydrometeorology*, 11(3), 721-738, https://doi.org/10.1175/2009JHM1174.1.

Barlage, M., F. Chen, M. Tewari, K. Ikeda, D. Gochis, J. Dudhia, R. Rasmussen, **B. Livneh**, M. Ek, and K. Mitchell, **2010**: Noah Land Surface Model Modifications to Improve Snowpack Prediction in the Colorado Rocky Mountains, *Journal of Geophysical Research*, 115 (D22), https://doi.org/10.1029/2009JD013470.

Casola, J.H., L. Cuo, **B. Livneh**, D.P. Lettenmaier, M. Stoelinga, P.W. Mote and J. M. Wallace, **2009**: Assessing the Impacts of Global Warming on Snowpack in the Washington Cascades, *Journal of Climate*, 22(10), 2758-2772, https://doi.org/10.1175/2008JCLI2612.1.

Livneh B., and M.H. El Naggar, **2008**: Axial testing and numerical modeling of square shaft helical piles under compressive and tensile loading, *Canadian Geotechnical Journal*, 45(8), 1142-1155, https://doi.org/10.1139/T08-044.

Papers in Preparation, Review, and in-Press:

(1) Pierce, D. W., L. Su, D. R. Cayan, M.D. Risser, **B. Livneh**, and D.P. Lettenmaier, **2021**: An extreme-preserving long-term gridded daily precipitation data set for the conterminous United States, *Journal of Hydrometeorology*, (*in revision*).

(2) Bjarke, N.R., **B. Livneh**, S. Elmendorf, N. Molotch, E. Hinckley, J. Morse, N. Emery, P. Johnson, and K. Suding, **2021**: The sensitivity of runoff generation to snowpack uniformity in an alpine watershed: Green Lakes Valley, Niwot Ridge Long Term Ecological Research Station, *Hydrological Processes*, (*in revision*).

(3) *Badger, A.M., N.R. Bjarke, N. Molotch, and **B. Livneh**, **2021**: Catchment scale observations at the Niwot Ridge Long-Term Ecological Research site, *Hydrological Processes*, (*in revision*).

(4) Culler, E.S., *A.M. Badger, J.T. Minear, K.F. Tiampo, and **B. Livneh**, **2021**: A Multi-sensor Evaluation of Precipitation Uncertainty for Landslide-triggering Storm Events, *Hydrological Processes*, (*in revision*).

(5) Hale, K.E., A.N. Wlostowski, S.P. Anderson, *A.M. Badger, K.N. Musselman, **B. Livneh**, and N.P. Molotch, **2021**: Streamflow sensitivity to climate warming through the lens of surface water input, (*in prep.*).

(6) Heldmyer, A.J., **B. Livneh**, B. Rajagopalan, N. Molotch, and, **2021**: Investigating the Relationship Between Peak Snow-Water Equivalent and Snow Timing Indices in the Western U.S. and Alaska, *Water Resources Research* (*in revision*).

(7) Heldmyer, A.J., N.R. Bjarke, and **B. Livneh**, 2021: A 21st century perspective on snow drought in the Upper Colorado River Basin, *Journal of the American Water Resources Association,* (submitted).

(8) Guinotte, J., S. Torbit, B. Grizzle, J. Barsugli, A. Ray, I. Rangwala, C. Dewes, A. Heldmyer, and **B. Livneh, 2021**: Future Snow Availability in Rocky Mountain Wolverine Habitat, *Journal of Wildlife Management and Wildlife Monographs* (submitted).

(9) Culler, E.S., **B. Livneh**, B. Rajagopalan, and K.F. Tiampo, **2021**: A data-driven evaluation of post-wildfire landslide hazards, *Natural Hazards and Earth System Sciences (NHESS)* (submitted).

(10) Brucker, C.P., **B. Livneh**, J.T. Minear, and F.L. Rosario-Ortiz, **2021**: A Critical Review of Simulation Experiment Techniques used to Analyze Wildfire Effects on Water Quality and Supply, *Water Research,* (submitted).

PEER REVIEWED CHAPTERS

Conant, R.T., D. Kluck, M. Anderson, *A. Badger, B.M. Boustead, J. Derner, L. Farris, M. Hayes, **B. Livneh,** S. McNeeley, D. Peck, M. Shulski, and V. Small, **2018:** Northern Great Plains. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 941–986. doi: 10.7930/NCA4.2018.CH22

CONFERENCE PROCEEDINGS PAPERS

Editor reviewed:

Brucker, C.B., A.J. Heldmyer, **B. Livneh**, F.L. Rosario-Ortiz, and J.T. Minear, **2019**: Wildfires in the West: Characterizing Drivers of Post-Disturbance Hydrologic and Sediment Response through Laboratory Analysis, *Sedimentation and Hydrology Conference*, June 2019 (Editor reviewed, full paper) https://www.sedhyd.org/2019/openconf/modules/request.php?module=oc_proceedings&action=view.php&id=112&file=1/112.pdf&a=Accept

Heldmyer, A.J. and B. Livneh, **2019**: Wildfire in the West: Characterizing Spatial Trends in Post-Disturbance Hydrologic and Sediment Response at the Watershed Scale, *Federal Interagency Sedimentation and Hydrologic Modeling Conference*, June 2019, (Editor reviewed, full paper) https://www.sedhyd.org/2019/openconf/modules/request.php?module=oc_proceedings&action=view.php&id=205&file=1/205.pdf&a=Accept

Not peer-reviewed:

*Badger, A. M., **B. Livneh**, and N. P. Molotch, **2019**: On the role of spatial snow distribution on alpine catchment hydrology, World Environmental and Water Resources Congress, May, pp. 215-225, https://ascelibrary.org/doi/10.1061/9780784482346.022 (full paper).

Heldmyer, A.J., **B. Livneh**, W. Farmer, J. Driscoll, and N. Molotch, **2019**: Evaluating the Potential to Regionalize Station-Observed SWE across the Western U.S., *World Environmental and Water Resources Congress*, May 2019, https:///doi.org/10.1061/9780784482346.029 (full paper).

Bensching, L., and **B. Livneh, 2018:** Hydrologic Disturbance Analysis: Methods Development on the Missouri River Basin, an article in the Colorado Water Institute FY18 Annual, available at: https://issuu.com/coloradowater/docs/coloradowater_v35-i3_web.

Livneh, B., *A.M. Badger, and J.J. Lukas, **2017**: Assessing the robustness of snow-based drought indicators in the Upper Colorado River Basin under future climate change, *World Environmental and Water Resources Congress*, May 2017-03, p 15, https://doi.org/10.1061/9780784480618.051 (full paper).

Stewart, J.R., B. Rajagopalan, J.R. Kasprzyk, W.J. Raseman, and **B. Livneh, 2017:** The Use of Ensemble Modeling of Suspended Sediment to Characterize Uncertainty, *World Environmental and Water Resources Congress*, May 2017-03, p 15, https://doi.org/10.1061/9780784480625.019 (full paper).

Livneh, B., and J. S. Deems**, 2013:** "Merging Satellite and Model Information to Improve Snowpack and Water Supply Forecasting", *Climate Change Technology Conference*, Montreal, QC, Canada, Paper Number 1569695429 (mini paper).

JOURNAL AND WEB-BASED ARTICLES

Editor reviewed:

Barsugli, J. J., M. P. Hoerling, and **B. Livneh, 2019**: Is the recent drought on the Colorado River the new normal?, *Eos, 100,* https://doi.org/10.1029/2019EO117173. Published on 01 March 2019.

Livneh, B., K. Friedrich, and P. D. Blanken, **2016**: New interest in reservoir evaporation in western United States, *Eos*, *AGU,* 97, https://doi.org/10.1029/2016EO048679. Published on 23 March 2016.

Livneh, B., E. Marino and J. E. Ten Hoeve, **2014**: Emerging Ideas and Interdisciplinary Perspectives on Climate Change, *Eos Trans. AGU*, 95(7), 65, https://doi.org/10.1002/2014EO070006.

Not peer reviewed:

Livneh, B., and D. W. Pierce, **2016**: New, Higher Resolution Climate Observations and Model Projections From Mexico Through Southern Canada, *Knowledge Stream, USBR Research and Development Office Magazine: Climate Variability and Extremes*, Summer 2016-03, p 17.

Gordon, E.S., Pugh, E.T. and **Livneh B.**, **2014:** Bark Beetles: Cause for Concern in Snowy Western Watersheds? *Utility Intelligence and Infrastructure*. Ellwood Media Lab. Web.

Ek, M. B., Xia, Y., Wood, E., Sheffield, J., Luo, L., Lettenmaier, D. P., **Livneh, B.**, … & Wei, H., **2011**: North American Land Data Assimilation System Phase 2 (NLDAS-2): Development and applications. GEWEX News, 2, 6-8. https://www.gewex.org/gewex-content/files_mf/1432209506May2011.pdf.

Munoz-Arriola, F., S. Shukla, T. Bohn, C. Zhu, **B. Livneh**, D.P. Lettenmaier, R. Lobato-Sanchez, A. Wagner-Gomez, **2009**. Prediccion de la Hidrologia Superficial en Norte America, *Resumen del Clima de la Frontera*, Julio 13: 1-5.

INTERVIEWS AND MEDIA

Video and Televised Interviews:

Livneh, B., *televised video interview conducted by Shaun Boyd on CBS Denver 4*, Monster Storm Still Not Enough To Bring State Out Of Drought, Mar, **2021** https://denver.cbslocal.com/2021/03/15/monster-storm-still-not-enough-to-bring-state-out-of-drought/.

Livneh, B., *video interview conducted by Daniel Grossman on Denver 7*, With less moisture, experts worried the 2021 fire season could be as bad as 2020, Feb, **2021** https://www.thedenverchannel.com/news/national/with-less-moisture-experts-worried-the-2021-fire-season-could-be-as-bad-as-2020.

Livneh, B., *televised interview conducted by Cory Reppenhagen on Denver 9 News*, Scientists: Early snowmelt in the spring leads to higher wildfire danger, November, **2020** https://www.9news.com/video/weather/weather-colorado/scientists-early-snowmelt-in-the-spring-leads-to-higher-wildfire-danger/73-680c386c-c6cc-4cbb-a379-a163670e44fa.

Livneh, B., *televised interview conducted by Cory Reppenhagen on Denver 9 News,* [2,200 views] April, **2020** https://www.youtube.com/watch?v=zT9UCB3sEA8

Livneh, B. and K. Jennings, Mar., *televised interview conducted by Cory Reppenhagen on Denver 9 News,* **2018**: http://www.9news.com/video/news/new-research-shows-that-colorado-gets-the-warmest-snow/73-8042155

Radio Interviews:

Livneh, B. KGNU Morning Magazine interview on the science and state of reservoir evaporation, January, **2016**. http://www.kgnu.org/morningmag/1/1/2016.

Other Interviews and Media:

Livneh, B. among several others, Colorado Public Radio (CPR) "*Colorado's Snowpack Was Almost Normal This Winter, But It May Not Be Enough Water For The Year*" interview by Miguel Otárola, April, **2021**: https://www.cpr.org/2021/04/02/colorados-snowpack-was-almost-normal-this-winter-but-it-may-not-be-enough-water-for-the-year/.

Livneh, B. among several others, KUNC "*When Wildfire Burns A High Mountain Forest, What Happens To The Snow?*" interview by Luke Runyon, December, **2020**: https://www.kunc.org/environment/2020-12-31/when-wildfire-burns-a-high-mountain-forest-what-happens-to-the-snow.

Livneh, B., November, **2020**: "*Drying and dying: Drought conditions plague the Pacific Northwest*", by Anthony Edwards, The Daily of the University of Washington http://www.dailyuw.com/news/scinews/article_3a378426-1d84-11eb-888c-67f5433d1c49.html.

Livneh, B. among several others, October, **2020**: "*Boulder County is among nearly 40% of the state experiencing severe drought; communities look at ways to adapt to a drier climate*", by Kelsey Hammon, The Longmont Times-Call https://www.timescall.com/2020/10/03/boulder-county-is-among-nearly-40-of-the-state-experiencing-severe-drought-communities-look-at-ways-to-adapt-to-a-drier-climate/.

Livneh, B., April, **2020**: "*Study: Snowpack Will Become A Less Reliable Predictor Of Drought In Western U.S.*", by Grace Hood, Colorado Public Radio https://www.cpr.org/2020/04/20/study-snowpack-will-become-an-unreliable-predictor-of-drought-in-western-u-s/.

Livneh, B., April, **2020**: "*Climate warming may hit Colorado River Basin farmers hardest as shrinking snowpack leads to less irrigation water*", by Bruce Finlay, The Denver Post https://www.denverpost.com/2020/04/21/colorado-river-basin-snowpack/.

Livneh, B., April, **2020**: "With shrinking snowpack, drought predictability melting away", by Kelsey Simpkins, CU Boulder Today, https://www.colorado.edu/today/2020/04/20/shrinking-snowpack-drought-predictability-melting-away.

Livneh, B. among several others, April, **2020**: "*Study: American Southwest faces a 'megadrought,' the region's worst in centuries*", by Miranda Wilson, The Las Vegas Sun https://lasvegassun.com/news/2020/apr/28/study-american-southwest-faces-megadrought-worst/.

Abolafia-Rosensweig, R. and **B. Livneh, 2020**: A GREAT WAY TO MEASURE IRRIGATION, Whiteboard Animation [450 views] available at: https://www.youtube.com/watch?v=y1yxz2ZpM9k&feature=emb_logo

Livneh B. and C. Brucker, "When it rains: The hidden impact of wildfire", *CU Boulder Today* **Oct. 2019**, video and article available at: https://www.colorado.edu/today/2019/10/01/when-it-rains-hidden-impact-wildfire?fbclid=IwAR1F-XmMiNUnGHh8mqN1NqaRhtL4Z8Yd81M_7O6A2xxvxc6C9TGYrhmR6mw.

Livneh B. among several others, **2018**: University of Colorado professors, scholars helped author federal climate report, Boulder Daily Camera interview on publication of the 4th National Climate Assessment, 2018: http://www.dailycamera.com/cu-news/ci_32294222/university-colorado-professors-scholars-helped-author-federal-climate.

Livneh, B., Mar., **2018**: *Inside the Greenhouse: http://www.insidethegreenhouse.org/media/ben-livneh-cires*

Livneh, B., Nov., **2017**: "UNL shares the consequences of climate change in Nebraska" in The Daily Nebraskan, Interview by Denise Munoz, http://www.dailynebraskan.com/news/unl-shares-the-consequences-of-climate-change-in-nebraska/article_1d7dc04e-c2a5-11e7-86b5-17e34615c6e6.html

Livneh, B. "West's water reservoir managers face big losses from evaporation". Interview by Bruce Finlay *The Denver Post*, December, **2015**. http://www.denverpost.com/2015/12/29/wests-water-reservoir-managers-face-big-losses-from-evaporation/.

Livneh, B. "More water flowing from bark beetle infested watersheds". Interview by J. Gilles. *Environmental Monitor*, March, **2015**. http://www.fondriest.com/news/more-water-flowing-from-bark-beetle-infested-watersheds.htm.

SCIENTIFIC REPORTS

Kasprzyk, J.R., J.R. Stewart, A.J. Heldmyer, K. Reeves, W. Raseman, R. Balaji, R.S. Summers, F. Rosario-Ortiz, and **B. Livneh, 2019**: An Integrated Modeling and Decision Framework to Evaluate Adaptation Strategies for Sustainable Drinking Water Utility Management Under Drought and Climate Change, *Water Research Foundation,* Nov 2019, available at: https://www.waterrf.org/system/files/resource/2019-10/DRPT-4636.pdf

Ray, Andrea J., Barsugli, Joseph J. Jr., **Livneh, Ben**, Dewes, Candida F., Rangwala, Imtiaz, Heldmyer, Aaron, Stewart, Jenna. **2017**. Future snow persistence in Rocky Mountain and Glacier National Parks: An analysis to inform the USFWS Wolverine Species Status Assessment. NOAA Report to the U.S. Fish and Wildlife Service. 101pp. Available at: https://psl.noaa.gov/assessments/pdf/noaa-future-snow-persistence-report-2017.pdf.

Livneh, B., M.P. Hoerling, *A.M. Badger, and J. Eischeid, **2016**: Causes for Hydrologic Extremes in the Upper Missouri River Basin, *NOAA Climate Assessment Report,* July 2016, available at: https://www.esrl.noaa.gov/psd/csi/factsheets/pdf/mrb-climate-assessment-report-hydroextremes_2016.pdf

Downscaled CMIP3 and CMIP5 Climate Projections – Addendum Release of Downscaled CMIP5 Climate Projections (LOCA) and Comparison with Preceding Information, July **2016**.

Severe Flooding on the Colorado Front Range, September 2013, Lukas J., …, **Livneh B.**, et al., **2013**, Western Water Assessment Report, http://wwa.colorado.edu/resources/front-range-floods/assessment.pdf?album=1&pid=43#top_display_media.

Online Lectures:

Livneh, B. "Groundwater Resources in the Western U.S." *Coursera*, Water in the Western U.S., Video Lecture, **2015**. https://www.coursera.org/course/waterwestus.

PUBLIC DATASETS

1. Heldmyer, A.J.; and **Livneh, Ben** (**2021**), "Annual Snow Timing Index Rasters for the Western US and Alaska, WY2001-2019", Zenodo, http://doi.org/10.5281/zenodo.4327643.
2. Abolafia-Rosenzweig, Ronnie; *Badger, Andrew; Small, Eric; **Livneh, Ben** (**2020**), "E-SMAP: Evaporation-Soil Moisture Active Passive", Mendeley Data, V1, http://dx.doi.org/10.17632/ffw8zbdmpm.2.
3. Abolafia-Rosenzweig, Ronnie; **Livneh, Ben** (**2020**), "Remotely sensed ensemble of the water cycle", Mendeley Data, v2, http://dx.doi.org/10.17632/r24rdxt73j.2.
4. Jennings K.S., Winchell T.S., **Livneh B**, Molotch N.P. (**2018**) Data from: Spatial variation of the rain-snow temperature threshold across the Northern Hemisphere. Dryad Digital Repository. https://doi.org/10.5061/dryad.c9h35.
5. Luce, C. H., Lute, A. C. Kormos, P., and **Livneh, B. (2017)**. Modeled historical streamflow metrics for the contiguous United States and National Forest Lands. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2017-0046.
6. Yanto, **Livneh B**, Rajagopalan B, (**2017**) Development of a gridded meteorological data set over the Java island, Indonesia 1985-2014, http://dx.doi.org/10.5061/dryad.36rs0 (Date Published: May 22, 2017).
7. **Livneh, Ben**; Bohn, Theodore J.; Pierce, David W.; Muñoz-Arriola, Francisco; Nijssen, Bart; Vose, Russell; Cayan, Daniel R.; Brekke, Levi (**2016**) A spatially comprehensive, hydrologic model-based data set for Mexico, the U.S., and southern Canada, 1950-2013,. NOAA National Centers for Environmental Information. Dataset. https://doi.org/10.7289/v5qz27zg.

PUBLICLY AVAILABLE CODE

Livneh, B., and A.M. Badger, **2020**: Release of essential processing scripts and companion geospatial files to calculate and evaluate changes in ETS, https://doi.org/10.5281/zenodo.3630827.

FUNDING (Grants based at CU-Boulder, unless otherwise specified)

Awards with B. Livneh as Lead-PI:

North Central Climate Adaptation and Science Center (NCCASC) (Duration: 7/1/2021-6/30/2023)
$249,973 *Estimation of future high-mountain snowpack to inform terrestrial and aquatic species status assessments, recovery plans, and monitoring*
Research PI: Ben Livneh, Institutional PI: Jennifer Balch

NOAA Climate Program Office. Modeling, Analysis, Predictions, and Projections (MAPP) (Duration: 9/2020 - 8/2023)
$508,951 *Identifying alternatives to snow-based streamflow predictions to advance future drought predictability*.
PI: Livneh B. Co-PI: Benet Duncan, Joseph Kasprzyk.

National Science Foundation. Dynamics of Coupled Natural Human Systems (CNH2-S) (Duration: 8/2020 - 8/2023)
$743,315 *Water-mediated coupling of natural-human systems: drought and water allocation across spatial scales*.
PI: Livneh B. Co-PI: Eric Small (CU-Bouloder), Jared Carbone (Colorado School of Mines), Cameron Wobus (Lynker Technologies).

CU Boulder Earthlab Ideas Collider (June 2020)
$8,000 *Projecting Rocky Mountain Snow Persistence and Depth Under Climate Change*

PI: Ben Livneh; Co-PI: Robin O'Malley (USGS, North Central Climate Adaptation and Science Center), Aparna Bamzai-Dodson (USGS, NC CASC).

CIRES Innovative Research Program Program (Duration: 9/2018 - 12/2019)
$24,980 *A terrestrial simulator of wildfire impacts on watersheds across the western U.S.*
PI: Livneh B.

Niwot Ridge Long Term Ecological Research (LTER-NSF) (Duration: 5/2018 - 5/2019)
$18,664 *Catchment Integration of Sensor Array Observations to Understand Hydrologic Connectivity*
PI: Livneh B.

NASA New (Early Career) Investigator Program (Duration: 3/2018 - 3/2021)
$269,754 *REESEN: A Remotely Sensed Ensemble to Understand Human Impacts on the Water Cycle*.
PI: Livneh B.

College of Engineering Water-Energy Nexus Interdisciplinary Research Theme (Duration: 3/2018 - 5/2019)
$14,001 *Toward water and energy security via improved characterization of reservoir sedimentation*.
PI: Livneh B. Co-PI: J.R. Kasprzyk.

ORAU Ralph E. Power Junior Faculty Enhancement Award (Duration: 6/2017 - 5/2018)
$5,000 **Livneh B. PI.** $5,000 matching funds from CIRES.

Niwot Ridge Long Term Ecological Research (LTER-NSF) (Duration: 5/2017 - 5/2018)
$31,500 *Catchment Integration of Sensor Array Observations to Understand Hydrologic Connectivity*
PI: Livneh B.

NASA Research Opportunities in Space and Earth Science (Duration: 8/2016 - 8/2019)
$293,288 *Monitoring soil evaporation using SMAP surface soil moisture in a water balance framework*.
PI: Livneh B.; Co-PI: E. Small.

NOAA Climate Program Office. The Sectoral Applications Research Program (Duration: 7/2016 - 6/2019)
$286,368 *Advancing the use of drought early warning systems in the Upper Colorado River Basin*.
PI: Livneh B; Co-PIs: L. Dilling, W. Travis.

U.S. Bureau of Reclamation (Duration: 10/2014 - 5/2015)
$59,986 *High-resolution meteorological and hydrologic data extension to trans-boundary basins in southern Canada and northern Mexico*.
PI: Livneh B.

Awards with B. Livneh as Co-PI:

NASA Early Stage Innovations (ESI) program (Duration: 1/21/2021 – 12/31/2023)

$521,215 *Studying the impact of water storage changes on earthquake seismicity using GRACE data*.
PI: Kristy Tiampo; Co-PI: Steve Nerem, **Livneh B.** CU-portion: $521,215.

NOAA Climate Program Office. Modeling, Analysis, Predictions, and Projections (MAPP) (Duration: 9/2019 - 8/2021)

$315,612 *Physically-Based Evaluation of CMIP6 Hydrologic Projections for the Western United States Grant*.
PI: Joseph Barsugli; Co-PI: **Livneh B.** CU-portion: $178,196.

Colorado Water Institute (Duration: 7/2019 - 6/2020)

$50,000 *Streamflow estimation in Colorado ungauged basins*
PI: S. Kampf (CSU); Co-PIs: **Livneh B.**, G. Richard (Fort Lewis College), A. Bhaskar (CSU), J. Sholtes (Colorado Mesa University). CU portion: $13,511.

NOAA Climate Program Office. Joint Technology Transfer Initiative (JTTI) (Duration: 10/2018 - 9/2020)

$468,833 *Calibration of Channel Properties to Improve Streamflow Estimates in the National Water Model*.
PI: Toby Minear; Co-PI: **Livneh B.**

Center for Water, Earth Science and Technology (CWEST CU-Boulder) (Duration: 9/2018 - 8/2019)

$6,000 *A new approach for spatial SWE Mapping: applications improve snowmelt representation in the National Hydrologic Model.*
Funding awarded to PhD student Aaron Heldmyer, Livneh B. Graduate Advisor.

Colorado Water Institute (Duration: 7/2018 - 6/2019)

$49,963 *Streamflow estimation in Colorado ungauged basins.*
PI: S. Kampf (CSU); Co-PIs: **Livneh B.**, G. Richard (Fort Lewis College), A. Bhaskar (CSU), J. Sholtes (Colorado Mesa University. CU portion: $13,591.

NASA Research Opportunities in Space and Earth Science (Duration: 6/2017 - 7/2021)

$989,449 *The Interaction of Mass Movements with Natural Hazards Under Changing Hydrologic Conditions*
PI: K. Tiampo; **Co-PIs: Livneh B.,** J.T. Minear, M. Willis.

U.S. Bureau of Reclamation (Duration: 5/2017 - 4/2018)

$30,000 *Reservoir Sediment Prediction over the Western U.S.*.
PI: B. Greimann (USBR); Co-PI: **Livneh B.**, CU portion: $20,000.

Colorado Water Institute (Duration: 3/2017 - 2/2018)

$4,999 *Diagnosing the Role of External Forcings on Streamflow Variability.*
Funding awarded to MS student Leah Bensching, Livneh B. Graduate Advisor.

U.S. Fish and Wildlife Service (Duration: 7/2016 - 3/2018)

$130,000 *Wolverine Climate Change Snow Refugia Study*.
Lead-PI: J. Barsugli (NOAA/CIRES); **Co-PI: Livneh B.** CU portion: $69,927.

Environmental Protection Agency (Duration: 9/2015 - 8/2018)
$1,250,000 *An integrated modeling and decision framework to evaluate adaptation strategies for sustainable drinking water utility management under drought and climate change*.
PI: B. Rajagopalan; Co-PI: R.S. Summers, **B. Livneh**, J. Kasprzyk, F. Rosario-Ortiz.

U.S. Army Corps of Engineers, NWD MRBWM (Duration: 10/2015 - 7/2016)
$146,500 *Assessing Causes of Hydrologic Climate Extremes in the Upper Missouri Basin*.
PI: M. Hoerling (NOAA); Co-PI: **Livneh B.**

NOAA, Regional Integrated Science Assessment (Duration 2015-2019)
$4,084,000 *Western Water Assessment: Building Climate Resilience By Design.*
Lead-PI: L. Dilling; Co-PIs: W. Travis, N. Molotch, J. Barsugli, **Livneh B.**

National Aeronautical and Space Administration, Jet Propulsion Laboratory (2/2015 – 6/2015)
$28,562 *Observing System Synthetic Experiment (OSSE) Project: Quantify the utility of airborne LiDar surveys of snow information on improving hydrologic forecasts*.
Subcontractor/Lead-PI: **Livneh B.**

TEACHING

At the University of Colorado Boulder (Assistant Professor)
CVEN 4333 Engineering Hydrology (undergraduate)
CVEN 5363 Modeling Hydrologic Systems (graduate)

At Seattle University (Adjunct Professor):
Applied Hydraulics (undergraduate).
Fluid Mechanics Laboratory (undergraduate).

Other teaching:
COMET-MetEd: Sedimentation Impacts Under Climate Change (SIUCC) Virtual Course, UCAR, 2016 (Lead-Instructor)
Water in the Western U.S. *Coursera* Online Course, 2015 (Lead-Instructor for the Groundwater module).

STUDENT ADVISING AND COMMITTEES

Active Advisees (B. Livneh primary advisor unless stated otherwise):
Aaron Heldmyer (Ph.D. CEAE), began 2016, comprehensive exam 2020.
Elsa Culler (Ph.D. CEAE) began, 2017, comprehensive exam 2020.
Carli Brucker (Ph.D. CEAE, 2018-).
Nels Bjarke (Ph.D., CEAE, 2019-).
Melanie Holland (MS Report Option, 2020; Ph.D. co-advised with E. Thomas)
Parthkumar Modi (Ph.D., CEAE, 2020-).

Supervisees (B. Livneh primary advisor unless stated otherwise):
Fangfang Yao (Postdoc., CIRES, 2020-)
Andrew Badger (Postdoc., CIRES, 2015-2019)
Javier Cepeda (Associate Scientist, CIRES, 2018-2019)

Past Advisees (B. Livneh primary advisor unless stated otherwise):
Ronnie Abolafia-Rosenzweig (Ph.D. CEAE, graduated Fall 2020).
Stephanie Redfern (Ph.D., ATOC, temporary advisor, Fall 2017).
Mas Yanto (Ph.D., CEAE, Co-advised with Prof. Balaji, graduated Spring 2016)
Michelle O'Donnell (MS CEAE, graduated Summer 2020).
Leah Bensching (MS, CEAE, graduated Spring 2019)
Jenna Stewart (MS, CEAE graduated Spring 2017)
Elizabeth Houle (MS, CEAE, Co-advised with Prof Kasprzyk, graduated Spring 2015)

Undergraduate Research Advising (B. Livneh primary advisor unless stated otherwise):
Undergraduate Research Opportunities Program (UROP)
2019: Rollin Jones (CEAE), Clair Butler (CEAE)
College of Engineering Discovery Learning Apprenticeship
2020-2021: Cole Pradiges (CEAE), Sarah Lundell (Computer Science)
2019-2020: Yuexuan Meng (CEAE), Jun Lin Zeng (CEAE)

Other undergraduate advising
CEAE: Abbey Turner (2020), Casey Bangs (2018), Yashwanth Kumar (2017 Summer research, visiting from India Institute of Technology Gandhinagar).
ENVS: Baxter Wilson (Primary Advisor, 2016).
GEOG: Michal Fagrelius (Honors Committee, 2013).
GEOL: Brielle Kissack (2016 Summer research).
Research Experiences for Community College Students (RECCS, NSF-funded): Alex Brunson (2019).

Undergraduate General Advising:
CEAE: Ryan Martin, Haoyu Nie, Bailey Vigil, Jack Costello, Kayla Hoag, Ginger Lucas, Benjamin Simon.

Doctoral Committee (Excludes students whom I primarily advise or co-advise):
CEAE: Benjamin Abel, Kelsey Reeves, Brian Straight, Sarah Baker, Mas Yanto, Andrew Verdin, Cameron Bracken, Daniel Broman, Srijita Jana, Adam Wlostowski;
Aerospace Engineering: Michael Croteau;
GEOG: Dominik Schneider, Theodore Barnhart, Keith Jennings, Qinghuan Zhang, Kehan Yang;
GEOL: Hannah Bonner, Peter Shellito, Thomas Enzminger, Claudia Corona.
ATOC: Richard Bateman*, Brian Rainwater, William Frey, Eric Keenan.
ENVS: Christa Torrens.
CU-Denver, Civil Engineering: Maryam Poshtiri

Masters Committee (Thesis option, unless otherwise stated):
CEAE: Colleen Wilson, Taylor Winchell, Timothy Clarkin, Erin Jenkins, Brennan Middleton (non-thesis MS), Trisha Shrum (report-based MS), Conor Felletter (report-based MS);
GEOL: Emily Carbone;

EBIO: Eric Gordon;
APPM: Gregory Benton.

Doctoral Preliminary Exam Committee:
CEAE: Rebecca Smith, Kelsey Reeves, Alvaro Ossandon, Benjamin Abel.

Mentoring

2020-2021	CIRES Mentoring Program
2020	College of Engineering and Applied Science First-Year Under-Represented Minorities Mentoring
2019-2020	AGU Mentoring365
2013-2015	Mentor, *Faculty Mentoring Students Program*, CU-Boulder.

STUDENT AWARDS

Leah Bensching: $4,999, Colorado Water Institute: "*Diagnosing the Role of External Forcings on Streamflow Variability"*. March, 2017.

Aaron Heldmyer: $8,781, Center for Water, Earth Science and Technology Fellowship: "*A new approach for spatial SWE Mapping: applications improve snowmelt representation in the National Hydrologic Model*". June 2018.

Carli Brucker: Hydrologic Sciences Symposium: Best Student Presentation: "*Simulator of Wildfire Impacts on Watersheds across the Western U.S.*" April 2019.

Michelle O'Donnell: NSF Graduate Research Fellowship Program: April, 2019.

SERVICE

2021	Senior editorial board member, *Scientific Data* (*Nature*)
2020	Lead Panelist, *NASA Postdoctoral Program (NPP)* [panel held virtually, Dec. 18, 2020].
2020	Mentor, College of Engineering and Applied Science *First-Year Under-Represented Minorities Mentoring Program, University of Colorado Boulder*
2020	Co-organizer, Collider workshop on future snowpack: *Projecting Rocky Mountain Snow Persistence and Depth Under Climate Change*, Jun. 2020, CU-BOulder
2020	Lead Panelist, *NASA Postdoctoral Program (NPP)* [panel held virtually, Aug. 20, 2020].
2020	Lead-organizer and Guest Associate Editor of special collection in the journal *Earth's Future* titled *CMIP6: Trends, Interactions, Evaluation, and Impacts*
2020	Lead Panelist, *NASA Postdoctoral Program (NPP)* [panel held virtually, Apr. 23, 2020].
2020 -	Faculty Representative for the University of Colorado Boulder, *Consortium of Universities for the Advancement of Hydrologic Science*
2020 -	Ecohydrology Technical Committee Member, Hydrology Section, *American Geophysical Union*
2019 -	Lead, NOAA-funded CMIP6 Task Force
2019 -	Mentor, *Mentoring 365 Live, American Geophysical Union*
2018	Co-organizer, Workshop on Colorado River Drought: *The New Normal*, Sep. 2018, NOAA-ESRL
2018 - 2020	Uncertainty Technical Committee Member, Hydrology Section, *American Geophysical Union*

2018	Co-organizer, Workshop on Drought Early Warning Systems, Aug. 2018, Glenwood Spgs, CO
2017 - 2021	Editorial Board Member, *Scientific Data* (Nature)
2017 - 2018	Co-Author, *4th National Climate Assessment, Northern Great Plains Chapter*
2017 -	Associate Editor, *Journal of Hydrometeorology*
2017 -	Surface Water Hydrology Technical Committee, Water Resources Division, ASCE
2016 - 2019	Associate Editor, *Journal of the American Water Resources Association*
2015	Co-organizer, *Reservoir Evaporation Workshop*, Oct. 2015, CU Boulder
2015	Science-lead, *Climate Change and Water Working Group*, Aug. 2015 Seattle
2014 -	Annual speaker, International English Center, *Go English Program*, CU-Boulder
2014 -	NASA User Working Group, Distributed Active Archive Center (DAAC) at NSIDC.
2014	Contributor: *Water Programming Blog* (http://waterprogramming.wordpress.com/)
2013-2015	Mentor, *Faculty Mentoring Students Program*, CU-Boulder.
2013	Resource Speaker, *Water Education Foundation:* Lower Colorado River Tour.
2013-2020	Lead Session Convener, *American Geophysical Union, Fall Meeting, San Francisco, CA.*
2013	Symposium Scholar, DISCCRS VIII: Dissertations Initiative for the Advancement of Climate Change Research

WORKSHOPS ORGANIZED

Livneh B., lead-PI of workshop grant: co-organized with Robin O'Malley, Alisa Wade, and Aparana Bamzai-Dodson, Video-enabled remote workshop, June, **2020**: Projecting Rocky Mountain Snow Persistence and Depth Under Climate Change, Earthlab Ideas Collider, Boulder, CO.

Goals: Bring state, federal and tribal land and resource managers in the region together with university researchers to identify snow modeling and snowpack tool needs to support habitat assessment and planning.

Link: https://www.usgs.gov/center-news/snow-collider-workshop-held-improve-projections-future-snow-north-central-us

Livneh B., co-organized with Martin Hoerling and Joseph Barsugli, Boulder Colorado, September, **2018**: Colorado River Drought—*The New Normal?* National Oceanic and Atmospheric Administration Earth Science Research Laboratory (NOAA-ESRL), Boulder, CO.

Goals: Is the recent drought on the Colorado River "the new normal"? A Workshop on understanding the causes of the historical changes in flow of the Colorado River.

Livneh B., co-organized with the Western Water Assessment, Glenwood Springs Colorado, August, **2018**: Advancing Drought Early Warning in the Early Warning in the Upper Colorado River Basin. Colorado River District, Glenwood Springs, CO.

Goals: Connecting physical and social science findings with regional water managers. Focus on decisions surrounding drought management and the implications of changing snowpack for water supply forecasting.

Livneh B., co-organized with CU faculty, Katja Friedrich and Peter Blanken, University of Colorado, Boulder, October, **2015**, Reservoir Evaporation Workshop.

Goals: Bring together national and state agencies with university scientists to define the state of the science and identify key needs.

REVIEWING

Panelist for proposal review

Panelist NASA Cyclone Global Navigation Satellite System (CYGNSS), held virtually, February 2021.

Lead Panelist NASA Postdoctoral Program (NPP), virtual panels held April 2020, August 2020, December 2020.
Panelist NASA Terrestrial Hydrology Program (THP), Silver Spring MD, November 2017.

Proposal review
U.S. Agency for International Development (USAID) Partnerships for Enhanced Engagement in Research (PEER) Program (2020)
National Science Foundation (NSF) Hydrological Sciences Program: proposal reviewer (2015, 2018, 2020)
National Environment Research Council (NERC, UK): proposal reviewer (2014)
NOAA: Internal reviewer (2015)
NASA Postdoctoral Program (NPP) reviewer (2015-)
NASA Graduate Fellowships (NESSF) reviewer (2017)
NASA Established Program to Stimulate Competitive Research (EPSCoR) reviewer (2020)

Nebraska Research Initiative (NRI) reviewer (2017)
US Bureau of Reclamation (S&T Program) reviewer (2015-)
US-Israel Binational Science Foundation: proposal reviewer (2014)

Journal reviewer:
Climatic Change, Climate Dynamics, Cold Regions Science and Technology, Earth's Future, Ecohydrology, Earth Interactions, Environmental Modeling and Software, Environmental Research Letters, Geophysical Model Development, Geophysical Research Letters, Hydrologic Processes, Hydrology and Earth System Sciences, International Journal of Climatology, Journal of Climate, Journal of Geophysical Research, Journal of Hydrology, Journal of Hydrometeorology, Journal of the Atmospheric Sciences, Journal of Water Resource Planning and Management, Monthly Weather Review, Natural Hazards and Earth System Sciences, Nature Climate Change, Nature Partner Journals Climate and Atmospheric Science, Nature Scientific Data, Nature Scientific Reports, Science of the Total Environment, Stochastic Environmental Research and Risk Assessment, Water, Water Resources Research.

Reports: California's Fourth Climate Change Assessment (2018).

Convened Conference Sessions:

Livneh B., and S. Shukla, American Geophysical Union Fall Meeting, held virtually, Dec. **2020**: Advances in Quantifying Impacts and Extents of Land Use/Land Cover Change in Hydrology I Posters: *Oral H094, Posters H083*.

Livneh B., S. Shukla, N. Zegre, and C. Mohr, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: Advances in Quantifying Impacts and Extents of Land Use/Land Cover Change in Hydrology I Posters: *Oral H11B, H12C, Posters H13K*.

Livneh B., and S. Shukla, American Geophysical Union Fall Meeting, Washington, DC, Dec. **2018**: Advances in Quantifying Impacts and Extents of Land Use/Land Cover Change in Hydrology I Posters: *Oral H21A, Posters H11J*.

Livneh B., S. Zipper, S. Shukla, and L. Condon, American Geophysical Union Fall Meeting, New Orleans, LA, Dec. **2017**: Understanding the Extent and Impacts of Land-Use/Land-Cover and Climate Change on Water Resources: *Oral H42H, Posters H42J*.

Livneh B., N. Montaldo, S. Shukla, and G. Vico, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2016**: Understanding the Extent and Impacts of Land-Use/Land-Cover and Climate Change on Ecohydrology: *Oral H33R, Posters H33G*.

Livneh B., S. Shukla, A.A. Harpold and S. Kumar, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2015**: Understanding the Extent and Impacts of Land Use/Land Cover Change on Hydrology: *Oral H13S, Posters H11I*.

Livneh B., S. Shukla, and A. Gaughan, and B. Buma, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2014**: Understanding the Extent and Impacts of Land Use/Land Cover Change on Hydrology: *Oral H51T, Posters H53E*.

Livneh B., S. Archfield, and R. Kumar, and R. Singh, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2013**: Regional Hydroclimatic Observations, Patterns, Changes, and Implications for Modeling: *Oral H32E, Posters H33G*.

2013 Co-chair of Symposium Steering Committee, *CU-Boulder Hydrologic Sciences Program*.

INVITED PANELIST

Pacific Northwest Drought Early Warning System 2020 Drought and Climate Outlook, held virtually, Dec. **2020**. Panelists: John Abatzoglou, Andrea Bair, Daniel Leavell, Bart Nijssen, and **Ben Livneh**.

Oregon-Washington Water Year 2020 Recap and 2021 Outlook Meeting, held virtually, Oct. **2020**. Panelists: Kirby Cook, **Ben Livneh,** Jeff Marti, Steve Jilk, Kelsey Jensco, Guillaume Mauger, Steve King, and Bart Nijssen.

Wyoming Fish and Game Department Climate Workshop, held virtually, Apr **2020**. Panelists: Bryan Shuman, Imtiaz Rangwala, **Ben Livneh,** Annika Walters, Molly Cross, Patrick Donnelly.

The Future of Skiing: The Science Behind Snow, Arapahoe Basin Ski Area, Dillon, CO, Apr **2018**. Panelists: Jennifer Kay, Marca Hagenstad, Lindsay Bourgoine.

State-of-the-art Uncertainty Analysis in Hydroclimate Modeling, World Environmental and Water Resources Congress, Sacramento, CA, May **2017**. Panelists: Jery Stedinger, Soroosh Sorooshian, **Ben Livneh**, Paul Bloch.

Updating the National-scale Water Balance for Chile: Experts Workshop, Universidad de Chile, Santiago, Chile, Mar **2017**. Panelists: John Pomeroy, Scott Tyler, **Ben Livneh,** Graham Fogg.

Downscaling climate and hydrology data, Climate Change and Water Working Group (CCAWWG), Seattle, WA, Aug **2015**. Panelists: Martyn Clark, **Ben Livneh,** Bart Nijssen.

Strengths, Weaknesses, and Motivations for Creating a Large-Scale Hydrologically Consistent Dataset, Workshop on Quantitative Evaluation of Downscaled Data, National Centers for Atmospheric Research (NCAR), Aug **2013**.

INVITED TALKS

Livneh, B. (Invited), Niwot Ridge and City of Boulder Water and Climate Summit, *held virtually,* Feb. **2021**: Alternatives to Snow-Based Prediction of Seasonal Water Supply.

Livneh, B. (Invited), American Meteorological Society Annual Meeting, *held virtually,* Jan. **2021**: Joint 11.2 The Resilience of Computational Approaches for Future Water Supply Predictions in California.

Livneh, B. (Invited), Pacific Northwest Drought Early Warning System 2020 Drought and Climate Outlook, *held virtually,* Dec. **2020**: Identifying Alternatives to Snow-based Streamflow Predictions to Advance Future Drought Predictability.

Livneh, B. (Invited), Oregon-Washington Water Year 2020 Recap & 2021 Outlook Meeting, *held virtually,* Oct. **2020**: Future Changes in Drought Predictability in the Western U.S.

Livneh, B. (Invited), North Central Climate Adaptation Science Center (NC CASC), Snow Collider, Projecting Rocky Mountain Snow Persistence and Depth Under Climate Change Workshop, *held virtually*, Jun. **2020**: Recent experiences in modeling mountain snow in the western U.S.

Livneh, B. and N.R. Bjarke (Invited), Wyoming Fish and Game Department Climate Workshop, *held virtually*, Apr. **2020**: Climate change impacts on Wyoming Streamflow and Snowpack.

Livneh, B (Invited), Colorado School of Mines, Economics-Business Seminar Series, Golden, CO., Sep. **2019**: Predicting the fate of our water: A look at the changing roles of snow and forests for water supply prediction.

Livneh, B (Invited), Texas Water Development Board Meeting, Austin, TX, Feb. **2019**: Estimating reservoir evaporation: Evaluating current and future practices and research-to-operations pathways.

Livneh, B. (Invited), American Geophysical Union Fall Meeting, Washington, DC, Dec. **2018**: *H12H-22 What makes watersheds sensitive to forest disturbance?*

Livneh B. (Invited), Princeton University, Princeton NJ, July **2018**: *Understanding Natural and Anthropogenic Impacts on the Water Cycle through Analysis of Soil Moisture and Snowpack.*

Livneh B. (Invited), NASA Goddard Space Flight Center, College Park, MD, July **2018**: *Using Soil Moisture and Snowpack Variability to Predict Variations in the Water Cycle.*

Livneh B. (Invited), National Centers for Environmental Prediction, Environmental Modeling Center, College Park, MD, July **2018**: Hydrologic Prediction through Changes in Soil Moisture and Snowpack: Estimating Natural and Anthropogenic Fluxes. [Video: https://www.youtube.com/watch?v=uvFH7xWAeJE]

Livneh, B. (Invited), The Future of Skiing: The Science Behind Snow, Arapahoe Basin Ski Area, Dillon, CO. Apr., **2018**: The importance of Snowpack on Water Resources in the Upper Colorado River Basin.

Livneh, B. (Invited), Rocky Mountain National Park Science Symposium, Continental Divide Research Learning Center, Mar., **2018**: Assessing the impacts of land-cover changes and snowpack changes on hydrology in the western U.S.

Livneh, B. (Invited), A.M. Badger, J.J. Lukas, L. Dilling, and R. Page, American Geophysical Union Fall Meeting, New Orleans, LA, Dec. **2017**: *H14H-01 Characterizing Drought Risk Management and Assessing the Robustness of Snowpack-based Drought Indicators in the Upper Colorado River Basin.*

Livneh, B. (Invited), University of Nebraska, School of Natural Resources, Fall Seminar Series: *Our Natural Resources in a Changing Environment* Oct., **2017**: The Role of Climate on Hydrologic Extremes in the Northern Great Plains Region: Updates from the National Climate Assessment [Video: https://mediahub.unl.edu/media/8608].

Livneh, B. (Invited), *Updating the National-scale Water Balance for Chile: Experts Workshop*, Universidad de Chile, Santiago, Chile, Mar **2017**: Continental-scale Hydrometeorology: Application to an Extreme Hydrologic Event.

Livneh, B. (Invited), *Frontiers in Geosciences Lecture*, Los Alamos National Laboratory, Los Alamos, NM, Feb **2017**: Watershed Response to Hydrologic Disturbances: Local, Regional, and National Perspectives.

Livneh B. (Invited), Missouri River Basin Federal Climate Collaboration Webinar, Aug., **2016**: Hydrologic Extremes in the Upper Missouri Basin and Central Great Plains.

Livneh B. (Invited), United States Geological Survey, Lakewood, CO, June, **2016**: Modeling Watershed Response to Hydrologic Extremes in the Upper Missouri River Basin and Colorado Front Range.

Livneh B. (Invited), and J.R. Stewart, U.S. Bureau of Reclamation— Sedimentation and River Hydraulics Group, Lakewood, CO, May, **2016**: Development of a multi-physics modeling framework for analyzing the effects of disturbance on suspended sediment flow in the Colorado Front Range.

Livneh B. (Invited), Lamont Doherty Earth Observing Laboratory, Palisades, NY, Apr., **2016**: A Land-Surface Perspective of Extremes in the Upper Missouri Basin and Central Great Plains.

Livneh B. (Invited), Columbia Water Center, New York, New York, Apr., **2016**: From Scarcity to Overabundance: Hydrologic Extremes in the Northern and Central Great Plains, USA.

Livneh B. (Invited), J.S. Deems, B. Buma, J.S. Stewart, J.J. Barsulgi, D. Schneider, N.P. Molotch, C.A. Wessman, and K. Wolter, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2015**: *Hydrologic impacts of land cover disturbances in the Upper Colorado River Basin.*

Livneh, B. (Invited), Climate Change and Water Working Group (CCAWWG), Seattle, WA, August **2015,** Summary of Intermountain West Climate Networks.

Livneh, B. (Invited), American Meteorological Society, Mountain Meteorology Webinar Series, July, **2014**. The treatment of snow in numerical model land surface schemes.

Livneh, B. (Invited) and J.S. Deems, Wyoming State Engineers Forum, Cheyenne, WY, May, **2014**. Beetles and Dust: unraveling influences on snowmelt and streamflow timing in the Upper Colorado River Basin.

Livneh, B. (Invited) Workshop on Quantitative Evaluation of Downscaled Data, National Centers for Atmospheric Research (NCAR), Aug., **2013**: Strengths, Weaknesses, and Motivations for Creating a Large-Scale Hydrologically Consistent Dataset.

Livneh, B. (Invited), Water Education Foundation, Lower Colorado River Tour, Las Vegas, NV, Hoover Dam, AZ, Imperial Irrigation District, CA, Mar. **2013**, Colorado River Spring 2013 Runoff Outlook; Climate Change Projections on the Colorado River Basin – The Long Perspective from GCMs and Tree Rings.

Livneh, B. (Invited), J.S. Deems, and B. Buma, National Centers for Atmospheric Research (NCAR) Seminar, Boulder, CO, Jan. **2013**, Deciphering the impacts of competing hydrologic disturbance factors in the Upper Colorado River Basin.

Livneh, B. (Invited), Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germany, May, **2012**, Development of a Unified Land Model and Multi-Criteria Parameter Identification.

PRESENTATIONS

Pierce, DW, DR Cayan, MD Risser, **B Livneh**, and DP Lettenmaier, American Geophysical Union Fall Meeting, held virtually, Dec. **2020**: *H175-09 - An Extreme-Preserving Long-Term Gridded Daily Precipitation Data Set for the Conterminous United States.*

Livneh, B, M O'Donnell, P. Modi, *AM Badger, and NR Bjarke, American Geophysical Union Fall Meeting, held virtually, Dec. **2020**: *H190-03 - Seasonal Drought Prediction: The Changing Role of Snow in Water Supply Forecasting across the Western U.S..*

Brucker, C, **B Livneh**, F Rosario-Ortiz, P Wilkerson, A Heldmyer, and JT Minear, American Geophysical Union Fall Meeting, held virtually, Dec. **2020**: *H087-0019 - An observational framework for quantifying post-fire sediment and water quality response.*

Culler, ES, *AM Badger, **B Livneh**, KF Tiampo, and JT Minear, American Geophysical Union Fall Meeting, held virtually, Dec. **2020**: NH030-0028An evaluation of uncertainty in extreme landslide-triggering precipitation, *NH030-0028 - An evaluation of uncertainty in extreme landslide-triggering precipitation.*

Bjarke, NR, **B Livneh**, JJ Barsugli, and MP Hoerling, American Geophysical Union Fall Meeting, held virtually, Dec. **2020**: *H102-11 - Precipitation variability and the future of water in the West: A multi-catchment analysis.*

*Yao, F, J Wang, **B Livneh**, B Rajagopalan, J-F Cretaux, and Y. Wada, American Geophysical Union Fall Meeting, held virtually, Dec. **2020**: *H025-07 - Quantifying and attributing recent changes in global lake and reservoir storage using satellite observations and hydrological modeling.*

Minear, JT, JL McCreight, L Read, T Enzminger, AJ Heldmyer, and **B Livneh**, American Geophysical Union Fall Meeting, held virtually, Dec. **2020**: *H014-06 - Utilizing Discharge Flow Measurements to Estimate Continental-Scale Hydraulic Resistance and Channel Geometry.*

Modi, P, EE Small, CW Wobus, J Carbone, and **B Livneh**, American Geophysical Union Fall Meeting, held virtually, Dec. **2020**: *GC025-0006 - The Impacts of Drought and Water Allocation Practices on River Systems and Communities.*

Wang, G, C Kirchoff, J Abatzoglou, **B Livneh**, and D Pierce, American Geophysical Union Fall Meeting, held virtually, Dec. **2020**: *GC090-08Projected changes of precipitation extremes in the U.S. Northeast based on two downscaled climate datasets LOCA and MACA.*

Knowles, JF, AM Badger, MB Berkelhammer, JA Biederman, NR Bjarke, P Blanken, M Bretfeld, SP Burns, BE Ewers, JM Frank, L Lestak, **B Livneh**, DE Reed, RL Scott, and NP Molotch, American Geophysical Union Fall Meeting, held virtually, Dec. **2020**: *B064-0003 - Bark Beetle Impacts on Forest Evapotranspiration and its Partitioning.*

Abolafia-Rosenzweig, R., **B. Livneh**, and M. Pan, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: *H44G-07 - REESEN: A remotely-sensed ensemble for estimating the terrestrial water balance.*

O'Donnell, M., *A. Badger, A. Wood, and **B. Livneh**, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: *H14E-07 - The implications of changes in peak SWE timing and magnitude for drought prediction in the Western U.S.*

Kampf, S., A. Eurich, J. Hammond, **B. Livneh**, K. Puntenney, G. Richard, J. Sholtes, and H. Harrison, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: *H31A-08 - What is the fate of snowmelt water in the Colorado Rocky Mountains?.*

Heldmyer, A.J., **B. Livneh**, W. Farmer, J. Driscoll, and N. Molotch, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: *C33C-1592 - An observationally-based spatial SWE model for the western United States and Alaska.*

Brucker, C., **B. Livneh**, A. Heldmyer, F. Rosario-Ortiz, and J.T. Minear, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: *H23S-2179 - An observational framework for quantifying post-fire runoff and sediment response.*

Culler, E.S., **B. Livneh**, K. Tiampo, and B. Rajagopalan, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: *H23S-2176 - A data-driven approach to identifying post-fire landslide triggers.*

Bjarke, N.R., **B. Livneh**, and J. Cepeda, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: *H23J-2037 - Implications of Hydrometeorological Data Infilling for Portrayal of Hydrological Variability in High Alpine Environments.*

Livneh, B., R. Abolafia-Rosenzweig, *A. Badger, and E. Small, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: *H54E-03 - A SMAP-based Continental-scale Soil Evaporation Dataset.*

Barsugli, J.J., M. Hoerling, **B. Livneh**, and Q. Xiaowei, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: *A11Q-2746 - Evaluating hydrologic realism across scales in mountainous regions: a Budyko approach.*

Safeeq, M., **B. Livneh**, R. Bart, C. Kumar, and S. Shukla, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: *H33M-2151 - Assessment of hydrologic impacts of climate change in the Sierra Nevada: comparisons between radiative change and CO2 fertilization.*

Kumar, S., M. Newman, D. Lawrence, M-H., Lo, S. Akula, C-W, Lan, **B. Livneh**, and D. Lombardozzi, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2019**: *H54G-06 - The GLACE-Hydrology Experiment: Effects of Land-Atmosphere Coupling on Soil Moisture Variability and Drought Predictability.*

Culler, E.S., **B. Livneh** and K. Tiampo, 13th Annual Earth System and Space Science Poster Conference, Boulder, CO, Dec **2019**: *A data-driven approach to identifying post-fire landslide triggers*

Barsugli, Joseph J , Andrea J. Ray, **B. Livneh**, Candida Dewes, Aaron Heldmeyer, Imtiaz Rangwala, John Guinotte and Stephen Torbit, The Wildlife Society and American Fisheries Society Joint Conference, Reno, NV, Sep., **2019**: *High-Resolution Projections of Snowpack Persistence in Occupied and Potential Wolverine Habitat in the Rocky Mountains. Presentation.*

Brucker, C.B., A.J. Heldmyer, **B. Livneh**, F.L. Rosario-Ortiz, and J.T. Minear, Sedimentation and Hydrology Conference, Reno, NV, June **2019**: *Wildfires in the West: Characterizing Drivers of Post-Disturbance Hydrologic and Sediment Response through Laboratory Analysis.*

Heldmyer, A.J. and **B. Livneh**, Federal Interagency Sedimentation and Hydrologic Modeling Conference, Reno, NV, June **2019***: 205: Wildfire in the West: Assessing the Detectability of a Post-fire Signal at the Watershed Scale.*

Culler, E.S., **B. Livneh** and K. Tiampo, Community Surface Dynamics Modeling System Annual Meeting, Boulder, CO, May **2019**: *Modeling the hydrology of a post-fire landslide: Case study of the Thomas Fire, CA.*

O'Donnell, M.C., JR Kasprzyk, **B Livneh**, and L Bensching, ASCE World Environmental & Water Resources Congress, Pittsburgh, PA, May **2019**: *Exploring Regional Rates of Reservoir Sedimentation.*

*Badger, A. M., **B. Livneh**, and N. P. Molotch, World Environmental and Water Resources Congress, Pittsburgh, PA, May **2019**: *On the role of spatial snow distribution on alpine catchment hydrology.*

Livneh, B., L. Dilling, A. M. *Badger, and R. Page, CIRES Rendezvous, Boulder, CO, May **2019**: Advancing the use of drought early warning systems in the Upper Colorado River Basin: A transdisciplinary project.

Abolafia-Rosenzweig, R., **Livneh, B**. and Small, E.E., CIRES Rendezvous, Boulder, Colorado, May **2019**: *A data assimilation framework to estimate irrigation: merging soil moisture retrievals with land surface models*

*Badger, A. M., **B. Livneh**, and N. P. Molotch, Hydrologic Sciences Research Symposium, Boulder, CO, April **2019**: *The role of spatial snow variability on alpine catchment hydrology.*

Brucker, C.B., A.J. Heldmyer, **B. Livneh**, F.L. Rosario-Ortiz, and J.T. Minear, Hydrologic Sciences Symposium, Boulder, CO, April **2019**: *Simulator of Wildfire Impacts on Watersheds across the Western U.S.*

Heldmyer, A.J., **B. Livneh**, W. Farmer, J. Driscoll, and N. Molotch, Hydrologic Sciences Student Research Symposium, Boulder, CO, Apr. **2019**: *An Observationally-based spatial SWE model for the western United States: applications in montane subdomains.*

Livneh, B., Workshop on Adaptation Strategies for Sustainable Drinking Water Utility Management Under Drought and Climate Change, Boulder, CO., Mar., **2019**: *Modeling watershed-scale sediment response to climate and wildfire.*

Livneh, B., *A.M. Badger, J. Cepeda, N.P. Molotch, and K. Suding, City of Boulder Climate Change Seminar, Jan. **2019:** *Hydrologic Response to Climatic Variability in the Green Lakes Valley Watershed.*

Abolafia-Rosenzweig, R., **B. Livneh**, Y. Xia, P.A. Dirmyer, S.V. Kumar, C.D. Peters-Lidard, H. Wei, and J. Kain, American Meteorological Society Annual Meeting, Phoenix, AZ, Jan. **2019**: *2B.3 Comparing Operational NLDAS-2 and Experimental NLDAS-3 Soil Moisture with Observational Soil Moisture Data from In-Situ Networks and SMAP Remote Sensing*.

Barsugli, J.J., M. Hoerling, J. Eischeid, K. Wolter, and **B. Livneh**, American Meteorological Society Annual Meeting, Phoenix, AZ, Jan. **2019**: *6.4 How Well Do Observations Constrain the Sensitivity of the Upper Colorado River Basin Streamflow to Temperature and Precipitation Trends?*

Culler, E.S., **B. Livneh**, B. Corsa and K. Tiampo, American Geophysical Union Fall Meeting, Washington, DC, Dec. **2018**: *H23L-2104: A Global Analysis of the Role of Wildfires on Landslide Susceptibility.*

*Badger, A.M., **B. Livneh**, K. Tiampo, J.T. Minear, and C. Williams, American Geophysical Union Fall Meeting, Washington, DC, Dec. **2018**: *H51C-08 Evaluating Differences in Precipitation Datasets for Characterizing Cascading Hazards.*

Raseman W.J, J.R. Kasprzyk, R.S. Summers, B. Rajagopalan, F. Rosario-Ortiz, W. Kleiber, and **B. Livneh**, American Geophysical Union Fall Meeting, Washington, DC, Dec. **2018**: *H21Q-1932 Advancing Stochastic Water Quality and Simulation-Optimization Techniques for Potable Water Systems Facing Source Water Quality Degradation.*

Heldmyer, A.J, and **B. Livneh**, American Geophysical Union Fall Meeting, Washington, DC, Dec. **2018**: *H23L-2130 Wildfire in the West: Characterizing Spatial Trends in Post-disturbance Hydrologic and Sediment Response at the Watershed Scale.*

Livneh, B., R. Abolafia-Rosenzweig, E.S. Small, A.M. Badger, and S. V. Kumar, American Geophysical Union Fall Meeting, Washington, DC, Dec. **2018**: *H23A-06 A framework for predicting irrigation through soil moisture data assimilation.*

Migone, B., K. Averyt, D. C. Steinberg, J. Macknick, K. Eurek, Y. Sun, *A. M. Badger, and **B. Livneh**, USAEE/IAEE North American Conference, Washington, DC, September **2018**: *Decomposing supply and demand-side impacts of climate change on the U.S. electricity system through 2050.*

Livneh B., *Badger, A.M, and Lukas, J.J., Advancing Drought Early Warning Workshop, Glenwood Springs, CO, Aug **2018**: *Snowpack-streamflow modeling results: How well does snowpack predict streamflow in a future climate?*

Minear, J.T., Tiampo, K., **B. Livneh,** M. Willis, C. Williams, *A. Badger, and M. Jacquemart, Asia Oceania Geosciences Society Meeting, Honolulu, Hawaii, USA, June, **2018**: *The Interaction of Mass Movements with Natural Hazards Under Changing Hydrologic Conditions.*

Livneh, B., PA.M. Badger, J.J. Lukas, L. Dilling, and R. Page, Global Energy and Water Cycle Experiment (GEWEX) Meeting, Canmore, Alberta, Canada, May, **2018**: *Characterizing Drought Risk Management and Assessing the Robustness of Snowpack-based Drought Indicators in the western U.S.*

B. Livneh. (Invited), Earthlab Extremes Collider, Boulder, CO, May **2018**: *Regional Extremes: What, Why, and How.*

Shellito P., E.E. Small, and **B. Livneh**, Global Energy and Water Cycle Experiment (GEWEX) Meeting, Canmore, Alberta, Canada, May, **2018**: *Controls on surface soil drying rates observed by SMAP and simulated by the Noah land surface model.*

Heldmyer, A.J., **B. Livneh**, and S. Kampf, CIRES Rendezvous, Boulder, CO, May **2018**: Sedimentation and runoff in the Colorado Front Range: Diagnosing fire-related changes.

Abolafia-Rosenzsweig, R., **B. Livneh**, E.S. Small, and PA.M. Badger, Colorado State University, Hydrology Days, Fort Collins, CO, Mar. **2018**: *Evaluation of soil moisture data assimilation to improve hydrologic partitioning over agricultural areas*.

Heldmyer, A.J., **B. Livneh**, and S. Kampf, Colorado State University, Hydrology Days, Fort Collins, CO, Mar. **2018**: *Assessing the Impacts of Wildfire on Sedimentation and Runoff in the Colorado Front Range*.

Newman, M, S. Kumar, Y. Want, and **Livneh, B.**, American Meteorological Society Annual Meeting, Austin, TX, Jan. **2018**: *Potential Reemergence of Seasonal Soil Moisture Anomalies in North America*.

Livneh, B., E.S. Small, *A.M. Badger, and R. Abolafia-Rosenzweig, American Meteorological Society Annual Meeting, Austin, TX, Jan. **2018**: *Using SMAP Satellite Observations to Estimate Terrestrial Evaporation Rates*.

*Badger, A.M., **B. Livneh**, E.E. Small, and R. Abolafia-Rosenzweig, American Geophysical Union Fall Meeting, New Orleans, LA, Dec. **2017**: *H11M-02 A Method for a Multi-Platform Approach to Generate Gridded Surface Evaporation.*

Kasprzyk, J.R. R. Smith, W. J. Raseman, M.A. DeRousseau, L. Dilling, K. Ozekin, R.S. Summers, R. Balaji, **B. Livneh**, F. Rosario-Ortiz, L. Sprain., and W.V. Srubar III, American Geophysical Union Fall Meeting, New Orleans, LA, Dec. **2017**: *PA41A-0289 Collaborative Workshops for Assessment and Creation of Multi-Objective Decision Support for Multiple Sectors.*

Ray, A.J, J.J. Barsugli, J.M. Guinotte, **B. Livneh**, C. Dewes, I. Rangwala, A. Heldmyer, and S. Torbit, American Geophysical Union Fall Meeting, New Orleans, LA, Dec. **2017**: *GC31A-0993 Co-production of Snow Projections for a Study of Snow Persistence Projections for the American Wolverine Gulo gulo.*

Heldmyer, A.J, **B. Livneh,** J.J. Barsugli, J.M. Guinotte C. Dewes, and S. Torbit, American Geophysical Union Fall Meeting, New Orleans, LA, Dec. **2017**: *C53A-1006 Simulation of Current and Projected Montane Snowpacks for the Preservation of the Wolverine in the Western U.S.*

Sun, Y., K. Eurek, J. Macknick, D.C. Steinberg, K. Averyt, *A. Badger, and **B. Livneh**, American Geophysical Union Fall Meeting, New Orleans, LA, Dec. **2017**: *GC31D-1033 Decomposing climate-induced temperature and water effects on the expansion and operation of the US electricity system.*

Jennings, K.S., T. Winchell, **Livneh, B.**, and N.P. Molotch, American Geophysical Union Fall Meeting, New Orleans, LA, Dec. **2017**: *H41N-05: Precipitation phase partitioning variability across the Northern Hemisphere.*

Kumar, S.J., M. Newman, D.M. Lawrence, **Livneh, B.**, and D. Lombardozzi, American Geophysical Union Fall Meeting, New Orleans, LA, Dec. **2017**: *H42B-02: Land-atmosphere coupling and soil moisture memory contribute to long-term agricultural drought.*

S. Redfern, **Livneh, B.**, N.P. Molotch, K. Suding, J.C. Neff, and E. Hinkley, American Geophysical Union Fall Meeting, New Orleans, LA, Dec. **2017**: *H43C-1656: Catchment Integration of Sensor Array Observations to Understand Hydrologic Connectivity.*

Livneh, B., *A.M. Badger, J. J. Lukas, R. Page, and L. Dilling, *Upper Colorado River Basin Water Forum*, Colorado Mesa State University, Nov **2017**: *Assessing the robustness of spring snowpack as a drought indicator in the Upper Colorado River Basin under future climate change.*

Heldmyer, A.J., **Livneh, B.**, and B. Rajagopalan, *Upper Colorado River Basin Water Forum*, Colorado Mesa State University, Nov **2017**: *Assessing the Impacts of Drought and Wildfire on the Colorado Front Range.*

Livneh, B. NASA SUSMAP Workshop, Massachusetts Institute of Technology (MIT), Oct., **2017**: *Using the SMAP soil drying cycle to produce a unique estimate of direct evaporation from soil: E-SMAP.*

Livneh, B., CVEN 5333 Advanced Hydrology, Guest Lecture, CU-Boulder, Oct., **2017**: *An Overview of Distributed Hydrologic Modeling.*

Livneh, B. (Invited), EarthLab Postdoctoral Mentoring Series, University of Colorado, Sep., **2017**: *How to write a strong academic research statement.*

Livneh, B., S. Redfern, N.P. Molotch, E. Hinckley, and J. Neff, Niwot Ridge Annual Team Meeting, University of Colorado, Jul. **2017:** *Integration of Sensor Array Observations to Understand Hydrologic Connectivity.*

Livneh, B. (Invited), International English Center, University of Colorado, May., **2017**: *Drought in Colorado: What you should know.*

Livneh, B., *A.M. Badger, and J. J. Lukas, World Environmental and Water Resources Congress, Sacramento, CA, May **2017**: *Assessing the robustness of snow-based drought indicators in the Upper Colorado River Basin under future climate change*.

Stewart, J.R., B. Rajagopalan, J.R. Kasprzyk, W.J. Raseman, and **B. Livneh**, World Environmental and Water Resources Congress, Sacramento, CA, May **2017**: *The Use of Ensemble Modeling of Suspended Sediment to Characterize Uncertainty.*

Carbone, E., E.E. Small, *A. Badger, and **B. Livneh**, CU-Boulder Hydrologic Sciences Symposium, Boulder CO, Apr. **2017:** *Generating a global soil evaporation dataset using SMAP soil moisture data to estimate components of the surface water balance.*

Kasprzyk, J.R., J.R. Stewart, and **B. Livneh**, CU-Boulder Hydrologic Sciences Symposium, Boulder CO, Apr. **2017:** *Improving the Holistic Calibration of Simulated Hydrologic Processes using Multiple Objectives.*

Livneh B. National Climate Assessment, Northern Great Plains Regional Engagement Workshop, Fort Collins, CO, Feb, **2017**: *Impacts of Climate Change on Northern Great Plains Water Resources.*

*Badger, A.M., J.K. Eischeid, M.P. Hoerling, and **B. Livneh**, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2016**: *Analysis of Recent Changes in Extreme Hydrologic Events in the Upper Missouri River Basin.*

Macknick, J., K. Averyt, **B. Livneh**, *A. Badger, D.C. Steinberg, K. Eurek, and R.L. Newmark, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2016**: *Isolating the effects of climate-mediated changes in temperature and water availability on the capacity expansion and operations of the U.S. power sector.*

Zhang, Q., M.W. Williams, and **B. Livneh**, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2016**: *Streamflow predictions under climate scenarios in the Boulder Creek Watershed at Orodell.*

Stewart, J., W.J. Raseman, J.R. Kasprzyk, R. Balaji, and **B. Livneh**, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2016***: Ensemble Modeling of Suspended Sediment in Steep Mountain Catchments.*

Raseman, W.J., J.R. Kasprzyk, F. Rosario-Ortiz, R.S. Summers, J. Stewart, and **B. Livneh**, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2016:** *Multi-objective Optimization for the Robust Performance of Drinking Water Treatment Plants under Climate Change and Climate Extremes.*

Livneh, B., *A. Badger, N.P. Molotch, C. Bueno de Mesquita, and K. Suding, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2016:** *Hydrologic Response to Climatic and Vegetation Change in an Extreme Alpine Environment.*

Carbone, E., E.E. Small, *A. Badger, and **B. Livneh**, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2016:** *Generating a global soil evaporation dataset using SMAP soil moisture data to estimate components of the surface water balance.*

Kumar, S., M. Newman, D.M. Lawrence, and **B. Livneh**, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2016:** *Intensified multi-year droughts in California due to land-atmosphere interactions and land-memory processes.*

Yanto, M., J.R. Kasprzyk, B. Rajagopalan, and **B. Livneh**, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2016:** *Multi-objective Optimization Based Calibration of Hydrologic Model and Ensemble Hydrologic Forecast for Java Island, Indonesia.*

Livneh, B., CEAE Water Resources Seminar, CU-Boulder, Sep **2016**: *Hydrologic Interactions Across Multiple Scales: Drought, Disturbance and Responses.*

Livneh, B. (Invited), International English Center, University of Colorado, Aug., **2016**: *Drought in Colorado: What you should know.*

Kumar S., M. Newman, Y. Wang, and **B. Livneh,** 21st Annual CESM Workshop, 20-23, Breckenridge, Colorado USA June **2016**: *Potential re-emergence of seasonal soil moisture anomalies in North America.*

Livneh B. (Invited) and J.R. Stewart, Sedimentation Impacts Under Climate Change (SIUCC) Virtual Course, Boulder, CO, June, **2016**: *A multi-physics modeling framework for the Colorado Front Range.*

Barnhart, T.B., N.P. Molotch, **B. Livneh**, A.A. Harpold, J.F. Knowles, and D. Schneider, Western Snow Conference, Seattle, WA., Apr. **2016**: *Rapid Snowmelt Leads to Greater Streamflow Across the Western United States.*

Winchell, T.S., **Livneh, B.**, Molotch, N.P., Western Snow Conference, Seattle, WA, Apr. **2016**: *Variation of the Rain-Snow Temperature Threshold Over North America.*

Barnhart, T.B., **B. Livneh**, D.J. Gochis, and N.P. Molotch, University of Colorado Hydrologic Sciences Symposium, Boulder, CO., Mar, **2016:** *Streamflow Sensitivity to Changes in Snowpack Across Trans-Basin Diversions.*

Barnhart, T.B., **B. Livneh**, D.J. Gochis, and N.P. Molotch, Water Sustainability and Climate Principle Investigator Meeting, Arlington, VA., **2016**: Streamflow Sensitivity to Changes in Snowpack Across Trans-Basin Diversions, poster.

Newman M, Wang, Y., Kumar S., and **Livneh, B.**, National Centers for Atmospheric Research, Boulder, CO, Feb. **2016**: *Potential re-emergence of seasonal soil moisture anomalies in North America.*

Livneh, B., K. Friedrich, R. Grossman, J. Huntington, and P. Blanken, American Meteorological Society Annual Meeting, New Orleans, LA, Jan. **2016**: *Estimating reservoir evaporation: Evaluating current and future practices and research-to-operations pathways*.

Kim J, Cifelli R., Johnson L.E., **Livneh, B.**, and V. Chandrasekar, American Meteorological Society Annual Meeting, New Orleans, LA, Jan. **2016**: *Comparison of Semi-Distributed and Fully Distributed Hydrological Models in Complex Terrain.*

Livneh, B., and M.P. Hoerling, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2015**: *Assessing Causes of Hydrologic Extremes in the Upper Missouri Basin.*

Barnhart, B., **Livneh B.,** N.P. Molotch, J. Knowles, A.A. Harpold, and D. Schneider, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2015**: *Rapid Snowmelt Leads to Greater Streamflow Across the Western United States.*

Hoerling, M.P., and **Livneh B.,** American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2015**: *The Physics of Great Plains Drought.*

Buma B., and **Livneh B.,** American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2015**: *Quantifying the Sensitivity of Water Yield to Forest Disturbances Across a Diverse Set of Unmanaged Watersheds throughout the Continental United States.*

M. Yanto, **B. Livneh**, B. Rajagopalan, and J.R. Kasprzyk, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2015**: *Hydrologic Modeling and Parameter Estimation under Data Scarcity for Java Island, Indonesia.*

Kim J, Cifelli R., Johnson L.E., **Livneh, B.**, and V. Chandrasekar, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2015**: *Effect of Rainfall Spatial Distribution on Flood Forecasting in Complex Terrain.*

Cheng L., Hoerling M.P., Aghakouchak A., **Livneh B.**, Qian X-W., Eischeid J, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2015**: *How Has Human-induced Climate Change Affected California Drought Risk?*

Kim J, Cifelli R., Johnson L.E., **Livneh, B.**, and V. Chandrasekar, America Water Resources Association, 2015 Annual Water Resources Conference, Denver, CO, Nov **2015**: *Comparison of Distributed Rainfall-Runoff models: A Case Study for the Storm Event on December 10, 2014.*

Livneh, B. (Invited), U.S. Army Corps of Engineers, Omaha, NE, Nov **2015**: *Assessing Causes for Hydrologic Extremes in the Upper Missouri Basin.*

Hoerling M. P., and **Livneh, B.**, Implications of a Changing Arctic on Water Resources and Agriculture in the Central U.S., Lincoln, NE, Nov **2015**: The Physics of Great Plains Drought.

Livneh, B., CEAE Water Resources Seminar, CU-Boulder, Nov **2015**: *Hydrologic Interactions Across Multiple Scales: Drought, Disturbance and Responses.*

Livneh, B., and M. P. Hoerling, Climate Diagnostics and Prediction Workshop, Denver, CO, Oct **2015**: The Physics of Great Plains Drought: *It's Predictability and It's Changed Risk in a Warmer World.*

Newman, M., Y. Wang, S. Kumar, and **Livneh, B.**, Climate Diagnostics and Prediction Workshop, Denver, CO, Oct **2015**: The Seasonal and spatial dependence of soil moisture memory over North America.

Livneh, B. (Invited) ATOC 7500 Seminar Series: Reading the IPCC Working Group II and III Reports: Impacts and Mitigation, University of Colorado, Boulder, August **2015,** IPCC AR5 Working Group II Chapters 3 & 4: Fresh Water Resources/ Terrestrial and Inland Water Systems.

Livneh, B., Webinar for Climate Science Centers and National Center for Environmental Prediction, June **2015,** Development of a spatially comprehensive, daily hydrometeorological data set for Mexico, the conterminous U.S., and southern Canada: 1950-2013.

Livneh, B., and M. P. Hoerling, North Central Climate Science Center Conference, Fort Collins, CO, May **2015**, Assessing Antecedent Soil Moisture Impacts on Great Plains Drought Development.

Livneh, B., (Invited), CU-Boulder Hydrologic Sciences Symposium, Boulder, CO, Apr. **2015**, Establishing Proximal Causes of Soil Moisture Deficits Accompanying Great Plains Drought Development.

Livneh, B., and M. P. Hoerling, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2014**, Exploring the linkage between drought, high temperatures, and hydrologic sensitivities: A case study of the 2012 Great Plains drought.

Livneh, B., T.J. Bohn, R. Vose, and F. Munoz-Arriola. Tercera Reunión Annual de la Red de Desastres Hidrometeorológicos y Climaticos (REDESCLIM). Mexico City, Nov. **2014**. Base de Datos Hidroclimatica Subcontinental ("Hydroclimatic Subcontinental Database").

Bohn, T.J., **B. Livneh**, F. Munoz-Arriola, A. Robles-Morua, D.W. Pierce, R.S. Vose, and E.R. Vivoni, Mexican Geophysical Union (UGM) Annual Meeting, Puerto Vallarta, Jalisco, Mexico, Nov. **2014**. Long-Term Gridded Meterological Observations over the Continental US, Mexico, and Southern Canada, 1950-2013: Assessment over the North American Monsoon Region.

Livneh, B. (Invited), International English Center, University of Colorado, Aug., **2014**. Drought in Colorado: *What you should know*.

Livneh, B. (Invited), Evapotranspiration mini-workshop, North Central Climate Science Center, Fort Collins, CO, May, **2014**. Evapotranspiration via Water Balance Methods in Land Surface Models.

B. Buma, **B. Livneh ,** C. A. Wessman, Alaskan Coastal Rainforest Center lecture series, University of Alaska Southeast, Juneau AK, March, **2014**: Linking forest ecology, hydrology, and management to explore the implications of climate change on a critical ecosystem service.

Livneh, B. (Invited), National Centers for Atmospheric Research (NCAR) Seminar, Boulder, CO, Feb. **2014**: Hydrologic Interactions Across Multiple Scales: Stressors, Thresholds, and Responses.

Livneh, B., and J.S. Deems, AGU Chapman Conference on Seasonal to Interannual Hydroclimate Forecasts and Water Management, Jul., **2013**: From catchments to regional scales: hydrologic impacts of land cover disturbances in the Upper Colorado River Basin.

Livneh, B., and J. S. Deems**,** Climate Change Technology Conference, Montreal, QC, May, **2013:** Merging Satellite and Model Information to Improve Snowpack and Water Supply Forecasting.

Livneh, B. (Invited), Guest Lecture, Geology 5700, University of Colorado, Boulder, Apr. **2013**: Parameter Selection for Hydrologic Models.

Livneh, B. (Invited), J.S. Deems, and B. Buma, San Juan Bark Beetles & Watersheds Workshop, Durango, CO., Apr. **2013**: Beetles, Dust, and Climate Change: Unraveling Snowmelt Perturbations in the Intermountain West.

Livneh, B., E.A. Rosenberg, C. Lin, B. Nijssen, V. Mishra, K. Andreadis, E.P. Maurer, and D.P. Lettenmaier, American Meteorological Society Annual Meeting, Austin, TX, Jan. **2013**, A long-term hydrologically based dataset of land surface fluxes and states for climatic modeling and analysis over the conterminous United States.

Livneh, B., J.S. Deems, B. Buma, J.J. Barsugli, D. Schneider, N. Molotch, and C. Wessman, American Geophysical Union Fall Meeting, San Francisco, CA, Dec. **2012**, Interpreting changes to Upper Colorado River Basin hydrologic response via alternate climatic and land-cover scenarios.

Livneh, B., J.S. Deems, B. Buma, J.J. Barsugli, D. Schneider, and C. Wessman, Upper Colorado River Basin Water Conference, Grand Junction, CO, Nov. **2012**, Modeling Hydrologic Impacts of Bark Beetles and Desert Dust on Tributary Catchments of the Upper Colorado River Basin.

Livneh, B. (Invited), CU-Boulder Hydrology and Water Resource Seminar, Boulder, CO, Sep. **2012**, Development of a Land Surface Model and the Prediction of Land-Atmosphere Fluxes and Streamflow Forecasting.

Livneh, B., B. Thrasher, and D.P. Lettenmaier, Climate Change Conference, Seattle, WA, Jul. **2012**, Updates and extensions to a long-term Hydrologically based dataset over the Conterminous United States.

Livneh, B., and D.P. Lettenmaier, European Geosciences Union General Assembly, Vienna Austria, Apr, **2012**, Transferability of land surface model parameters using remote sensing and in situ observations.

Livneh, B., and D.P. Lettenmaier, AGU Fall Meeting, San Fransisco, CA., Dec. **2011**, Land Surface Model parameter regionalization via remote sensing and observations (*poster*).

Livneh B. (co-presented with T.J. Bohn), University of Washington Hydrology Seminar, Aug. **2011**, Evaluating performance of MTCLIM and other hydrometeorological algorithms against a global set of station data.

Livneh, B., P.J. Restrepo, and D.P. Lettemnaier, 91st AMS Annual Meeting, Seattle, WA, Jan. **2011**, Application of a Unified Land Model for estimation of the terrestrial water balance (*poster*).

Koster, R. D., S. Mahanama, **B. Livneh,** D. P. Lettenmaier, and R. H. Reichle, 91st AMS Annual Meeting, Seattle, WA, **2011**, Predicting hydrological drought: relative contributions of soil moisture and snow information to seasonal streamflow forecast skill.

Livneh, B., P.J. Restrepo, and D.P. Lettemnaier, AGU Fall Meeting, San Fransisco, CA., Dec. **2010**, Exploring terrestrial and atmospheric constraints in land surface model validation (*poster*).

Livneh, B., D.P. Lettenmaier and K.E. Mitchell, University of Washington Climate Impacts Group, Seattle, WA, Jan. **2010**, Noah LSM Snow Model Diagnostics and Enhancements.

Livneh, B., and D.P. Lettenmaier, UBC-UW Hydrology Symposium,University of British Columbia, Vancouver, BC, Canada, 25 Sep. **2009**, Evapotranspiration Parititioning in Land Surface Models.

Livneh, B., Y. Xia, K.E. Mitchell, M.B. Ek, and D.P. Lettenmaier, CPPA PI's Meeting, Washington, DC, Sep **2008**, Noah LSM snow model diagnostics and enhancements (*poster*).

Livneh, B., E.P. Salathe, and D.P. Lettenmaier, UW/UBC, Hydrology Conference, Seattle, WA, Sep. **2008**, Understanding the sensitivity of Washington State snowpacks to climate change.

Livneh, B., D.P. Lettenmaier and K.E. Mitchell, AGU Fall Meeting, San Fransisco, CA., Dec. **2007,** Diagnosis of Performance of the Noah LSM Snow Model.

Stefanie A. Kroll, Ph.D.

Stream Ecologist, Research Team Leader, Assistant Research Professor

EDUCATION

Ph.D. in Ecology, State University of New York, College of Environmental Science and Forestry (SUNY-ESF), Syracuse, New York. 2012.

Master's equivalent, Ecology, Department of Agronomic Engineering, University of Castilla-La Mancha (UCLM), Albacete, Spain.

B.S. in Environmental and Forest Biology, SUNY-ESF.

PROFESSIONAL EXPERIENCE

9/2017-present: **Head of Watershed Ecology Section**, **Senior Scientist,** Patrick Center for Environmental Research (PCER), Academy of Natural Sciences of Drexel Univ. (ANS)

- Seek funding and develop projects related to macroinvertebrates and algae as bioindicators, target-setting for freshwater restoration, resilience in agricultural streams, and novel uses of bioindicators. Research on headwater system function and climate change, DNA metabarcoding, eDNA, freshwater snails. Directly supervise 3 full-time and several temporary staff, who run a macroinvertebrate laboratory. Develop data outputs for technical and non-technical audiences, such as community scientists & watershed groups.

3/2013-present: **Project Science Director**, Delaware River Watershed Initiative, PCER:

- Coordinate biomonitoring and research efforts for the large, collaborative Delaware River Watershed Initiative within ANS as well as in a consulting role for 30 conservation partners. As Project Science Lead, I supervise 15 colleagues and staff on monitoring, communications, and performing outreach to community science programs and practitioners. This work has allowed me to learn a lot from on-the-ground conservation experts, their data and information needs as well as their processes.

9/2016-present: **Assistant Research Professor**, **Adjunct Professor,** Department of Biodiversity, Earth and Environmental Sciences (BEES), Drexel University.

5/2012-3/2013: **Postdoctoral Associate**, Entomology Department, Cornell University with Dr. Ann Hajek: Behavior and ecology *Sirex noctilio* and native Siricidae of the U.S.

- Refined experimental protocols for choice and non-choice studies on *Sirex* and fungal symbionts, dissected insects, prepared and maintained fungal cultures, supervised undergraduates, analyzed data, and published 2 manuscripts.

4/2010-1/2011: **Field Biologist**, **Graduate Research Assistant,** Onondaga Lake Ecosystem Recovery Project, Dr. Neil Ringler, SUNY-ESF/Honeywell Corporation, Syracuse, NY.

- Collaborated on studies of fish, macroinvertebrate and aquatic macrophyte communities in Onondaga Lake and its tributaries, performed field work and identified macroinvertebrates in gut contents of fish.

9/2007-12/2009: **Staff Scientist, Graduate Research Fellow**, Regional Center for Water Studies, University of Castilla-La Mancha.

- Field work and data analysis for the regional water monitoring program.

1/2003-9/2011: **Interpreter, Translator, Editor** (Spanish-English), Spain and Syracuse, NY.

- Translated and revised business and technical documents, performed simultaneous and consecutive interpreting.

TEACHING HISTORY (with course number & type)

Southern New Hampshire University Online:

Conservation Biology (330, majors)	6 terms 2019-20
Ecological Principles and Field Methods (315, majors)	4 terms 2019-21

Drexel University

A Watershed Approach (203, majors)	Fall 2018
Environmental Science & Society (260, majors & non-majors)	3 terms Summer 2017-19
Introduction to Environmental Science (169, non-majors)	Spring 2018
Aquatic Insects and Water Quality with Laboratory (380/580 undergraduate & graduate levels)	Fall 2014, Winter 2017

Colgate University

Organismal Biology: Insects (206, majors)	Spring 2012

Onondaga Community College

Introduction to Biology with Laboratory II (152, majors)	Spring 2012
Introduction to Biology with Laboratory I (151, majors)	Fall 2011, Summer 2011
Exploring Biology with Laboratory (121, non-majors)	Summer 2011
General Ecology (131, majors & non-majors)	Fall 2010, 2011

PEER REVIEWED PUBLICATIONS

Kroll, S.A., U. Malvadkar, M. Campagna. Land use differentially predicts macroinvertebrate index scores in the Delaware Basin. Short communication submitted to Ecological Indicators, June, 2021.

Kroll, S.A., H.C. Oakland, 2021 (in press) Macroinvertebrate and diatom indicators of ecosystem integrity for setting targets in agricultural BMP restoration. Ecosphere.

Kroll, S.A., H.C. Oakland, 2019. Review of studies documenting the effects of agricultural best management practices on stream ecosystem integrity. Natural Areas Journal 39(1): 58-77.

Kroll, S.A., R.J. Horwitz, D.H. Keller, B.W. Sweeney, J.K. Jackson, L.B. Perez, 2019. Large-scale protection and restoration programs aimed at protecting stream ecosystem integrity: The role of science-based goal-setting, monitoring, and data management. Journal of Freshwater Science 38(1): 23-39.

Kroll, S.A., N.H. Ringler, J. De las Heras, 2017. Macroinvertebrates on the front lines: projected community response to temperature and precipitation changes in Mediterranean streams. *Journal of Freshwater Ecology* 32(1): 513-528.

Hajek, A.E., P. Tobin, S.A. Kroll, S.J. Long, 2017. Symbionts mediate oviposition behavior in invasive and native woodwasps. *Agricultural and Forest Entomology*. 20(3): 442-450.

Kroll, S.A., E.E. Morris, S.J. Long, A.E. Hajek, 2013. Parasitism of *Sirex noctilio* by non-sterilizing *Deladenus siricidicola* in northeastern North America. *Biological Control* 67: 203-211.

Kroll, S.A., N.H. Ringler, J. De las Heras, J.J. Gómez-Alday, A. Moratalla, R.D. Briggs, 2012. Changes in stream water quality and macroinvertebrate communities in response to flow regulation and inter-basin transfer: The Segura River Basin (SE Spain), *Ecohydrology* 6(5): 878-888.

Kroll, S.A., C. Navarro, M.C. Cano, J. De las Heras, 2009. The influence of land use on stream water quality and macroinvertebrate biotic indices in rivers within Castilla-La Mancha (Spain). *Limnetica* 28(2): 203-214.

MANUSCRIPTS IN PREPARATION

Oakland, H.C., S.A. Kroll, M.J. Kurz, T.H. Dapkey, M. Hurley, M. Bross, M. Baker. Threshold analysis to project community recovery from agricultural restoration.

Dilworth, R., S.A. Kroll, M.J. Kurz, editors. Shared Governance of the Delaware River Basin. Book proposal to Temple University Press, July, 2021. Expected publication 2022.

Kroll, S.A., M.J. Kurz, L.B. Perez. Science for decision-making in the Delaware Basin. Book chapter within Dilworth et al. (above), expected publication 2022.

Oakland, H.C., S.A. Kroll, , A. Chan, D.H. Keller, A.M. Stoklosa. Multiple indicators of in-stream and bank restoration success.

Kroll, S.A., S. Buczek, D.H. Keller. The influence of adventitious tributaries on the ecological integrity of receiving streams.

T.H. Dapkey, Kroll, S.A., H.C. Oakland, M.J. Kurz, M. Bross, D.H. Keller, A.M. Stoklosa. Use of ecological traits in projecting vulnerability and potential for recovery of aquatic ecosystems after restoration.

RESEARCH FUNDING

$162,000, "Biodiversity of Pennsylvania Headwaters for Assessing Conservation," Pennsylvania Department of Environmental Protection, Growing Greener Program. March, 2021-December, 2023. (**Principal Investigator, Dr. Steven Rier is co-PI**)

$327,000, "Evaluating Headwater Biodiversity, Vulnerability, and Potential Resilience to Inform Conservation in the Delaware Basin." National Fish & Wildlife Foundation, U.S. Fish and Wildlife Service, Delaware Watershed Conservation Fund. November, 2020-November 2022. (**PI, Dr. Steven Rier is co-PI**)

$280,000, "Project Impact Assessment for DRWI projects in agricultural areas and their effects on aquatic ecosystems." National Fish and Wildlife Foundation for September, 2020- September, 2021. Supports sampling and data analysis.(**co-PI with Dr. Marie Kurz**)

$50,000, "Land Protection Impact Assessment." Open Space Institute, October, 2019-June, 2020. Supports analysis of aquatic integrity relative to forested land cover in the Delaware basin for prioritizing land preservation. In collaboration with Stroud Water Research Center (J. Jackson) (**co-PI with Dr. Marie Kurz**).

$77,000 "Cobbs Creek Stormwater Control through Residential Actions." Subcontract with Darby Creek Valley Association's $250,000 grant from PA DEP's Growing Greener Program. October 2019-June 2021. Supports scientific material for outreach products to residents and community scientists, sampling and data analysis (**Co-PI** with DCVA).

$1.05 million "Science lead to support conservation through the Delaware River Watershed Initiative (DRWI)." William Penn Foundation, February 2020- February 2021. Supports monitoring, research, consulting with collaborating NGOs on monitoring plans and data use for outreach, focusing on the effects of agricultural Best Management Practices on aquatic ecosystems (**co-PI with Lin Perez)**

$2.7 million for the Delaware River Watershed Initiative (as above). William Penn Foundation, February 2018- February 2020 (**co-PI with Roland Wall**).

$20,000, "Pilot study for using DNA metabarcoding of macroinvertebrates in bioindicator research." Academy of Natural Science's research endowment, June 2020-June 2021. Supports analyses of DNA metabarcoding of macroinvertebrate communities in headwater streams and potential use as bioindicators (**PI**).

$1.3 million grant from the William Penn Foundation for the Delaware River Watershed Initiative (as above), February 2017- February 2018 (**co-PI with Roland Wall**).

$159,886 grant from Pennsylvania Department of Environmental Protection's Growing Greener Program, July 2015 – December, 2018. Supports monitoring past restoration projects for evaluation of their success (**PI**).

$2.89 million "Science lead to support conservation through the Delaware River Watershed Initiative." William Penn Foundation, February 2014- February 2017 (**co-PI with R Wall**).

$11,000 "Macroinvertebrate communities of lentic habitats in the DRWI." Academy of Natural Science's research endowment, July 2017-July 2018 (**PI**).

$15,000 "Identification of macroinvertebrate samples and data analyses for study on TMDL in Wissahickon Creek." Temple University, September, 2017-December, 2018. (**PI**).

$150,000 "Study on stream integrity around a small dam on Wissahickon Creek." Erdenheim Farm, September, 2017- March, 2019. (**Head of Macroinvertebrate portion; Dr. William Ryan, PI**).

$45,000, 3-year research scholarship from the University of Castilla-La Mancha, funded by the Autonomous Community of Castilla-La Mancha for routine biomonitoring studies on regional streams. Fall, 2007-January, 2010. (**Graduate student**)

TECHNICAL REPORTS/ OTHER PUBLICATIONS

DiverSeTEM blog series. December, 2020-present. Medium.com Co-developer of collaborative network of environmental practitioners writing 6 articles about Diversity, Equity and Inclusion in STEM fields. Collaboration with Amberly Choi, Lara Heacock, Tykee James, Wenny Lin, Lauren McGrath, Jen Orr-Greene, Nancy Popkin.

Dapkey, T.H., S.A. Kroll, M.J. Kurz, L.B. Perez, M. Campagna, M. Hurley, K. Christopher. 2019-2020. Multiple data products for the DRWI partners: Non-technical descriptions of indicators and presentation of data.

Kroll, S.A. March 30, 2020. Work from home tips from our scientist. ANS, https://www.anspblog.org/wfh-tips-from-our-scientist/

Kroll, S.A. January 2, 2019. Where have all the insects gone? Article review, ANS, www.anspblog.org/where-have-all-the-insects-gone.

Perez, L.B., Christopher, K.A., Kroll, S.A., December, 2018. Impact of Phase 1 actions in the DRWI. *Report to the William Penn Foundation.*

Christopher, K.A., M.J. Kurz, S.A. Kroll, 2017. Data summaries for the DRWI for all sites sampled 2013-2016. *Report to the William Penn Foundation.*

Christopher, K.A., S.A. Kroll, G.J. Barren, 2016. Two-page summaries of DRWI cluster stream conditions using multiple indicators. *Report.* http://ansp.org/drwi

Kroll, S.A., R. Abell, 2015. Points of Departure: Baseline Conditions in the Subwatershed Clusters of the Delaware River Watershed Initiative, Academy of Natural Sciences of Drexel University, 65 pp. http://www.ansp.org/~/media/Files/ans/research/pcer-other/Points%20of%20Departure.ashx?la=en.

Kroll, S.A., L. Perez, 2014. Delaware River Watershed Initiative: Cluster Characterization Report, ANS, 34 pp. http://www.ansp.org/research/environmental-research/projects/watershed-protection-program/.

Kroll, S.A., L. Perez, K. Christopher, 2014. Coordinated Monitoring Plan for the Delaware River Watershed Initiative, ANS, 50pp. http://www.ansp.org/~/media/Files/

ans/research/pcerother/Monitoringplan150728compressed.ashx?la=en.

Navarro-Llacer, C., S. Kroll, J. de las Heras, 2009. Ecological status of rivers of Castilla-La Mancha: Relationships with land use, flow regulation and ecological flow criteria. University of Castilla-La Mancha, Regional Center for Water Studies, Submitted to the Castilla-La Mancha Ministry of the Environment.

Kroll, S.A. May 13, 2020. Coping with anxiety and worry during COVID. Medium.com

RELATED SKILLS AND ACTIVITIES

- Invited member or Drexel's Office of Research and Innovation's Allyship group for Diversity Dialogues, August, 2020-present.
- Development of monitoring plans for measuring the effects of conservation actions for use by professional scientists, non-profit organizations and watershed associations.
- Consulting with community monitoring groups to tailor monitoring plans and data communication for outreach.
- Publishing data in user-friendly forms for outreach to decision-makers and constituents.
- Knowledge of aquatic macroinvertebrate taxonomy (genus level) in Spain and NE USA.
- Experience performing and assigning various algae, fish and macroinvertebrate sampling techniques.
- Experience with 'R', SPSS, CANOCO and e-Primer statistical software packages.
- Experience with QGIS and ArcGIS software packages.
- Environmental Leadership program Fellow (2020)
- Completion of Supervisory Certificate Program (Drexel University; 2016).
- Completion of Drexel Leaders 20/20 Program (2018).
- Fluent in Spanish, intermediate level in French.
- Certified medical interpreter for Spanish (MAMI Certification, Syracuse, NY)
- Preparation of tissue samples for Stable Isotope Analysis.
- Experience with PCR, DNA isolation, sterile technique.

PROFESSIONAL ACTIVITIES AND OTHER INTERESTS

- All You Can Save Book Circle facilitator, summer, 2021.
- Advisory Board Co-chair, Tookany-Tacony-Frankford Watershed Partnership, 2016-present, Diversity Committee (2018-20).
- Diversity committee, Academy of Natural Sciences, 2019-present.
- Diversity talk planning committee, Office of Research and Innovation, Drexel University.
- Monitoring Advisory Committee, Raritan Headwaters Association (RHA), 2014-2020; Volunteer, annual stream monitoring, 2014-2017.
- Community-Based Global Learning professional learning community (Drexel University).
- Volunteer, Mentor, Women in Natural Sciences Program (engaging young women from underrepresented minorities in an out-of-school science program during high school), Academy of Natural Sciences.
- Volunteer, Big Brothers, Big Sisters Independence Region, 2014-2016; 2018-2020.
- Mentor, Drexel Liberty Scholars Program (volunteering to mentor a student with full, need-based scholarship), 2018-2019.
- Peer reviewer: PLOS ONE, Canadian Journal of Zoology, Northeastern Naturalist, Restoration Ecology, Diversity.
- Professional Memberships:
    - Society of Freshwater Science (SFS) National and Mid-Atlantic Chapters
    - 500 Women Scientists, Philadelphia Pod
    - American Association for the Advancement of Science
    - American Water Resources Association

- Society for Ecological Restoration
- Society of Women Environmental Professionals of Philadelphia.

- Active hobbies (snowshoeing, hiking, yoga), poetry and songwriting, playing the ukulele, singing. Certified yoga teacher (200 hour training).

AWARDS

DRWI project receives Integrated Water Resource Management Award from the American Water Resources Association, 2018.

Excellence in Project Management, Academy of Natural Sciences, 2014.

Excellence in Advising Undergraduate Research, SUNY-ESF, 2012.

Graduate research fellowship award, University of Castilla-La Mancha, 2008-2010.

PARTICIPATION IN CONFERENCES (students in **bold)**

September, 2020. Forum of the Coalition for the Delaware River Watershed, Online
Presentation: Research in the Delaware River Basin Lightning Talk: ANS research on indicators of recovery in the DRWI. (SA Kroll, ML Kurz, DH Keller, M Hurley)

May, 2019: Society of Freshwater Science, Salt lake City, Utah. Moderator
Presentation: Past restoration: Success or failure? And what are the criteria? (SA Kroll, **HC Oakland**, **A Chan**, DH Keller, L Aycock)

May, 2019: Week of Undergraduate Excellence, Drexel University
Poster: River restoration—Assessing "Successful" Indicators. (**L Chamberlain**, SA Kroll, **A Chan**, **HC Oakland**, MJ O'Donnell)

January, 2019: Partnership for the Delaware Estuary Science Summit, Cape May, NJ.
Poster: Coordinated conservation through the DRWI-- how much improvement do we predict? (SA Kroll, **HC Oakland**, MJ O'Donnell, JK Jackson, J Battle)

November, 2018: Delaware Watershed Research Conference, Philadelphia, PA. Moderator.

November, 2018: American Water Resources Association, Baltimore, MD.
Presentation: Connecting Baseline conditions to potential recovery of biotic communities due to restoration through the Delaware River Watershed Initiative (SA Kroll, DH Keller, RJ Horwitz, JK Jackson)

October, 2018: Academy Research Day, Academy of Natural Sciences, Philadelphia, PA.
Presentation: Better farming, better streams?

September 2018: Delaware River Watershed Forum, Coalition for the Delaware River Watershed, Cape May, NJ.

July 2018: University Council on Water Resources, Pittsburgh, PA.
Presentation: Monitoring and data management to support conservation in the Delaware River Watershed Initiative. (SA Kroll, DH Keller, RJ Horwitz, JK Jackson, SM Haag)

June, 2018: Society of Freshwater Science, Detroit, MI.
Presentation: Structure and function of macroinvertebrate communities for setting targets for agricultural BMP restoration. (SA Kroll, HC Oakland, **MJ O'Donnell**, JK Jackson)

May, 2018: Week of Undergraduate Excellence, Drexel University
Poster: Past restoration: Success or failure? **(A Pilla**, **A Chan**, **MJ O'Donnell**, SA Kroll, **HC Oakland**)

May, 2018: River Rally, Lake Tahoe, CA.

Presentation: Better farming, Better Streams?

June, 2017: Society of Freshwater Science, Raleigh, NC.
Presentation: Connecting baseline conditions to potential recovery of macroinvertebrate and diatom communities due to restoration through the DRWI. (SA Kroll, **MJ O'Donnell**, AD Minerovic, JK Jackson)

May, 2016: Society of Freshwater Science, Sacramento, CA.
Presentation: Planning and assessing restoration using multiple indicator monitoring and integrated data management in the Delaware River Basin. (SA Kroll, SM Haag, DH Keller, RJ Horwitz, JK Jackson)

April, 2016: National Conference on Ecological Restoration, Coral Springs, FL.
Presentation: Monitoring and data management to inform conservation in the DRWI. (SA Kroll, DH Keller, RJ Horwitz, JK Jackson, SM Haag)

May, 2015: Society of Freshwater Science, Milwaukee, WI.
Presentation: Multiple indicator analysis of streams throughout the Delaware River Watershed (SA Kroll, RJ Horwitz, DH Keller, **AD Minerovic**, JK Jackson).

January, 2015: Partnership for the Delaware Estuary Summit, Cape May, NJ.
Presentation: Macroinvertebrate communities in the eight subwatershed clusters of the Delaware River Watershed Initiative (SA Kroll, JK Jackson).

October, 2014: 2nd Annual Delaware River Watershed Forum, Bethlehem, PA.
Presentation: Coordinated monitoring for the DRWI. (SA Kroll, RJ Horwitz).

November, 2014: American Water Resources Association, 50th Anniversary Conference, Vienna, VA.
Presentation: Monitoring to inform modelling for the DRWI. (SA Kroll, RJ Horwitz)
Moderator: Watershed Protection Modeling I.

May, 2014: Joint Aquatic Sciences Meeting, Portland, OR.
Presentation: Coordinated restoration and conservation actions and monitoring the Delaware Watershed Conservation Program. (SA Kroll, RJ Horwitz, R Wall).
Poster: Predicted effects of climate change on aquatic insect communities in the short-term in Castilla-La Mancha, Spain. (SA Kroll, NH Ringler).

February, 2014: Research Day (student posters), Drexel University, Philadelphia, PA
Poster: The effects of land use on water quality and benthic macroinvertebrate indices of biological integrity, a historical study of the Delaware River Basin (**D Luong**, SA Kroll, *et al.*).

August, 2013: Society for Invertebrate Pathology, Pittsburgh, PA.
Presentation: Parasitism of *Sirex noctilio* by non-sterilizing *Deladenus siricidicola* in northeastern North America. (SA Kroll, **EE Morris**, S Long, AE Hajek).

January, 2013: USDA Interagency Research Forum on Invasive Species, Annapolis, MD.
Poster: Parasitism of *Sirex noctilio* by non-sterilizing *Deladenus siricidicola* in northeastern North America. (SA Kroll, **EE Morris**, S Long, AE Hajek).

April, 2011: North American Benthological Society (NABS) meeting, Providence, RI.
Presentation: The impact of hydroelectric dams on the macroinvertebrate community in two climates: Salmon River, USA and Segura River, Spain. (SA Kroll, NH Ringler, J de las Heras).

June, 2010: NABS/Association for the Sciences of Limnology and Oceanography (ASLO) Joint Meeting, Santa Fe, NM.
Presentation: Changes in the macroinvertebrate community as a result of flow regulation and inter-basin transfer on the in the Segura River Basin, Spain. (SA Kroll, NH Ringler, J de las Heras).

September, 2008: XIV Congress of the Iberian Limnological Association, Huelva, Spain.

Presentation & Poster: The influence of land use on stream water quality and macroinvertebrate biotic indices in rivers within Castilla-La Mancha. (SA Kroll, C Navarro-Llacer, J de las Heras).

Poster: Biological and hydromorphological effects of river regulation downstream three reservoirs of South Spain. (D Baeza, C Navarro-Llacer, SA Kroll, J de las Heras).

OTHER RECENT PRESENTATIONS

April 21, 2021. Defining and protecting headwater resilience, NOAA Earth to Sky series in the Delaware Basin.

October 22, 2020. Setting targets for watershed health in the DRWI and related research on the projected effects of on-the-ground actions. Virtual Delaware Watershed Research Conference.

August 21, 2020. Panelist and contributor: "Diversity Dialogue: Allyship: Something You Do, Not Something You Are." Webinar with Drexel University's Office of Research and Innovation and ANS's Black and Brown Caucus.

August 5, 2020. "Data and communication data products in the DRWI." Webinar with River Network, Stroud Water Research Center.

June 20, 2020. "Study on stream restoration through PA DEP's Growing Greener and other programs." Webinar with **Hayley Oakland** and **Amanda Chan**.

June, 2020 "Tools for data collection and sharing in the DRWI" Webinar with River Network

November 1, 2019. "Macroinvertebrates tell all: Bioindicators of environmental conditions" Biology and Allied Health Sciences Departmental Seminar Series, Bloomsburg University.

September 24, 2019. Panel member for Philadelphia Environmental Film festival screening: Anthropocene: The Human Epoch, ANS.

June 6, 2019. Engaging the Environment, Drexel University.

May 5, 2019. Raft debate, Drexel University (2nd place).

January 8, 2019. Panel member, Academy Conversation: What happens if federal regulations protecting clean water are scaled back? Academy of Natural Sciences of Drexel University.

October 25, 2018. Guest lecture for Introduction to Environmental Studies, Drexel University.

September, 2018. Dean's Seminar, Drexel University.

August 22, 2018. Drexel InSites, panel discussion on urban ecology, Academy of Natural Sciences of Drexel University.

Summer, 2017. Farmer's breakfast, Honey Brook, PA. Water quality in your region.

John C. Stella

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EDUCATION

University of California, Berkeley — Environmental Science, Policy and Management — Ph.D., 2005
Dissertation advisors: Drs. John J. Battles and Joe R. McBride
Title: *"A field-calibrated model of pioneer riparian tree recruitment for the San Joaquin Basin, CA"*

University of California, Berkeley — Environmental Science, Policy and Management — M.S., 1998

Yale University — Architecture — B.A., 1988

APPOINTMENTS

Vice President, Division of Research, SUNY-ESF, 2021–present

Professor, Dept. of Sustainable Resources Management, SUNY-ESF, 2019–present

Associate Professor, Dept. of Forest and Natural Resource Management, SUNY-ESF, 2013–2019

Assistant Professor, Dept. of Forest and Natural Resource Management, SUNY-ESF, 2006–2013

Adjunct Assistant Professor, Dept. of Geography, Syracuse University, 2009–present

Faculty Fellow, Collegium de Lyon, École Normale Supérieure, Lyon, France, 2013–2014

CALFED Science Program Post-Doctoral Research Fellow, University of California, Berkeley, 2006

Senior Ecologist / Project Manager, Stillwater Sciences, Berkeley, CA, 1998–2006

Doctoral Student Researcher, University of California, Berkeley, 2000–2005

RESEARCH GRANTS

National Science Foundation GSS-1660490. *Linking Basin-Scale, Stand-Level, and Individual Tree Water Stress Indicators for Groundwater-Dependent Riparian Forests in Multiple-Use River Basins.* 2017–2021. J.C. Stella (PI), M.B. Singer (PI, UCSB), and D.A. Roberts (PI, UCSB). $449,982.

National Science Foundation EAR-1700517. *Collaborative Research: Impacts of Dynamic, Climate-Driven Water Availability on Tree Water Use and Health in Mediterranean Riparian Forests.* 2017–2021. J.C. Stella (PI), M.B. Singer (PI, UCSB), K. Caylor (Co-PI, UCSB). Total budget, ESF share: $53,787; total $450,353

Strategic Environmental Research and Development Program (SERDP). *Understanding and assessing riparian habitat vulnerability to drought-prone climate regimes on Department of Defense bases in the southwestern USA.* 2018–2022. M.B. Singer (PI, UCSB), J.C. Stella (PI), K. Caylor (Co-PI, UCSB) and D.A. Roberts (Co-PI, UCSB). ESF share $348,623; total $1,704,236

The Nature Conservancy. *Assessing riparian forest water sources in the Santa Clara River basin*. 2018–2021. M. Singer (PI, UCSB), J.C. Stella (Co-PI), L. Kui (Co-PI, UCSB). $110,000

European Union COST Program. *CONVERGES: Knowledge conversion for enhancing management of European riparian ecosystems and services*. 2017-2021. S. Dufour (PI), J.C. Stella (Collaborator) and 33 others.

USDA Cooperative State Research Service. *The effects of Riparian Management Zone delineation on timber value and ecosystem services in diverse forest biomes across the United States*. 2017–2018. R. Germain (PI) and J.C. Stella (Co-PI). $63,274.

National Science Foundation EAR-1024820. *Collaborative Research: Quantifying Feedbacks between Fluvial Morphodynamics and Pioneer Riparian Vegetation in Sand-Bed Rivers.* 2010–2015. J.C. Stella (PI), A.C. Wilcox (PI, U. Montana), and A.F. Lightbody (PI, UNH). SUNY-ESF share: $205,680 ; total: $650,000.

U.S. Geological Survey. *Responses of floodplain vegetation to sediment dynamics and feedbacks*. 2015. J.C. Stella (PI). $10,000.

The Nature Conservancy/ESSA Technologies. *Riparian wood recruitment analysis for bank migration scenarios on the Middle Sacramento River, CA*. 2015. J.C. Stella (PI). $37,925.

Centre National de la Recherche Scientifique, Observatoire Homme Milieux (CNRS, France). *Ecosystem service of carbon sequestration associated with riparian management strategies on the old Rhône River.* 2015. V. Matzek and J.C. Stella (PI's). $11,100.

European Institute for Advanced Study (EURIAS). *Common challenges and opportunities in riparian zone management along large, Mediterranean-climate rivers*. 2013–2014. J.C. Stella (PI). $75,000.

Centre National de la Recherche Scientifique, Observatoire Homme Milieux (CNRS, France). *Riparian forest composition and structure in former Girardon engineering structures of the old Rhône River, France.* 2014. J.C. Stella (PI). $16,000.

USDA Forest Service, Northeastern States Research Cooperative. *Quantifying Beaver Impacts on Adirondack Forest Communities at a Landscape Scale.* 2012–2014. J.C. Stella (PI), E. Bevilacqua (Co-PI) and J. Frair (Co-PI). $87,850.

USDA Cooperative State Research Service. *Beaver Influence on Vegetation Structure and Avian Diversity at Local and Landscape Scales.* 2013–2015. S. McNulty (PI), J.C. Stella (Co-PI). $52,000.

SUNY-ESF, Research Seed Grant. *A New Tool for Restoration Ecology: Stable Carbon Isotopes in Tree Rings as Indicators of Ecosystem Change.* 2010–2011. J.C. Stella (PI) and M. Teece (Co-PI). $8,000.

Western Caucus Pooled Fund. *Riparian Study Development for the Lower Yuba River*. 2010–11. South Yuba River Citizens League. Travel and meeting coordination funding for J.C. Stella. $7,000.

USDA Cooperative State Research Service. *Restoring Small, Ephemeral Wetlands in Forested Landscapes in New York State.* 2009–2012. J.P. Gibbs, J.C. Stella (Co-PI). $89,850.

Centre National de la Recherche Scientifique (CNRS, France). *Programme International de Coopération Scientifique: Contrôles géomorphologiques et dynamique des ripisylves dans les rivières à méandres de piémont (étude comparée de l'Ain et du Sacramento)*. 2009–2011. H. Piégay (PI) and G.M. Kondolf (PI). International research funding for J.C. Stella. Total for all collaborators: $120,000.

CALFED Science Fellows Program. *Modeling physical drivers and age structure of cottonwood forest habitat: an integrated systems approach.* 2008–2010. J.C. Stella (PI) and A.K. Fremier. $228,750.

USDA Cooperative State Research Service. *Quantifying riparian zone structure and function to guide management of the northern hardwood forest ecosystem*. 2008–2011. J.C. Stella (PI). $82,000.

SUNY-ESF, Research Seed Grant. *Elemental stoichiometry and ecosystem health of Onondaga Creek*. 2008. J.C. Stella (PI) and K.E. Limburg. $8,000.

CALFED Science Fellows Program. *Effects of river regulation and climate on sustainability of Fremont cottonwood (Populus fremontii) forests in California's Central Valley.* 2006–2008. J.J. Battles (PI) and J.C. Stella. $228,750.

NSF Doctoral Dissertation Improvement Grant. *Developing a predictive understanding of recruitment and survival of pioneer riparian trees on regulated rivers.* 2003. J.C. Stella (doctoral fellowship), with J.J. Battles (PI). $11,950.

CALFED Science Fellows Program. *A mechanistic model to evaluate and improve riparian restoration success.* 2003–2004. J.C. Stella (doctoral fellowship), with J.J. Battles (PI). $93,491.

CALFED Ecosystem Restoration Program. *A mechanistic approach to riparian restoration in the San Joaquin Basin.* 2002–2003. Research grant #1999-B152 awarded to Stillwater Sciences (Project developed by J.C. Stella; data collection used for dissertation research). $289,666.

PUBLICATIONS

Peer-Reviewed Articles (***undergrad advisee; ** grad advisee; *other student contributor)

Rodríguez-González, P., S. Dufour, **J.C. Stella,** et al. (in review). Bringing the margin to the focus: ten challenges for riparian vegetation. *Frontiers in Ecology and the Environment*.

Beslity, J.O.*, S.B. Shaw, J.E. Drake, J. Fridley, **J.C. Stella**, J.R. Stark*, K. Singh. (in review) A low cost, low power sap flux device for distributed and intensive monitoring of transpiration. *Agricultural and Forest Meteorology*.

Kibler, C.L.*, E.C. Schmidt*, D.A. Roberts, **J.C. Stella,** L. Kui, A.M. Lambert, M. Singer. 2021. A brown wave of riparian woodland mortality following groundwater declines during the 2012-2019 California drought. *Environmental Research Letters.* DOI: 10.1088/1748-9326/ac1377

Stella, J.C., L. Kui, G.H. Golet, F. Poulsen. (in press). Modeling riparian forest structure to estimate large wood inputs and other ecosystem services on geomorphically active floodplains. *Earth Surface Processes and Landforms.*

Rohde, M.M.**, **J.C. Stella**, D.A. Roberts, M.B. Singer. 2021. Groundwater dependence of riparian woodlands and the disrupting effect of anthropogenically altered streamflow. *Proceedings of the National Academy of Sciences.* DOI: 10.1073/pnas.2026453118

Haynes, K.R.*, J. Friedman, **J.C. Stella**, D.J. Leopold. 2021. Assessing climate change tolerance and the niche breadth-range size hypothesis in rare and widespread plants. *Oecologia*

Jayasuriya, M.T.*, **J.C. Stella**, R.H. Germain. 2021. Elevated streambank plant community diversity and composition define functional riparian zones in mesic headwater forests across the northeastern U.S. *Journal of Forestry* DOI: 10.1093/jofore/fvab034

Sabathier, R.*, M.B. Singer, **J.C. Stella,** D.A. Roberts, K.K. Caylor. 2021. Vegetation responses to climatic and geologic controls on water availability in southeastern Arizona. *Environmental Research Letters* 16 : *(ERL-109499)* DOI: 10.1088/1748-9326/abfe8c

Stephan, E.*, T. Endreny, P. Groffman, P.G. Vidon, **J.C. Stella**. 2021. Interacting drivers and their tradeoffs for predicting denitrification potential across a strong urban to rural gradient within heterogeneous landscapes. *Journal of Environmental Management* 294 DOI: 10.1016/j.jenvman.2021.113021

Warter, M.M.*, M.B. Singer, M.O. Cuthbert, D.A. Roberts, K. Caylor, R. Sabathier*, **J.C. Stella**. 2021. Onset and propagation of the 2012 – 2019 drought in Southern California. *HESS.* DOI: 10.5194/hess-2020-479

Janssen P., **J.C. Stella**, H. Piégay, B. Räpple**, R. Gruel**, B. Pont, S. Dufour. 2020. Response of riparian forest structure and composition to long-term, cumulative impacts along a large river. *Journal of Environmental Management* DOI: 10.1016/j.jenvman.2020.111630

Mayes, M., K. Caylor, M.B. Singer, **J.C. Stella**, D.A. Roberts, P. Nagler. 2020. Climate sensitivity of water use by riparian woodlands at landscape scales. *Hydrological Processes.* DOI: 10.1002/hyp.13942

Diehl, R.M., A.W. Wilcox and **J.C. Stella**. 2020. Evaluation of the integrated riparian ecosystem response to future flow regimes on semiarid rivers. *Journal of Environmental Management* DOI: 10.1016/j.jenvman.2020.111037

Mahoney, M.***, **J.C. Stella.** 2020. Stem size selectivity is stronger than species preferences for beaver, a central place forager. *Forest Ecology and Management.* DOI : 10.1016/j.foreco.2020.118331

Kua, Z.X.**, **J.C. Stella,** J.M. Farrell. 2020. Ecosystem engineer disturbance enhances plant diversity in wetlands subject to water regulation and biotic invasion. *Ecosphere.* DOI: 10.1002/ecs2.3256

Janssen P., **J.C. Stella**, H. Piégay, B. Räpple**, B. Pont, J-M Faton, J.H.C. Cornelissen, A. Evette. 2020. Divergence of riparian forest composition and functional traits from natural succession along a degraded river with multiple stressor legacies. *Science of the Total Environment* 720. DOI: 10.1016/j.scitotenv.2020.137730

Lightbody, A., Kui, L.**, **J.C. Stella**, K.W. Skorko, S. Bywater-Reyes, A.C. Wilcox. 2019. Riparian vegetation and sediment supply regulate the morphodynamic flood response of an experimental stream to floods. *Frontiers in Environmental Science (Freshwater Science section).* DOI: 10.3389/fenvs.2019.00040

Kui, L.**, **J.C. Stella**, R. M. Diehl, A.C. Wilcox, A. Lightbody, L.S. Sklar. 2018. Can environmental flows moderate riparian invasions? The influence of seedling morphology and density on scour losses in experimental floods. *Freshwater Biology* DOI: 10.1111/fwb.13235

Matzek, V., **J.C. Stella**, P. Ropion*. 2018. Development of a carbon calculator tool for riparian restoration. *Applied Vegetation Science* DOI: 10.1111/avsc.12400

Thorel, M., H. Piégay, C. Barthélémy, B. Räpple**, C-R Gruel*, P. Marmonier, T. Winiarsky, J-P Bedell, F. Arnaud*, G. Roux, **J.C. Stella**, G. Seignemartin*, A. Tena-Pagan, V. Wawrzyniak*, D. Roux-Michollet, B. Oursel, S. Fayolle, C. Bertrand*, E. Franquet. 2018. Socio-environmental stakes associated with process-based restoration strategies in large rivers: should we remove novel ecosystems along the Rhône (France)? *Regional Environmental Change* DOI: 10.1007/s10113-018-1325-7

Räpple, B.**, H. Piégay, **J.C. Stella**, D. Mercier*. 2017. What drives riparian vegetation establishment in river channels at patch to corridor scales? Insights from annual airborne surveys (Drôme River, SE France). *Ecohydrology* DOI: 10.1002/eco.1886

Kui, L.**, **J.C. Stella**, P.B. Shafroth, P.K. House, A.C. Wilcox. 2017. The long-term legacy of geomorphic and riparian vegetation feedbacks on the dammed Bill Williams River, Arizona, USA. *Ecohydrology* DOI:10.1002/eco.1839

Ledford, S.H.*, L.K. Lautz, P.G. Vidon, **J.C. Stella.** 2017. Impact of seasonal changes in stream metabolism on nitrate concentrations in an urban stream. *Biogeochemistry* DOI:10.1007/s10533-017-0336-7

Diehl, R.M., A.C. Wilcox, **J.C. Stella**, L. Kui**, L. Sklar, A. Lightbody. 2016. Fluvial sediment supply and pioneer woody seedlings as a control on bar-surface topography. *Earth Surface Processes and Landforms* DOI:10.1002/esp.4017

Hultine, K.R., K.C. Grady, T.E. Wood, S.M. Shuster, **J.C. Stella**, T.G. Whitham. 2016. Climate change perils for dioecious plant species. *Nature Plants.* DOI:10.1038/nplants.2016.109

Ledford, S.H.*, L.K. Lautz, **J.C. Stella**. 2016. Hydrogeologic processes impacting storage, fate, and transport of chloride from road salt in urban riparian aquifers. *Environmental Science and Technology* 50: 4979–4988 DOI:10.1021/acs.est.6b00402

Kui, L.** and **J.C. Stella**. 2016. Fluvial sediment burial increases mortality of riparian tree seedlings but induces compensatory growth response in survivors. *Forest Ecology and Management,* 366. DOI: 10.1016/j.foreco.2016.02.001

Bywater-Reyes, S.*, A.C. Wilcox, **J.C. Stella**, and A.F. Lightbody. 2015. Flow and scour constraints on uprooting of pioneer woody seedlings, *Water Resources Research*, 51. DOI:10.1002/2014WR016641

Dixon, M.D. and **J.C. Stella**. 2015. Temporal variability in hydrology modifies the influence of geomorphology on wetland distribution along a desert stream: a commentary on Dong et al. 2015. *Journal of Ecology.* DOI:10.1111/1365-2745.12499

Bishop, D.A.*, C.M. Beier, N. Pedersen, G.B. Lawrence, **J.C. Stella**, T.J. Sullivan. 2015. Regional growth decline in sugar maple (*Acer saccharum*) and potential causes. *Ecosphere*. DOI:10.1890/ES15-00260.1

Manners, R., A.C. Wilcox, L. Kui**, A. Lightbody, **J.C. Stella**, L. Sklar. 2015. When do plants modify fluvial processes? Plant-hydraulic interactions under variable flow and sediment supply rates. *Journal of Geophysical Research – Earth Surface.* DOI:10.1002/2014JF003265

Kui, L.**, **J.C. Stella**, A. Lightbody, A.C. Wilcox. 2014. Ecogeomorphic feedbacks and flood loss of riparian tree seedlings in meandering channel experiments. *Water Resources Research.* 50, DOI: 10.1002/2014WR015719

Dufour, S., M.K. Hayden*, **J.C. Stella**, H. Piégay, J.J. Battles. 2014. Maintaining channel abandonment processes increases riparian plant diversity within fluvial corridors. *Ecohydrology*. DOI: 10.1002/eco.1546

Riddle, J., N. Pedersen, **J.C. Stella,** D.L. Leopold. 2014. Shifting climate sensitivity and contrasting growth trends in *Juniperus* species growing together at opposite range margins. *Tree-Ring Research* 70:101–111. DOI:10.3959/1536-1098-70.2.101

Stella, J.C., J. Riddle*, H. Piégay, M. Gagnage*, M-L. Trémélo. 2013. Climate and local geomorphic interactions drive patterns of riparian forest decline along a Mediterranean Basin river. *Geomorphology.* DOI:10.1016/j.geomorph.2013.01.013

Stella, J.C., P. Rodríguez-González, S. Dufour, J. Bendix. 2013. Riparian vegetation research in Mediterranean-climate regions: common patterns, ecological processes, and considerations for management. *Hydrobiologia* 719:291–315. DOI:10.1007/s10750-012-1304-9

Eallonardo, A. S.*, D.J. Leopold, J.D. Fridley and **J.C. Stella**. 2012. Salinity tolerance and the decoupling of resource axis plant traits. *Journal of Vegetation Science.* DOI:10.1111/j.1654-1103.2012.01470.x

Singer, M.B., **J.C. Stella,** S. Dufour, L.B. Johnstone**, H. Piégay, and R.J.S. Wilson**.** 2012. Contrasting water uptake and growth responses to drought in co-occurring riparian tree species. *Ecohydrology.* 6: 402–412. DOI:10.1002/eco.1283

Beier C.M., **J.C. Stella**, M. Dovçiak, S.A. McNulty. 2012. Local climatic drivers of changes in phenology at a boreal-temperate ecotone in eastern North America. *Climatic Change* 115:399–417. DOI: 10.1007/s10584-012-0455-z

Schifman, L.A.**, **J.C. Stella**, M. Teece and T.A. Volk. 2012. Plant growth and water stress response of hybrid willow (Salix spp.) among sites and years in central New York. *Biomass & Bioenergy* 36: 316–326. DOI:10.1016/j.biombioe.2011.10.042

Stella, J.C., M.K. Hayden*, J.J. Battles, H. Piégay, S. Dufour, and A.K. Fremier. 2011. The role of abandoned channels as refugia for sustaining pioneer riparian forest ecosystems. *Ecosystems* 14: 776–790. DOI:10.1007/s10021-011-9446-6

Harper, E.B., **J.C. Stella**, A.K. Fremier. 2011. Global sensitivity analysis for complex ecological models: a case study of riparian cottonwood population dynamics. *Ecological Applications* 21: 1225–1240. DOI:10.1890/10-0506.1

Downs, P.W., M.S. Singer, B.K. Orr, Z.E. Diggory, T.C. Church, and **J.C. Stella**. 2011. Restoring ecological integrity in highly regulated rivers: The role of baseline data and analytical references. *Environmental Management* 48:847–864. DOI:10.1007/s00267-011-9736-y

Stella, J.C., and J.J. Battles. 2010. How do riparian woody seedlings survive seasonal drought? *Oecologia* 164:579–590. DOI:10.1007/s00442-010-1657-6

Stella, J.C., J.J. Battles, J.R. McBride, B.K. Orr. 2010. Riparian seedling mortality from simulated water table recession, and the design of sustainable flow regimes on regulated rivers. *Restoration Ecology*. 18(S2): 284–294. DOI:10.1111/j.1526-100X.2010.00651.x

Rodríguez-González, P.M.*, **J.C. Stella**, F. Campelo, T. Ferreira, A. Albuquerque. 2010. Subsidy or stress? Tree structure and growth in wetland forests along a hydrological gradient in southern Europe. *Forest Ecology and Management* 259: 2015–2025. DOI:10.1016/j.foreco.2010.02.012

Stella, J.C., J.J. Battles, B.K. Orr, J.R. McBride. 2006. Synchrony of seed dispersal, hydrology and local climate in a semi-arid river reach in California. *Ecosystems* 9:1200-1214. DOI:10.1007/s10021-005-0138-y

Book Chapters and Conference Proceeding Papers (*indicates student contributor)

Stella, J.C. and J. Bendix. 2018. Chapter 5: Multiple stressors in riparian ecosystems. In *Multiple stressors in river ecosystems: status, impacts and prospects for the future* (S. Sabater, A. Elosegi, R. Ludwig, Eds.). Elsevier, San Diego. ISBN: 9780128117132

Orr, B.K., A.G. Merrill, Z.E. Diggory, **J.C. Stella**. 2017. Use of the biophysical template for riparian restoration and revegetation in the Southwest. In: Ralston, B.E., and Sarr, D.A., Eds. Case studies of riparian and watershed restoration in the southwestern United States—principles, challenges, and successes. U.S. Geological Survey Open-File Report 2017-1091, 116 p. DOI: 10.3133/ofr20171091

Sabater, S., X. Timoner, G. Bornette, M. de Wilde, J.C. Stromberg, **J.C. Stella**. 2016. The biota of intermittent rivers and ephemeral streams: algae and vascular plants. In *Intermittent Rivers: Ecology and Management* (T. Datry, N. Bonada and A. Boulton, Eds.). Elsevier, San Diego. DOI:10.1016/B978-0-12-803835-2.00016-4

Stella, J.C., H. Piégay, J.D. Riddle, C. Gruel*, B. Räpple**. 2015. Riparian forest impacts and dynamics on large rivers managed for multiple uses; insights from the Sacramento (California, USA) and Rhône (France). Proceedings of the Second Integrative Sciences and Sustainable Development of Rivers (IS Rivers) Conference, Lyon, France, 22–26 June 2015.

Räpple, B.**, K. Michel, H. Piégay, R. Dunford, D. Mercier*, **J.C. Stella**. 2015. Caracteristiques et dynamique de la vegetation riveraine sur la riviere Drôme: analyses à partir d'images aeriennes de très haute résolution. Proceedings of the Société Hydrotechnique de France (SHF) annual congress. Paris, France, April 2015.

Bendix, J., and **J.C. Stella.** 2013. Riparian Vegetation and the Fluvial Environment: A Biogeographic Perspective. In *Treatise on Geomorphology 12: Ecogeomorphology* (D. Butler and C. Hupp, Eds.). Elsevier, San Diego. DOI 10.1016/B978-0-12-374739-6.00322-5

Stella, J.C., J.D. Riddle, J.J. Battles, M.K. Hayden*, and A.K. Fremier. 2012. Riparian forest dynamics on a large, regulated river (California, USA): impacts and implications for management. Proceedings of the Integrative Sciences and Sustainable Development of Rivers (IS Rivers) Conference, Lyon, France, 26–28 June 2012. http://www.graie.org/ISRivers/actes/pdf2012/1B109-237STE.pdf

Skorko, K.*, A. Lightbody, L. Kui**, **J.C. Stella**, A.C. Wilcox. 2012. Hydraulic and topographic response of sand-be rivers to riparian vegetation presence and patterns: field-scale laboratory methods and results. Proceedings of the Hydraulic Measurements and Experimental Methods Conference (HMEM 2012). Snowbird, UT.

Stella, J.C., J.C. Vick, B.K. Orr. 2004. Riparian vegetation dynamics on the Merced River. *The Wilderness Society Riparian Floodplains Conference Proceedings.* Sacramento, CA. March 2001.

Stella, J.C. 1998. The Greywacke Cover-up. *Soil Survey Horizons* 39(4): 127-130.

Applied Research Reports and Non-Peer Reviewed Articles

Stella, J.C. and L. Kui**. 2015. Large Woody Debris enhancement model for Sacramento River Environmental Flow Tool (SacEFT). Prepared for The Nature Conservancy. Chico, CA.

Wilcock, P., **J.C. Stella**, D. Orth and Atkins Environmental. 2012. Senior scientific review of Trinity River Restoration Program, Fiscal Year 2013 Preliminary Science Workplan. Provided to the Trinity Management Council (U.S. Bureau of Reclamation and Partners).

Stella, J.C.. 2012. Senior scientific review of Platte River Recovery Implementation Program, Directed Vegetation Research. Nebraska Community Foundation, Inc.

Stella, J.C. 2011. Yuba River Riparian Study: Cottonwood Limiting Factors Analysis. Prepared for Yuba County Water Agency. Yuba River Development Project, FERC Project No. 2246.

Stillwater Sciences. 2006. Restoring recruitment processes for riparian cottonwoods and willows: a field-calibrated predictive model for the lower San Joaquin Basin. Prepared for CALFED Bay-Delta Ecosystem Restoration Program, Sacramento, California. Prepared by Stillwater Sciences and Dr. **J.C. Stella**, in conjunction with Dr. J.J. Battles and Dr. J.R. McBride, Department of Environmental Science, Policy, and Management, University of California, Berkeley. (http://www.stillwatersci.com/resources/2006riprecruitbrochure.pdf)

Stillwater Sciences. 2006. Merced River Ranch revegetation experiment. Prepared by Stillwater Sciences, Berkeley, California, for CALFED, Sacramento, California. (http://merced.stillwatersci.com/pdf/10/Tech%20Memo_10_Reveg%20Expt_compiled.pdf)

Stillwater Sciences. 2002. Merced River corridor restoration plan. Prepared by Stillwater Sciences, Berkeley, California for CALFED Bay-Delta Program, Sacramento, California (http://www.stillwatersci.com/resources/2004mercedrestoplan.pdf)

Stillwater Sciences. 2001. Merced River Restoration Plan Phase II. Volume II: Baseline evaluations; geomorphic and riparian vegetation investigations. Prepared by Stillwater Sciences, Berkeley, CA for CALFED Bay-Delta Ecosystem Restoration Program, Sacramento, CA. (http://www.stillwatersci.com/resources/2001mercedrestov2.pdf)

HONORS AND AWARDS

Faculty Fellowship, European Institute for Advanced Study (EURIAS), Lyon France 2013–2014

Schubert Prize, Dept. of Environmental Science, Policy and Management, UC Berkeley, 2005

Colman Fellowship in Watershed Management, UC Berkeley, 2000, 2003

ESPM Departmental Fellowships, UC Berkeley, 1996, 1997, 2000

INVITED PRESENTATIONS AND SPECIAL SESSIONS

Stella, J.C. Riparian tree stress in relation to streamflow. Annual Meeting of the Ecological Society of America, Salt Lake City, UT, August 2020

Stella, J.C., Modelling riparian forest development to predict floodplain inputs of large wood to meandering rivers. Invited presentation at the American Geophysical Union Fall Meeting, Washinton, D.C.. December 2018.

Stella, J.C., Riparian vegetation interactions with fluvial processes. Concordia University, Montreal, Canada, October 2018.

Stella, J.C., Patterns of natural regeneration of early successional riparian forest habitat. California Yellow-billed Cuckoo Workshop. Sacramento National Wildlife Refuge, Willows, CA. Sept. 6, 2018

Stella, J.C., Cumulative impact legacies create novel riparian forests on large, multi-use rivers (Sacramento, CA and Rhône, France). Invited presentation at the Society of Wetland Scientists, Denver, June 2018.

Stella, J.C., Multiple stressors and the response of riparian vegetation. Invited presentation at the Third I.S. Rivers conference (Integrative sciences and sustainable development of rivers). Lyon, France, June 2018.

Stella, J.C., Defining groundwater-dependent ecosystems and assessing critical water needs for their foundational plant communities. Invited presentation at the American Geophysical Union Fall Meeting, New Orleans, LA. December 2017.

Stella, J.C., Approaches and tools for assessing dependence and vulnerability of GDE plant communities. Putting Policy into Practice: Achieving Sustainable Groundwater Management for People and Nature. Annual Meeting of the Ecological Society of America, Portland, OR, August 2017.

Stella, J.C., Confluence to Influence: Preserving and enhancing the multiple functions and services of riparian zones in a changing climate. Davis, CA. 17–19 October, 2017. **(conference organizing committee)**

Stella, J.C. 2015. 11th Annual Berkeley River Restoration Symposium. Berkeley, CA. 5 December 2015., **(invited panelist)**.

Stella, J.C., 2015. El Nino Climate Summit. University of California, Davis. 5 December 2015, **(invited panelist)**.

Stella, J.C., Hydrologic Analysis for Ecosystem Restoration. Presentations on behalf of The Nature Conservancy for the U.S. Army Corps of Engineers Hydrologic Engineering Center, Davis, CA. 18-19 November 2015.

Stella, J.C., Panel on Climate Challenges for the Sacramento–San Joaquin Watershed. Southwest Climate Summit. Landscape Conservation Cooperative — Southwest Region. Sacramento, CA. 2–3 November 2015.

Stella, J.C., Second I.S. Rivers conference (Integrative sciences and sustainable development of rivers). Lyon, France. 22–26 June, 2015, **(conference organizing committee)**

Stella, J.C., H. Piégay, Synthesizing riparian science and management challenges on large, multi-use rivers: cross-system lessons from Europe and North America. Second I.S. Rivers conference (Integrative sciences and sustainable development of rivers). Lyon, France. 22–26 June, 2015, **(co-organizer)**.

Stella, J.C., Riparian vegetation and fluvial interactions at multiple scales. Symposium on aquatic-terrestrial linkages. Umeå, Sweden, March 2015.

Stella, J.C., H. Piégay, G.M. Kondolf, D. Roux-Michollet, International workshop on large river management, Rhône and Sacaramento rivers. Collaborative exchange among managers and scientists with the California Department of Water Resources, The Nature Conservancy, U.S. Fish and Wildlife Service, American Rivers, and the French Water Agency (Agence de l'eau), and the French National Center for Scientific Research (CNRS). Berkeley, CA. 14-17 December 2014, **(co-organizer)**.

Stella, J.C., H. Piégay, G. David, and B. Eaton, River-Floodplain Connectivity: Interactions among Riparian Vegetation, Fluvial Wood, Stream Morphodynamics and Biogeochemical Cycles. American Geophysical Union Fall Meeting, San Francisco, CA, December 2014, **(special session co-organizer)**.

Stella, J.C., Riparian forest dynamics and management challenges on Mediterranean-climate rivers. Restoring the West Conference, Utah State University. Logan, UT, October 2014

Stella, J.C., K. Holl, V. Matzek, and M. Dixon, Connecting mountains to the sea: riparian research and management challenges in large river systems. Annual Meeting of the Ecological Society of America, Sacramento, CA, August 2014., **(special session co-organizer)**.

Stella, J.C., 2014. Développement et enjeux de la gestion des ripisylves sur les grands fleuves (Riparian forest development and management challenges on large river floodplains). Café Fluvial, École Normale Supérieure de Lyon. Lyon, France, June 2014

Stella, J.C., Populus nigra growth and water use under a changing climate: insights from stable isotopes in tree rings. Institut National de la Recherche Agronomique d'Orléans and University of Tours. Orleans, France, May 2014

Stella, J.C., Trends in water use and growth for riparian trees undergoing climatic drying. Instituto Superior de Agronomia, Universidade de Lisboa. Lisbon, Portugal, March 2014

Stella, J.C., Trends in water use efficiency, and tradeoffs between growth and function for riparian trees undergoing climatic drying. Department of Geography, University of Rennes. Rennes, France, February 2014

Stella, J.C., Un fleuve durable? Managing large rivers for human and ecosystem needs: the case of the Middle Rhône. Collegium de Lyon Seminar Series, École Normale Supérieure de Lyon. Lyon, France, October 2013

Stella, J.C., Recent advances in quantifying plant and geomorphic feedbacks in alluvial rivers. Earth Sciences Department, University of New Hampshire. Durham,NH, April 2013

Stella, J.C. J. Riddle, J.J. Battles, Coevolution of floodplain and riparian forest dynamics on large, meandering rivers. Invited oral presentation at the American Geophysical Union Fall Meeting, San Francisco, CA, December 2012.

Stella, J.C., Emerging issues in riparian science in arid regions. Center for Watershed Sciences, University of California, Davis. Davis, CA, December 2012

Stella, J.C., Partnering with Beaver in Stream Restoration Short Course, Utah State University, Logan, UT, October 2012, **(invited instructor).**

Stella, J.C., Riparian forest dynamics on the Sacramento River (California, USA): impacts and implications for management. Research briefing for U.S. Fish and Wildlife Service personnel, Willows, CA. July 2012.

Stella, J.C., Com'Eau Labo Workshop - Better communication and collaboration between managers and scientists: discussions about current practices in France and the United States IS Rivers International Conference (Integrative Sciences and Sustainable Development of Rivers), Lyon, France, June 2012.

Stella, J.C., Réponse des ripisylves à une modification du régime hydrologique : diagnostic et propositions de restauration (Riparian forest response to modified riparian hydrological regimes: diagnosis and proposals for restoration). Colloque 13: Réhabilitation des hydrosystèmes: enjeux scientifiques et nouvelles perspectives ("Symposium 13: Rehabilitation of hydrosystems: scientific issues and new perspectives"). Entretiens Jacques Cartier 2011. Montreal, Canada, October, 2011.

Stella, J.C., Partnering with Beaver in Stream Restoration Short Course, Utah State University. Loga, UT September 2011, **(invited instructor).**

Stella, J.C. J. Riddle, H. Piégay, Dendroecology as an indicator of riparian function and drivers of meso-scale ecosystem impacts. International Association of Vegetation Science Meeting, Lyon, France, June 2011.

Stella, J.C. J. Riddle, H. Piégay, M. Teece, Integrating tree-ring and stable carbon isotope analysis to measure riparian ecosystem function, integrity, and meso-scale hydrogeomorphic impacts. Seventh Symposium for European Freshwater Sciences, Girona, Spain, June – July, 2011.

Stella, J.C., J. Bendix, H. Piégay, and P. Downs, Non-equilibrium drivers in Mediterranean climate river and riparian ecosystems.American Geophysical Union Fall Meeting, San Francisco, CA, December 2010, **(special session organizer)**.

Stella, J.C.,. INECOL/SUNY-ESF research collaboration workshop. Presentation on professional research program and FNRM discipline areas. Instituto de Ecología, A.C. (INECOL), Xalapa, Mexico. March 15, 2010.

Stella, J.C., A.K. Fremier. S. Dufour, and H. Piégay, Ecological processes on abandoned riparian floodplains. Annual Meeting of the Ecological Society of America, Albuquerque, NM, August 2009, **(special session organizer)**.

Stella, J.C., A river runs through it: modeling and restoring riparian forests on dynamic floodplains. Invited speaker, Bowdoin College Biology Seminar Series. Brunswick, ME. Sept. 2009.

Stella, J.C., Abiotic Controls on Riparian Forest Development at Leaf to Landscape Scales. Invited speaker, Syracuse University Biology Seminar Series. Syracuse, NY. February, 2009.

Stella, J.C., Scaling from the leaf to the floodplain: Linking physiology studies with life history traits to restore streamside forests in arid regions. IGERT Biogeochemistry and Environmental Biocomplexity Seminar, Cornell University. Ithaca, NY. October, 2007.

Stella, J.C., Quantitative approaches to restoring streamside forests in a water-limited ecosystem. Department of Geography Symposium, Syracuse University. Syracuse, NY. September, 2007.

Stella, J.C., Quantitative approaches to riparian restoration in California (USA). River Restoration International Symposium. Madrid, Spain. September, 2006.

Stella, J.C., Research featured in Forests Round the Bend, a special issue on riparian restoration efforts on the Sacramento River. Science-In-Action Newsletter, CALFED Bay-Delta Program. Sacramento, CA, 2003, **(special feature).**

PROFESSIONAL SERVICE

Boards of directors

- *The Nature Conservancy*, Western and Central New York Chapter. 2015–present.
- *Onondaga Earth Corps*, Syracuse, NY. 2016–present.
- *Town of DeWitt Urban Tree Committee*, DeWitt, NY. 2015–2016
- *The Star Foundation* private philanthropy, EIN 256761169. 2001–present.

Editorial roles and conference planning

- Subject Matter Editor, *Ecological Applications*, Ecological Society of America (2016–-2021)
- Editorial Advisory Board member, *Riparian Ecology and Conservation* (2012–2017)
- Conference planning committee, *Confluence to Influence: Preserving and enhancing the multiple functions and services of riparian zones in a changing climate*. Davis, CA. (Oct. 2017)
- Conference scientific committee, *2015 I.S. Rivers Conference — Integrative sciences and sustainable development of rivers.* Lyon, France (June 2015)
- Special session convener, *American Geophysical Union Annual Meeting* (2010, 2014) and *Ecological Society of America Annual Meeting* (2009, 2014)

Journal reviews for

Ecological Applications; Water Resources Research; Frontiers in Ecology and the Environment; BioScience: Ecohydrology; Global Change Biology; River Research and Applications; Hydrobiologia; Forest Ecology and Management; Earth Surface Processes and Landforms; Riparian Ecology and Conservation; Ecoscience; Wetlands; Ecological Restoration; Environmental Management; Journal of the American Water Resources Association

Proposal reviews for

- National Science Foundation
- French National Research Agency (ANR) proposal panel, 2019–2020
- French National Network of Institutes of Advanced Study (RFIEA)
- Northeastern States Research Cooperative (USDA Forest Service)
- USDA Cooperative State Research Service Grant Program

Technical reviews for:

- US Bureau of Reclamation, Technical Review for Grand Canyon/Glen Canyon Dam Adaptive Management Program, Grand Canyon Monitoring and Research Center 2020 Annual Report
- Trinity River Restoration Program, Technical Review for FY13 Preliminary Science Workplan
- Platte River Recovery Implementation Program, Directed Vegetation Research Study. 2011.
- Yuba River Development Project, FERC Relicensing Project No. 2246. 2011.

- USGS Geomorphic and Sediment Transport Laboratory. Project for monitoring vegetation change on the central Platte River, NE. 2007.
- CA Regional Water Quality Control Boards. Proposed Stream and Wetlands Protection Policy for North Coast and San Francisco Bay Regions. 2006.
- CA Dept. of Fish and Game. Protocol for quantitative studies of riparian restoration effectiveness. 2004.
- CA Dept. of Water Resources. Robinson Reach revegetation and monitoring plan, Merced River, CA. 2002.

PROFESSIONAL AFFILIATIONS

Ecological Society of America
American Geophysical Union
Society for Ecological Restoration
Society of Wetland Scientists

APPENDIX C: GCMRC RESPONSE

GCMRC Scientists' Response to Summary of Responses

GCMRC Scientists' Response to Individual Peer Reviewers

Response to GCDAMP Science Advisor Review of Grand Canyon Monitoring and Research Center Annual Report 2020

November 8, 2021

Prepared for
US Bureau of Reclamation
Glen Canyon Dam Adaptive Management Program
Upper Colorado Regional Office
Salt Lake City, Utah

Prepared by
U.S. Geological Survey
Southwest Biological Science Center
Grand Canyon Monitoring and Research Center
Flagstaff, Arizona

U.S. Department of the Interior
U.S. Geological Survey

Table of Contents

Acronyms

CRe	Colorado River ecosystem
GIS	Geographic Information Systems
GCDAMP	Glen Canyon Adaptive Management Program
GCMRC	Grand Canyon Monitoring and Research Center
LTEMP	Glen Canyon Dam Long-Term Experimental and Management Plan
P	phosphorus
ROD	Record of Decision
USGS	U.S. Geological Survey

Executive Summary

The operations of Glen Canyon Dam and other management activities have significant impact on ecological, hydrological, and cultural systems along the Colorado River from the forebay of the Glen Canyon Dam to upper Lake Mead, referred to as the Colorado River ecosystem CRe. The Glen Canyon Adaptive Management Program (GCDAMP) provides a process for adaptive management of dam operations, including monitoring and research, integration, and management of natural, cultural, and recreational resources affected by Glen Canyon Dam operations. The Grand Canyon Monitoring and Research Center (GCMRC) conducts scientific research on the effects of dam operations and associated management and provides robust, objective scientific data on the impact of dam operations.

There are eleven priority resources identified in the Long-Term Experimental and Management Plan (LTEMP). These eleven priority resources include archeological and cultural resources, natural processes, humpback chub, hydropower and energy, other native fish, recreational experiences, sediment, tribal resources, rainbow trout fishery, nonnative invasive species, riparian vegetation.

As part of the Science Advisors Program which provides independent review on the research programs, five peer reviewers were selected to provide a peer review of the *Fiscal Year 2020 Annual Project Report to the Glen Canyon Dam Adaptive Management Program* (USGS 2020). The reviewers represent a breadth of expertise related to fisheries and aquatic ecology, vegetation management and riparian ecology, hydrology of river systems, GIS data management and remote sensing, socioeconomics related to tribal resources, monitoring, and adaptive management. The peer reviewers were also selected to avoid conflicts of interest with the GCDAMP.

The peer reviewers evaluated the material provided by the GDCAMP, which included the annual report and associated project presentations. The review focused on two broad questions about goals and objectives as well as specific feedback on research design, program outcomes, indicators, and methods. While reviewers responded with suggestions and recommendations for improvements, they agreed the research programs being pursued by the GCDAMP are overall connecting to LTEMP goals.

GCMRC Chief Response

We appreciate the thoughtful reviews provided on our Fiscal Year 2020 Annual Project Report to the Glen Canyon Dam Adaptive Management Program. In this document we provide written responses to the review comments from Reviewers 1-4. Our project PIs, scientists, and cooperators responded to comments in the SUMMARY OF RESPONSES section of this document and also in the APPENDIX A: INDIVIDUAL REVIEWS section. The former section is a summary of the latter section, and thus responses we provided in the former often negated the need to also reply (i.e., in duplicate) to comments in the

latter. In those instances, we refer the reader to the responses provided to comments in the SUMMARY OF RESPONSES section. Also note that at the time of writing this, we have not received comments from Reviewer 5.

1.0 Background

The Glen Canyon Adaptive Management Program (GCDAMP) was established in following the 1996 Record of Decision (ROD) on the Operation of Glen Canyon Dam to comply with the 1992 Grand Canyon Protection Act. Dam operations affect river hydrology, sediment dynamics, temperature and chemistry, food web dynamics, and aquatic and riparian species and communities along the Colorado River from the forebay of Glen Canyon Dam to upper Lake Mead, referred to as the Colorado River ecosystem (CRe).

With an updated 2016 ROD, the activities of GCDAMP came under governance of the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP). LTEMP established key resource priorities in eleven areas and requires adaptive management of these resources through experimental and management actions such as, but not limited to, fall and spring high-flow experiments, humpback chub translocation, macroinvertebrate production flows, mechanical removal of rainbow trout, and riparian vegetation restoration. By monitoring these management actions, the Grand Canyon Monitoring and Research Center (GCMRC) provides credible, objective scientific information regarding the effects of Glen Canyon Dam operations on the CRe.

One element of the GDCAMP is a Science Advisors Program where outside experts in relevant fields evaluate and give feedback on the research and monitoring programs. These periodic independent reviews ensure scientific credibility by providing recommendations regarding monitoring and research, integration, and management of natural, cultural, and recreational resources affected by Glen Canyon Dam operations.

Independent scientific peer reviews offer perspective on how well technical conclusions are supported by data and analyses and whether research being conducted aligns with LTEMP key resource priorities. This is a key step in guaranteeing GCMRC provides credible, objective scientific information about the effects of Glen Canyon Dam operations on the CRe.

The purpose of this peer review is to review and provide feedback on each project element included in the *Fiscal Year 2020 Annual Project Report to the Glen Canyon Dam Adaptive Management Program* (2020 Annual Report). The review included evaluating whether projects aligned with expectations laid out in the LTEMP.

The period of performance for this peer review was 07/01/2021-9/30/2021.

2.0 Peer Reviewers

Peer reviewers were selected according to their previous experience conducting similar reviews, relevant expertise, independence from GCDAMP, and publishing records in scientific

journals. All peer reviewers were provided the language from the OMB (Office of Management and Budget) Bulletin (2004) with regard to independence and conflicts of interest, with respect to both GCDAMP and GCMRC.

The combined panel was selected to provide the following expertise:

- Fisheries and aquatic ecology
- Aquatic macroinvertebrates and food web ecology
- Vegetation management and riparian ecology
- Sediment transport, geomorphology, and/or hydrology of river systems, particularly those impacted by dams
- GIS data management and remote sensing
- Socioeconomics related to energy generation and/or tribal resources
- Monitoring and adaptive management

The five peer reviewers selected were mid- to senior-level scientists with PhDs in a relevant field who have previously conducted similar reviews or provided reviews of research for scientific literature. The full resumes for the peer reviewers are presented in Appendix B. The peer reviewers and their primary expertise were:

- Michael E. Colvin, PhD, Associate Professor at Mississippi State University – expertise with big river fisheries, salmonids, and arid ecosystems. (Reviewer 1)
- Stefanie A. Kroll, PhD, Assistant Research Professor at Academy of Sciences of Drexel University – expertise with food webs, aquatic macroinvertebrates, and community science. (Reviewer 2)
- Ben Livneh, PhD, Assistant Professor at University of Colorado, Boulder – expertise in sediment transport, hydrogeomorphology, and arid ecosystems. (Reviewer 3)
- Lynne Y. Lewis, PhD, Professor at Bates College – expertise in economics, hydropower, and community science. (Reviewer 4)
- John C. Stella, PhD, Professor at State University of New York – expertise in riparian vegetation ecology. (Reviewer 5)

Two reviewers have worked with Tribes in relation to river projects; although this is not considered a primary expertise, their prior experience was valuable during the peer review.

3.0 Summary of Responses

Reviewers were asked to evaluate the 2020 Annual Report, any appendices, and recorded presentations from the Annual Report meeting. Reviewers were asked to focus on two main questions when evaluating the report:

1. Is the best information being provided to meet the needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission?

2. Does the combined effectiveness of the programs advance understanding of the Grand Canyon ecosystem; ensure progress in defining and conducting adaptive management experiments; monitor resources affected by Glen Canyon Dam operations and the effects of those operations; provide options for managing these effects; and facilitate coordination and balancing among resource programs?

Reviewers only reviewed projects for which they felt they had a technical expertise to effectively review. In some cases, a reviewer only commented on a portion of a project within their technical expertise. The following summary provides the key points provided by the reviewers. The full reviews (Appendix A) include additional details and suggestions.

Project A: Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem

Reviewer 1

Sustainability requires a look to the future to forecast the effect of operations on sand resources, or possibly a retrospective analysis of what has happened in the past. Are the specific targets for sand or fine sediment resources defined? If so, what are they? The mass balance model could be used to parameterize a dynamic model that can be linked to dam operations, environmental conditions, and used to evaluate sustainability in sand resources over time.

Project A GCMRC PI Response

Please see Topping and others (2021) published in the Journal of Geophysical Research for information on whether the current management approach is sustainable for sand resources. As summarized in the Conclusions of that article,

"Sand storage in the bedrock-canyon Colorado River in Marble and Grand canyons is largely self-limiting. Fining of the bed-sand grain size as sand storage increases leads to higher suspended-sand concentrations, and therefore greater downstream sand export, a negative-feedback mechanism likely operating in other bedrock-canyon rivers. Except in the river segments proximal to the major sand-supplying tributaries, bed-sand grain size plays a dominant role in regulating whether sand erodes or deposits in the Colorado River. By virtue of this self-limitation, substantial increases in sand storage, as occurred during periods of low discharge pre-dam, are likely impossible in the Colorado River in Marble and Grand canyons at the higher discharges generally released from Glen Canyon Dam. Multiyear sand accumulation is only possible in the Colorado River in GCNP during years when the tributary sand supply exceeds ~130% of average and dam-released discharges are below average. Sand erodes during years of below-average to average tributary sand supply and average to above-average discharge; net erosion of at least 28 million Mg of sand from the Colorado River in GCNP has occurred since the 1963 closure of Glen Canyon Dam. Thus, sand storage sufficient for maintaining sandbars in the Colorado River may require timing periods of higher and lower dam-released discharge based on tributary sand-supply conditions. Whether the sand resources of the Colorado River in GCNP can be sustainably managed in perpetuity therefore remains an open question."

In addition, the model of Wright and others (Water Resources Research, 2010) is being modified within Project B in the FY 2021-23 TWP to use in attempted improvements of models linking sand transport and sandbar response.

Topping, D. J., Grams, P. E., Griffiths, R. E., Dean, D. J., Wright, S. A., & Unema, J. A. (2021). Self-limitation of sand storage in a bedrock-canyon river arising from the interaction of flow and grain size. Journal of Geophysical Research: Earth Surface, 126, e2020JF005565. https://doi.org/10.1029/2020JF005565.

Wright, S. A., Topping, D. J., Rubin, D. M., & Melis, T. S. (2010). An approach for modeling sediment budgets in supply-limited rivers. Water Resources Research, 46, W10538. https://doi.org/10.1029/2009WR008600.

Reviewer 2

There appears to be tension between the goal of supplying sufficient sediment to maintain sandy banks and sand bars for recreational and tribal activities, competing with the problems that turbidity is causing for biota.

Project A GCMRC PI Response

The natural Colorado River was a highly turbid river, 365 days of the year, as shown in Voichick and Topping (2014). However, the entire physical template of the river has been changed by damming and hydropower operations. For example, water temperatures are much colder, nutrient concentrations are lower, and base flows (median discharge) are much higher compared to the pre-dam river. Thus, the effect of turbidity and fine sediment on biota is likely much different in the post-dam river than it was in the pre-dam. It is also worth noting that hydropeaking operations play a major role in fine sediment dynamics, which slows biological processes including gross primary production and insect growth. In the absence of hydropeaking, the effect of fine sediment on biota (e.g., gross primary production-Project E, insect emergence-Project F) would be much different. Please see Figures 12 and 13 in that publication. The biota that evolved in the Colorado River evolved in highly turbid river, so there should be no problem.

Voichick, N., & Topping, D.J (2014) Extending the turbidity record—making additional use of continuous data from turbidity, acoustic-Doppler, and laser diffraction instruments and suspended-sediment samples in the Colorado River in Grand Canyon. U.S. Geological Survey Scientific Investigations Report 2014–5097, 31 p. http://dx.doi.org/10.3133/sir20145097.

Reviewer 3

Overall, progress has been made in terms of collating, analyzing, and modeling the CRe to identify drivers of sand and limitations in historical monitoring. A large number of data products, reports, and presentations indicate good progress, generally sound methods, and potential applications for further high flow analysis.

The continuous monitoring of sand would support greater understanding of the sustainability of current and future sand resources and critical connections between sand concentrations and high flows and other factors. It is difficult to interpret the uncertainty associated with flood flows in the Little Colorado River Basin. Long-term precipitation gage data could improve regressions and understanding of variability, relationships, and uncertainty. Reporting long-term rates of change and their uncertainties would be useful for overall planning and overall context.

Project A GCMRC PI Response

Please see Topping and others (2021) published in the Journal of Geophysical Research and Dean and Topping (2019) published in the Geological Society of America Bulletin. These questions are addressed in those articles.

Dean, D. J., & Topping, D. J. (2019). Geomorphic change and biogeomorphic feedbacks in a dryland river: The Little Colorado River, Arizona, USA. Geological Society of America Bulletin, 131, 1920–1942. https://doi.org/10.1130/B35047.1

Reviewer 4

No comment.

Reviewer 5

For this and other projects, the response from Reviewer 5 will be added once received.

Project B: Sandbar and Sediment Storage Monitoring And Research

Reviewer 1

Overall, it would be good to couple monitoring efforts of sandbars with recreational experience quality. A number of methodological suggestions were provided. Additional information about uncertainty is needed, as well as ways to tie results to the objectives and adaptive management.

Project B GCMRC PI Response

We note that sandbars and campsites are studied and monitored largely because they have been recognized by stakeholders as important aspects of the recreational experience. We also recognize that our monitoring does not measure recreational experience directly, but we believe that there is opportunity to more explicitly connect sandbars, campsites, and the economic value of the recreational experience, and hope to make that part of future work plans.

Reviewer 2

The modeling and monitoring effort is well designed. There is a tension here between the goal of supplying sufficient sediment to maintain sandy banks and sand bars for recreational and Tribal activities, competing with the problems that turbidity is causing for biota. I do not know if the hypothesis that sand can be managed to achieve all goals of the GCMRC can hold true for this topic. High Flow Experiments should be monitored in terms of the objectives of Projects E, F, and others to ensure that supporting one objective does not end up detracting from another objective.

Project B GCMRC PI Response

Studying and understanding the diverse resources and identifying these areas of potential conflict among stakeholder goals is certainly part of our goal as GCMRC scientists. We note that the issue of turbidity and its relation to biota is complex and in need of further study. We would caution readers of the annual report against a premature conclusion that turbidity is a “problem.”

Reviewer 3

Numerous data products, publications, and presentations indicate good progress, generally sound methods, and potential applications linking high-flow events with sand and camping impacts. Monitoring and data sharing are important continued activities from this project. Suggestions for future work and analysis are provided, particularly around camping, climate change, and remote sensing. Further exploration is warranted into potential applications of

the Bayesian framework as a tool for quantifying reach-scale sediment deficits and surplus relevant for future studies.

Project B GCMRC PI Response

We thank the reviewer for the helpful suggestions and provide more detailed responses below.

Reviewer 4

High flow experiments benefit campsites by causing temporary increases in campsite area, yet vegetation encroachment causes campsite declines. The relationship of this work to campsites needs to be clarified and any recommendations for recreational experience included (which is generally missing from all the projects, not just this one).

Project B GCMRC PI Response

The degree to which campsites are affected by sandbar erosion and deposition relative to vegetation change has been addressed more thoroughly in previous studies than was covered in this annual report (e.g. Hadley and others (2018a; 2018b). We will try to summarize and/or refer to this work more completely in future reports. Although it's not our goal in the annual reports to make specific recommendations, we will more explicitly address the connections between the resources we monitor and recreational experience in future reports.

Hadley, D.R., Grams, P.E., Kaplinski, M.A., Hazel, J.E., J., and Parnell, R.A., 2018, Geomorphology and vegetation change at Colorado River campsites, Marble and Grand Canyons, Arizona: U.S. Geological Survey Scientific Investigations Report 2017–5096, p. 64, doi:10.3133/sir20175096.

Hadley, D.R., Grams, P.E., and Kaplinski, M.A., 2018, Quantifying geomorphic and vegetation change at sandbar campsites in response to flow regulation and controlled floods, Grand Canyon National Park, Arizona: River Research and Applications, p. 1–11, doi:10.1002/rra.3349.

Reviewer 5

Project C: Riparian Vegetation Monitoring and Research

Reviewer 1

Vegetation monitoring for composition and cover, with emphasis on nonnative species appears to provide robust data that can be used for status and trend analysis, including statistical analysis. However, it was unclear how the long-term changes were evaluated and on what metric. How well did the model perform? It was not clear what the specific objectives were or how they provide decision support for management actions?

Project C GCMRC PI Response

The Status and Trends report is currently under colleague review and will be submitted as a USGS Open File Report before the end of the calendar year. But, briefly, we analyzed multiple metrics indicated as important in the GCDAMP using mixed-effects models focusing on the interaction between year and hydrologic zone. This allowed us to address our primary objective of identifying how each metric responded to different aspects of hydrology through time. When possible, observed trends were attributed to management actions – specifically daily fluctuating flows and HFEs in the active channel, HFEs in the active floodplain.

Reviewer 2

No comment.

Reviewer 3

This provides a useful set of monitoring data and methods that connect vegetation with flow, environmental variables, and management, with a good webpage. There are some details that would be helpful to have reported (e.g., criteria for error checking, fraction of woody riparian vegetation, uncertainties). Remote sensing could be a useful technology to support this research. The analysis relating climate variables with vegetation patterns (Butterfield et al. 2018) is interesting and should continue to be pursued. Additional data should be reported/collected to help inform management of campsites and other recreational areas.

Project C GCMRC PI Response

Please see our forthcoming Status and Trends for detailed information on data processing, vegetation status and uncertainty. We agree that remote sensing is a useful tool for vegetation monitoring and research, please see section C.2 of the report. We are continuing to work on interactions between climate and flows, an update will be provided in the 2021 Annual Report. Lastly, we will be more explicit in the 2021 report about how our monitoring and analysis of sandbar sites, along with work being

conducted by the NPS and other GCMRC projects, relates to campsites and other recreational areas.

Reviewer 4

Information specific to campsites was missing, including relevant goals and objectives. A summary and/or recommendations related to camping area, landscape beauty, and shade should be included and tied to Project J.

Project C GCMRC PI Response

Our repeat monitoring sandbar sites are highly relevant to campsite condition. We agree with the reviewer that this connection was not made as explicitly as it should have been. This suggestion will be incorporated into the FY21 Annual Report where appropriate.

Reviewer 5

Project D: Geomorphic Effects of Dam Operations and Vegetation Management for Archaeological Sites

Reviewer 1

An evaluation of how flow and non-flow actions affect cultural resources, preservation of resources, vegetation, and sediment dynamics should be completed. Can the monitoring objectives be clarified? Can this monitoring be used to inform a risk model? Clarifications on metrics, how they are estimated, and how those metrics fit with the LTEMP resource goals and overall monitoring objectives would be helpful. Lastly, clarification is needed on how weather data is used to achieve monitoring objectives.

Project D GCMRC PI Response

A goal of this project and the long-term body of work preceding this project is to evaluate how flow and non-flow actions affect preservation of cultural resources, and to evaluate the roles of riparian vegetation, weather, and sediment dynamics in affecting cultural resource condition directly and indirectly. The USGS Fact Sheet *Managing sand along the Colorado River to protect cultural sites downstream of Glen Canyon Dam* (https://pubs.er.usgs.gov/publication/fs20193054) is a recently published summary of the state of the science about the impact of flow and non-flow actions on these resources. We agree that using the monitoring to explicitly inform a risk model is an intriguing idea and we will consider that in the future. Development of metrics for these and other resources is part of ongoing work in the FY21-23 workplan. We will more clearly explain how the weather data are used and why they are important in future reports.

Reviewer 2

No comment.

Reviewer 3

The meteorological monitoring and data collection described by Caster et al. (2018) is extremely valuable and its continuation should be prioritized. Spaceborne remote sensing could complement existing aerial imagery.

Project D GCMRC PI Response

We agree that the weather data are important. We are also currently working on approaches to monitoring effects of dam operations for archaeological sites that incorporate spaceborne remote sensing and look forward to sharing that work in the future.

Reviewer 4

No comment.

Reviewer 5

Project E: Nutrients And Temperature as Ecosystem Drivers: Understanding Patterns, Establishing Links and Developing Predictive Tools for an Uncertain Future

Reviewer 1

The metrics monitored may not directly relate to LTEMP resource goals but are a necessary precondition to achieving LTEMP resource goals related to biota (humpback chub, rainbow trout, other native fish). There are several questions related to methods and how results inform adaptive management.

Project E GCMRC PI Response

The metrics monitored are also relevant to natural processes in the river.

Reviewer 2

The approach to monitoring and studying P dynamics is well designed. The studies before and after fire are also sound, and the shift to studying gross primary production is a good step toward characterizing the dynamics of nutrients in the system, especially regarding the food web. Was P historically limited or higher in this area, or how do levels compare with inputs into reservoirs? From the studies presented, the turbidity seems to be a greater limitation to algal growth and macroinvertebrate success (along with hydropeaking flows, of course), than bioavailable P into the system.

Improved analysis and modelling of food web dynamics is needed to better understand the bottom-up controls of P concentrations, turbidity, and flows through the food web and in connection to the dynamics of the fish communities. Relative to Projects E and F, macroinvertebrate diets could be analyzed using DNA metabarcoding of their whole abdomens to understand which diatoms and prey are most dominant in diets. Additional suggestions for improved data collection and analysis were included.

Project E GCMRC PI Response

Thank you for your comment. Using eDNA metabarcoding of whole abdomens is a good suggestion and is a technique that has proven useful in other applications. We are in the beginning stages of using eDNA to detect rare native and non-native fishes in the CRe and will explore the feasibility of using this emerging tool to assess dominant prey items in fish diet in future work plans, since we do not have the resources right now to conduct this work.

Reviewer 3

While improvements in the predictive model resulted from using solar radiation as a predictor, details of the radiation data were entirely missing. Clearer justification of the water temperatures chosen should be provided in the context of existing pool temperatures and temperatures relevant for other project components.

Project E GCMRC PI Response

We apologize for the lack of detail on solar radiation data used in our water temperature model. We acquired subdaily Global Horizontal Irradiance data from the National Solar Radiation Database (https://nsrdb.nrel.gov), Physical Solar Model (PSM, v. 3; data available 1998-2015) and Meteorological Statistical Models (MTS, v.1-2; data available 1985-2005). Since the PSM and MTS models overlapped from 1998-2005, we applied a slight correction to MTS data using the slope of the zero-intercept model for each river segment. We calculated mean GHI by month and year. Stations from the National Solar Radiation Database used in the water temperature model for the Colorado River downstream from Glen Canyon Dam include location ID's 553, 0, and 97653.

Reviewer 4

No comment.

Reviewer 5

Project F: Aquatic Invertebrate Ecology

Reviewer 1

The project illustrates good interaction with other projects to support inference and provides auxiliary information that might be needed to explain among year differences in higher trophic levels, like native fish and trout. The bases appear to be covered in terms of monitoring instream drifting and emerging aquatic invertebrates.

Project F GCMRC PI Response

We appreciate these supportive comments.

Reviewer 2

Weekend "breaks" are an excellent idea for egg survival and other possible mechanisms for macroinvertebrate success and increasing diversity. Once this experiment is complete, will there be another study on how weekend flows can be best designed as ecological flows for macroinvertebrates? The community science involved in this project was a great component, but there are ways to build on the work already started by following up with stakeholders and increasing opportunities for Tribal members and other groups not typically involved in this type of community science.

In this case, access to rafting trips may limit the participation of a diverse audience who 1) are not tourists and therefore may not consider participating in such a trip 2) are financially limited and may not be able to afford such a trip, and 3) have been historically excluded from such activities.

Project F GCMRC PI Response

We appreciate these supportive comments. We have scheduled workshops on October 28 and November 4 to identify potential next steps in ecological flow experiments for natural processes and macroinvertebrate assemblages. To improve opportunities for Tribal members and diverse audiences to participate in the community science project, GCMRC has partnered with Grand Canyon Youth to launch Partners in Science river trips for more than 20 years. In 2021, three Partners trips were launched, and all collected light trap samples of aquatic insects and several other data collection activities. These Partners in Science trips are comprised of high school age students and in 2021 one of these trips was comprised entirely of Tribal youth participants. These trips are a powerful tool for training the next generation of scientists in the scientific process and educating participants about the role that science plays in management of the Colorado River and Grand Canyon. Moving forward, we are exploring how to involve tribes in all Partners in Science trips to facilitate monitoring of tribal resources and to describe the

role that traditional ecological knowledge and tribal values plays in management of the Colorado River and Grand Canyon.

Reviewer 3

No comment.

Reviewer 4

No comment.

Reviewer 5

Project G: Humpback Chub Population Dynamics Throughout the Colorado River Ecosystem

Reviewer 1

The project provides advanced approaches to estimate population dynamics and project results have the potential to inform decisions. There are a few technical questions were included related to methodology and relevance of particular data elements to management.

Project G GCMRC PI Response

Responses to specific comments are provided below, in the subsections concerning Project G in the APPENDIX A: INDIVIDUAL REVIEWS section of this document.

Reviewer 2

No comment.

Reviewer 3

No comment.

Reviewer 4

No comment.

Reviewer 5

Project H: Salmonid Research and Monitoring

Reviewer 1

There needs to be more detail provided for Project H.1 to determine if can sufficiently inform operations and provide information relevant to objectives. The coupled brown trout, rainbow trout, and humpback chub models used to evaluate management scenarios are an interesting application. The salmonid research and monitoring project tied to experimental dam operations associated with meeting LTEMP resource objectives is valuable research. How will this long term datasets be used to evaluate experimental flows?

Project H GCMRC PI Response

The objectives of Project Element H.1 are to evaluate: 1) the effects of higher and potentially more stable flows in spring and summer during equalization events or weekend stable flows ("bug flows") on trout recruitment, growth, and dispersal; 2) the effect of fall HFEs on recruitment of trout in Glen Canyon, measured either through direct effects on juvenile survival or through reduced egg deposition in later years driven by reduced growth of trout; 3) the effect of spring HFEs on trout recruitment, growth, and dispersal, and 4) the effect of Trout Management Flows on rainbow and brown trout recruitment and dispersal. In the FY18-20 TWP, hypotheses related to objectives 3 and 4 could not be tested because spring HFEs and TMFs were not released as experimental flows. For objective 1, equalization flows were not released but stable "bug flows" were tested from 2018-2020. For objective 2, fall HFEs were only released in 2018.

While the effects of bug flows on trout recruitment and growth dynamics are still being evaluated, data from long-term mark-recapture efforts (2012-2020) from Project Element H.1 were analyzed to assess the effects of fall HFEs on trout population dynamics in Glen Canyon. The FY20 annual report describes the field sampling methodology to collect samples, but it lacks a description of the analytical methods used to evaluate experimental flows such as fall HFEs. These models are described in full by Korman and others (2017a, b,), but briefly, data are analyzed using a multi-state Cormack-Jolly-Seber open population model in a robust design framework (Kendall et al. 1995) to estimate trout population abundance, growth, survival, and capture probability for fish >75 mm. This model is stratified by fish size because capture probability and survival are size-dependent, so results presented in the FY20 annual report are presented in 5 size bins (75-124, 125-174, 175-224, 225-274, and >275 mm). The model is also spatially stratified to account for differences in sampling effort and the number of rainbow trout released in each reach. This model covers results presented in Figs 4-8 in the annual report pertaining to abundance and mean monthly growth rate. No model is needed to estimate brown trout catch rates reported in Figs 1-2 (catch per kilometer of

shoreline), while Fig. 3 includes estimates from a standard equation for relative condition factor (Korman and others, 2021).

Reviewer 2

No comment.

Reviewer 3

No comment.

Reviewer 4

There is significant overlap in topic with this project and Project J. It would be helpful if the connections between projects was more explicit. The economic value data is from 2016. Has more recent data been collected and how does it compare? There is little economic information provided about the recreational fishery or how operations impact the economic value. Results or an update related to the incentive program are valuable and should be included. The reviewer suggested using the term “Community Science” rather than “Citizen Science”.

Project H GCMRC PI Response

In the FY21 annual report we will try to make a better connection between the types of data collected by AZGFD in Project H.4 and the data collected in Project J. In addition, the angler surveys collected by AZGFD are designed to collect data on angler use with the intent of using that data to understand angler use, assess whether fishery management goals are being met, and manage the fishery. They are not designed to measure economic impact or collect socioeconomic data. GCMRC will pass the suggestion on to use the term “community science” rather than “citizen science” to AZGFD.

Reviewer 5

Project I: Warm-Water Native and Nonnative Fish Research and Monitoring

Reviewer 1

It appears these efforts support The LTEMP "Goal 10. Nonnative invasive species. Minimize or reduce the presence and expansion of aquatic nonnative invasive species" and helps inform the "mechanical removal of nonnative fish near the Little Colorado River confluence".

There are a number of important details that were either not included or were unclear. The following are some notable questions that were unanswered:

- How trends are calculated from monitoring data and this is likely important for informing adaptive operations of Glen Canyon dam and whether operations can achieve management objectives?
- Why is Asian tapeworm monitoring important and how does this support GCDAMP and LTEMP?
- How does this sampling inform a) sampling efforts needed at a larger scale to detect warm-water invasive fish and b) if warm-water invasives are expanding in range?
- How is the eDNA persistence from upstream factored into the eDNA analysis completed?

Project I GCMRC PI Response

Trends in Catch-per-unit-effort over time for system wide native and non-native fishes are calculated by examining deviations in the mean catch among years, compared with the calculated 95% confidence interval of catch rate for a given year. Consecutive years of catch rates above or below the 95% confidence interval of the mean would indicate a significant trend. Trends in Asian fish tapeworm loads are assessed as the proportion of fish containing at least one Asian fish tapeworm. A positive or negative trend in proportions over time may indicate population level changes in infestation. Trends in detection of rare invasive non-native species are assessed as changes in presence/absence or relative abundance over time. This additional clarification on how trends are calculated will be included in the 2021 annual report.

Asian tapeworm has been identified as 1 of 6 potential threats to the continued persistence of humpback chub in Grand Canyon and may decrease growth rate and increase predation risk for endangered cyprinid fishes. The GCDAMP is tasked with evaluating risks related to persistence of humpback chub. Additional justification for this project and how it relates to LTEMP goals will be added to the 2021 annual report to improve clarity.

Monitoring efforts to improve early detection of Invasive warm-water fishes will be used to direct future monitoring efforts or emergency responses as needed. Larger scale efforts will be dictated by this initial monitoring. This targeted sampling in places we believe warm water invasive fishes will be most likely to become established will indicate an expansion in range if detected. Additional details will be added to the 2021 annual report to clarify how this sampling informs larger scale efforts.

This is a great question about eDNA persistence, that we do not have the answer to yet under the specific water temperature and turbidity conditions in present in the Colorado River in Grand Canyon. The data collected this year should help to evaluate this question, and information will be included in the 2021 annual report to indicate how we will factor upstream persistence into the eDNA analysis. Our sampling methodology includes three replicates taken on each bank (left and right), spatially distributed every two miles from Lees Ferry to Pearce Ferry. At major tributary junctions (Little Colorado River, Bright Angel Creek, Tapeats Creek, Shinumo Creek, Kanab Creek, Havasu Creek, and Spencer Creek) we took three replicates just upstream from the tributary, in the tributary, and every 0.5 miles on both banks for 6 miles downstream. This intense sampling in and downstream from tributaries (where non-native species may reside in higher densities due to warm water) will allow us to get a better understanding of eDNA persistence from known sources in a large river ecosystem like Grand Canyon. We are using a combination of qPCR and metabarcoding methodologies to detect rare species in Grand Canyon. We are also collecting data on eDNA copy number for abundant species like rainbow and brown trout in Glen Canyon to compare population abundance estimates to concentrations of DNA in the water column. Subsequent studies currently planned using funding outside the AMP will provide additional information on eDNA degradation rates (e.g., from solar radiation or warm water temperatures) relative to dilution in the environment with higher flow volumes.

Reviewer 2

No comment.

Reviewer 3

No comment.

Reviewer 4

No comment.

Reviewer 5

Project J: Socioeconomic Research in the Colorado River Ecosystem

Reviewer 1

The applied decision and scenario analysis is an interesting application to evaluate and identify optimal management actions that presumably links back to socioeconomic values. A table linking back to the LTEMP and management actions is suggested. How will survey information from the Tribes be used to inform decision making and adaptive management?

Project J GCMRC PI Response

Thank you for the comments. We will address the 'table linking back to the LTEMP and management actions' in future annual reports. The tribal surveys will be used to 1) collect information to recognize Tribal values for downstream resources and support the prioritization of management goals, 2) identify Tribal preferences for experimental flows specified in the LTEMP EIS, and 3) evaluate trade-offs from a Tribal perspective. These are all important elements in an adaptive management decision framework and facilitate the consideration of Tribal perspectives.

Reviewer 2

The inclusion of some deliverables related to the use of USGS science by Tribal communities is valuable. Are there other ways to engage Tribal collaborators than workshops? A list of outreach and meetings and the associated stakeholders would be informative. There are issues with the way some of the surveys have been designed relative to Tribal input and suggestions are provided about how to improve those. Are there other (non-Tribal) stakeholders involved with the Willingness to Pay research?

Project J GCMRC PI Response

Thank you for the comments. There are other ways to engage Tribal collaborators in the program. In my opinion the important collaboration revolves around how cultural benefit knowledge, specifically relational values, are incorporated into decision making processes. I continue to collaborate with the tribes and academic researchers to identify these opportunities. Comments about survey design will be addressed in the detailed comments below (Appendix A). There is other 'willingness to pay' research. This research includes recreational (angling and whitewater) surveys (Bishop et al. 1987, Bair et al. 2016, Neher et al. 2017, Neher et al. 2019) that have been funded by this program and a public survey related to resource in the Grand Canyon (Welsh et al. 1995, U.S. Bureau of Reclamation 2016), the latter funded by the National Park Service.

Reviewer 3

Overall, this project is an important component of the CRe, GCMRC, and GCDAMP, because it allows for a broad assessment of the connections of ongoing activities with needs and economics downstream. Therefore, it is recommended to continue prioritizing this area of analysis. The proposal to evaluate nonstationary climate impacts using the Donovan et al. (2019) model it's an important priority; however, realistic constraints need to be used.

Project J GCMRC PI Response

Thank you for the comments.

Reviewer 4

The section on Tribal Resources is difficult to review since the reports are not available and audio for that portion of the meeting was not available. There are concerns about how the contingent valuation was designed that limit its utility.

The decision about which model to apply to willingness to pay data is not neutral and sensitivity analysis is important. It would be interesting to use some of the more commonly used approaches such as the non-parametric Turnbull with this data.

The report gives a brief description of the bioeconomic dynamic programming model that evaluates the tradeoffs between protecting humpback chub and rainbow trout abundance. Where is a summary of the findings? Who are the decision-makers?

Recreational fishing is covered above, but the rainbow trout fishery is also discussed in several of the other projects. There needs to be some summary material in this report that weaves these related topics together.

There is no mention of the on-going severe drought or climate change. Will new low-flow scenarios be tested? Are there recommendations going forward related to climate change? And how does the renegotiation of the Colorado River Compact impact this report?

Project J GCMRC PI Response

The Navajo Nation and Hualapai Tribal draft reports were provided to the Bureau of Reclamation for this review. It is unfortunate that you didn't have an opportunity to review. The surveys included a choice experiment (without a price attribute) and a 'willingness to pay' question that did not specify quantitative outcomes related to the resources being valued. The question format related to the contingent valuation question was intentional and researchers are explicit about the limited utility in estimating economic value in the report and in past presentations.

We agree that it would be interesting to use the non-parametric Turnbull with the recreation data. As you point out, the published analysis was intended to replicate the

Bishop et al. 1987 analyses. Recreation monitoring and research is not consistently funded in every fiscal year (FY). Recreation related monitoring and research was funded in FY17 and in Project O in the FY21 workplan. We will continue to undertake recreation related research as possible.

The summary of the findings of the bioeconomic model is found in Donovan et al. 2019. The objective of the Annual Report is to brief stakeholders on the recent outcome of research. In the 2020 Fiscal Year Annual Report the focus of Project J was on the utility of the bioeconomic model in identifying the cost-effectiveness of humpback chub translocations (Yackulic et al. 2021). The decision makers are stakeholders in the GCDAMP, specifically the U.S. Fish and Wildlife Service. For example, as part of the review of conservation triggers for humpback chub the results of the bioeconomic model were used to evaluate the current triggers.

The objective of the Annual Report is to brief stakeholders on the recent outcome of within year research. Recreational fishing economics research is part of the GCDAMP Technical Workplan FY21-23 (Project O - Spring Disturbance Flow and Project J – Brown Trout Incentivized Harvest). However, there was no recreational angling economics research in FY20. The last funded recreation economics project prior to FY20 was in FY17.

Climate change is important. I would argue that to provide the most value, the bioeconomic model could be used to evaluate multiple actions related to humpback chub conservation in various future climate scenarios. This type of robust decision making would better position the program to meet its goals. Additional bioeconomic modeling is occurring and research to address climate change is warranted.

Reviewer 5

Project K: Geospatial Science and Technology

Reviewer 1

It was uncertain what the needs of the GCDAMP and LTEMP are for geospatial science and data technology or how these systems support decision-making. There has been an impressive set of tools developed, however, to support the GCDAMP and LTEMP. There appears to be a significant effort to provide information to stakeholders and researchers.

Project K GCMRC PI Response

Yes, the data resource tools, including but not limited to geospatial analysis tools, have been designed and created in response to known needs for both individual GCDAMP-funded science projects and for overarching needs of GCMRC as a science entity concerned with long-term monitoring of the Colorado River. Many geospatial data sets and geospatial analyses have been developed to support multiple projects and are often re-used for new projects or to answer new questions. Any uncertainty in the language of the LTEMP or in the needs of the GCDAMP is an issue that is a bit outside the scope of this project. The approach taken in Project K is to be knowledgeable on emerging trends in Information Technology (IT) as it relates to GCMRC data needs, to work towards some consistency in the IT-related realms of software, hardware, techniques, source control for coding, application of advanced computing for the Center, and to be flexible in terms of how support to science projects can be provided. Having consistency, reliability, and accessibility to long-term data resources plays a fundamental role in the decision-making process.

Reviewer 2

No comment.

Reviewer 3

The migration of data into databases and cloud computing resources is an important innovation with payoffs over the long term. ArcGIS may not be the most effective tool due to the size of data sets. Other more powerful and efficient tools should be considered for these larger datasets and analyses. Tableau may not be a good long-term cost-benefit decision.

Project K GCMRC PI Response

The ESRI ArcGIS software suite, which includes desktop applications such as ArcGIS Pro and the Enterprise ArcGIS platform, is widely used throughout the U.S. Geological Survey and provides numerous functions for GCMRC's geospatial data workflows that would be difficult to reproduce without expensive and time-consuming changes in the

fundamental software architecture. GCMRC does utilize many, specialized pieces of software that range in function from sonar (HyPack, Qinsy) and LiDAR data processing to image processing (ENVI, ERDAS Imagine) to custom modelling programs, among others, and these tools have very specific uses for individual projects. Not knowing what the "other more powerful and efficient tools" are being recommended here makes it difficult to develop a full response; however, Project K has been instrumental in helping GCMRC leverage resources from the USGS in cloud computing through Amazon Web Services, high-performance computing (HPC), using USGS-approved source control sites (GitLab) for custom code development. So, there are many options provided to work with larger, more complex data sets. The ArcGIS software is but one of many tools employed by GCMRC. It allows for the integration of these specific data sets with uses ranging from simple data overlays to advanced geospatial analysis, and it provides a data serving platform for GCMRC's geospatial data sets online. The effort to push science project data from local hard drives to enterprise, relational databases is not separate from the use of ArcGIS – as one of many tools in the data toolbox – but rather it is complementary to the growth of relational database use, as ArcGIS is a well-documented, well-supported client for linking to and accessing data within these databases. Currently, the Tableau Desktop and Tableau Server applications are provided by the USGS Cloud Hosting Solutions (CHS) free-of-charge, and this has been the case for the past three fiscal years.

Reviewer 4

No comment.

Reviewer 5

Project L: Overflight Remote Sensing in Support of GCDAMP And LTEMP

Reviewer 1

It was unclear from the summary what the expected outcomes of this effort are, how the outcomes of these efforts will support the GCDAMP, or how this integrates with the LTEMP. A table that shows the relationship between expected products and their applications in projects would be helpful.

Project L GCMRC PI Response

The expected outcomes and integration with GCDAMP and LTEMP is summarized in the project description in our FY21-23 Triennial Workplan and we show a table like you describe in the workplan. We will incorporate this information into our FY21 Annual Report for the Overflight Remote Sensing project.

Reviewer 2

No comment.

Reviewer 3

The details of the overflight are not clearly articulated, although there is value in additional remote sensing. Evaluating opportunities to integrate remote sensing imagery with publicly available spaceborne imagery could provide cost-effective benefits.

Project L GCMRC PI Response

Please see our response to the similar comment about the purpose and outcomes of the overflight from Reviewer 1 above. With regards to spaceborne remote sensing, the canyon is extremely deep, narrow, and sinuous, which makes acquiring a synoptic, shadow-free orthomosiac at 20cm resolution from a space-based sensor currently not feasible for the entire >400km segment of the Colorado River between Lake Powell and Lake Mead. However, we do incorporate satellite imagery into our remote sensing science as feasible and appropriate. Please see our recent paper (Bransky and others, 2021 in the journal Remote Sensing) which is an example of work we do incorporating high-resolution spaceborne remote sensing (in that case from the Worldview satellite) with the high-resolution airborne imagery from the manned airplane overflights.

Reviewer 4

No comment.

Reviewer 5

Project M: Administration

Reviewer 1

No comment.

Reviewer 2

No comment.

Reviewer 3

A minor comment is that the citizen science programs extend budgets and elevate the awareness of visitors.

Project M GCMRC PI Response

Yes, we agree with this observation about citizen science programs.

Reviewer 4

No comment.

Reviewer 5

Project N: Hydropower Monitoring and Research

Reviewer 1

No comment.

Reviewer 2

No comment.

Reviewer 3

Continue to coordinate with partners to identify opportunities to improve hydropower and energy resources. For example, the impact of high flow experiments on total outflows, the sensitivity of greenhouse gas emissions to reservoir levels, etc.

Project N GCMRC PI Response

Thank you for the comments.

Reviewer 4

Goals and objectives could be clearer. Project N needs more detail (i.e., tables or other results summaries) and is lacking information about the economic value of hydropower. Several suggestions for improving the presentation and questions to clarifying methods and assumptions were included.

Project N GCMRC PI Response

Thank you for the comments. I agree that the goals and objectives of Project N could be clearer, however the limited funding only allows for coordination with partners to identify opportunities to improve hydropower and energy resources. Therefore, no specific project is identified prior, only opportunities to add minimal effort to ongoing projects that are identified within a fiscal year. The focus of Project N in FY20 was the greenhouse gas emissions to reservoir levels (Waldo et al. 2021). The Annual Report is not intended to be an in-depth review of fundamental concepts or past projects and results. I don't object to this, but that is not the direction I have been given. For example, the economic value of hydropower was not included as a specific result in the greenhouse gas emissions and reservoir level manuscript, and therefore was not included in the text.

Reviewer 5

Appendix 1: Lake Powell Water Quality Monitoring

Reviewer 1

No comment.

Reviewer 2

No comment.

Reviewer 3

The collaboration with EPA should continue to be prioritized.

Appendix 1 GCMRC PI Response

The collaboration with EPA for work on Lake Powell has ended. PI Deemer has funding from EPA for surveying reservoir GHG emissions from desert Southwest reservoirs more broadly, but Lake Powell was not randomly selected to be included in that study.

Reviewer 4

No comment.

Reviewer 5

Appendix 2: Deliverables (Products) FY 2018-2020

Reviewer 1

The program appears to be highly productive and the development of varying web based resources to serve, process and summarize data is an asset.

Appendix 2 GCMRC Response

Thank you. We are proud of our productivity and therefore appreciate this comment!

Reviewer 2

No comment.

Reviewer 3

No comment.

Reviewer 4

No comment.

Reviewer 5

Appendix 3: Budgets, All Projects

Reviewer 1

No comment.

Reviewer 2

No comment.

Reviewer 3

No comment.

Reviewer 4

No comment.

Reviewer 5

4.0 Peer Reviewer Summary

All reviewers provided suggestions to improve data presentation and use. All reviewers provided suggestions for additional analysis or expanded methodologies in one or more projects. All reviewers also identified multiple projects where it was hard to tie the project to the relevant LTEMP objective and related management actions. All reviewers commented on one or more projects that it was not easy to determine whether a metric could evaluate a goal or be used for decision-making (i.e., adaptive management).

Only some reviewers commented on Tribal involvement and engagement, but those that did all agreed that there appeared to be a disconnect with what were likely Tribal priorities in one way or another. They also made suggestions for improving Tribal involvement and engagement.

The socioeconomics elements were particularly difficult for reviewers to understand how projects impacted them or how they were tied to other projects. This is an area of great interest to stakeholders and yet was poorly presented throughout the 2020 Annual Report.

GCMRC Response

Please see responses in the SUMMARY OF RESPONSES section (3) above to specific instances of the comments that are more generally summarized here in the SUMMARY section (4).

5.0 References

Butterfield, B.J., Palmquist, E.C., and Ralston, B.E. 2018. Hydrological regime and climate interactively shape riparian vegetation composition along the Colorado River, Grand Canyon—poster presentation: Bozeman, MT, July 22-27, 2018, Natural Ecosystems as Benchmarks for Vegetation Science, International Association of Vegetation Scientists 61st Annual Symposium.

Donovan, P., Bair, L.S., Yackulic, C.B., and Springborn, M.R. 2019. Safety in numbers—Cost-effective endangered species management for viable populations: Land Economics, v. 95, no. 3:435-453.

Reclamation. 2016a. Glen Canyon Dam Long-Term Experimental and Management Plan and Final Environmental Impact Statement (October 2016). US Department of Interior, Bureau of Reclamation and National Park Service. Denver, CO.

Reclamation. 2016b. Record of Decision for Glen Canyon Dam Long-Term Experimental and Management Plan. US Department of Interior, Bureau of Reclamation and National Park Service. Denver, CO.

USGS. 2020. Fiscal Year 2020 Annual Project Report to the Glen Canyon Dam Adaptive Management Program. US Geological Survey, Grand Canyon Monitoring and Research Center. Flagstaff, AZ.

Appendix A: Individual Peer Reviewers

Reviewer 1 (Colvin) – August 2021

Reviewer 2 (Kroll) – August 2021

Reviewer 3 (Livneh) – July 2021

Reviewer 4 (Lewis) – September 2021

Reviewer 5 (Stella) – September 2021

Individual Peer Reviews

Peer Reviewer 1

AGENCY:	US Bureau of Reclamation, Glen Canyon Dam Adaptive Management Program (GCDAMP)
MATERIAL(S) REVIEWED:	2020 Grand Canyon Monitoring and Research Center (GCMRC) Annual Report
REVIEWED BY:	Michael E. Colvin, Mississippi State University
DATE:	August 26, 2021

I. Project A: Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem

A. General overview

1. The project indicates an understanding needed to identify conditions (dam operations and tributary conditions) that lead to sand accumulation in CR reaches. Mass balance results of sand mass changes over the fiscal year are presented for stream reaches.

B. Link to LTEMP

1. The project links to LTEMP resource goals related to natural resources (p2) and sediment (p5).
2. Are the specific targets for sand or fine sediment resources defined? If so, what are they?

C. Sustainability of sand resources

1. The sustainability of sand resources is referenced as a guiding question and hypothesis for Glen Canyon Dam. Sustainability requires a look to the future to forecast the effect of operations on sand resources, or possibly a retrospective analysis of what has happened in the past. The change in sand resources over the near or long term can then be evaluated for increases or decreases. The mass balance approach applied to evaluate sand mass dynamics and results shown in table demonstrate changes from one year to the next for varying reaches. Are there ways to aggregate this to the system level? The mass balance model could be used to parameterize a dynamic model that can be linked to dam operations, environmental conditions, and used to evaluate sustainability in

sand resources over time. For example, at the system level, the analysis might evaluate if the change in sand mass is approximately 0 indicating that the current sand resources are being sustained.

2. Related to the science questions of suitability, are dam operations coupled with environmental influences being used to sustain the current amount of sand resources in the (Colorado River ecosystem) CRe? Or is there a need to increase or decrease sand resources and then sustain? The LTEMP resource goals for sediment (p5) indicate increasing and retaining fine sediment within operational constraints, which suggests that sustainability of sand resources might be an objective after some level of increase occurs.

Project A GCMRC PI Response

These comments are addressed in Topping and others (2021). It remains an open question as to whether the current approach to dam management is sufficient to sustain a sufficient level of sand in each segment of the Colorado River in Marble and Grand canyons to maintain sandbars in perpetuity.

II. Project B: Sandbar and Sediment Storage Monitoring and Research

A. Overview, Project goals and objectives and Link to LTEMP

1. Although this project relates to sediment goals of the LTEMP, are there ways to couple monitoring efforts of sandbars and recreational experience quality (p4)?
2. Is there a way to synthesize information on sand bar volume with dam operations and environmental conditions to develop a predictive model of sand bar volume that can then be linked to objectives?

B. Project B.1. Sandbar monitoring using topographic surveys and remote cameras

1. This project element relates to the first purpose of Project B, “track the effects of individual high flow experiments on sandbars”.
2. The section was unclear on the application of topographic surveys; were they conducted and, if so, how?
3. Camera use is a neat application to passively monitor sandbars. Will the method provide sufficient power to detect changes and link to dam operations and tributary interactions? Will collecting time series sand bar change on a subset of sand bars be sufficient to inform the potential effects of dam operation and interaction with tributaries?

4. Figure 1 (p17) is there uncertainty associated with the point estimates presented for sandbar volume?

C. Project B.2. bathymetric and topographic mapping for monitoring long-term trends in sediment storage

1. This project element relates to the purpose b, "monitor the cumulative effect of successive HFEs and intervening operations on sandbars and sand conservation and to Investigate the interaction between dam operations, sand transport, and eddy sandbar dynamics".
2. P19. "long term trends in sandbars and sand storage…." How will the former and latter be quantified and how does that relate to the sand budget model where the SNR was determined to be >1?
3. P20. Recent progress in bedload transport models is interesting and a nice extension of the previous models used and can potentially inform adaptive management experiments.

D. Project B.3. Control network and survey support

1. The maintenance of the geodetic framework seems foundational to supporting monitoring efforts. No specific comments.

E. Review specific questions

1. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon ecosystem and ensuring progress in defining and conducting adaptive management experiments."*

   Assessing the report and recorded presentations the monitoring appears to satisfy these questions. The monitoring program quantifies sand and fine sediment dynamics, albeit analyses of trend and link to resources goals can be clarified.

Project B GCMRC PI Response

- Sandbars and campsites have been identified by stakeholders of the AMP to be important aspects of the recreational experience. We have therefore designed monitoring programs to track these resources directly and we infer that improvements in sandbars and campsites add value to the recreational

experience. The economic value of sandbars and campsites as part of the recreational experience has not been quantified directly but has been addressed indirectly in studies on the preference for different flow levels by whitewater boaters (Bishop and others, 1987; Neher and others, 2017). We believe that it is possible to more explicitly connect sandbars, campsites, and the economic value of the recreational experience, and hope to make that part of future work plans.

- The sandbar volume data have been analyzed with streamflow and sediment data (dam operations) and we have developed a sandbar volume model (Mueller and Grams, 2020). Because that work was the product of a previous workplan and the paper was not net published, it was not discussed in this annual report, but the now-published model was presented at a recent stakeholder meeting.
- Topographic surveys are an important part of the sandbar monitoring and are conducted annually at each of 45 long-term monitoring sites using conventional total stations. We will be sure to clarify this in future reports.
- For certain dam operations, such as the high-flow experiments, the sandbar response is sufficiently large that the response is easily detectable on the remote camera images and a robust conclusion is possible. We are still in the process of evaluating whether we can obtain useful information about other dam operations.
- There is uncertainty associated with the volume estimates, but at the scale presented in these figures, the uncertainty is very low (about the size of the data points themselves). We will, however, add those error bars to future plots.
- The long-term trends in sandbars will be measured by the annual topographic surveys at the 45 long-term sandbar monitoring sites. The long-term trends in sand storage will be measured by the repeat bathymetric surveys of the channel bed that occur on the order of every 3 to 10 years, depending on reach. The repeat measurements of the channel bed are used to test and verify the results of the sand budget model.
- We will add additional information on analyses of trends and links to resource goals in future annual reports.

Bishop, R. C., Boyle, K. J., Welsh, M. P., Baumgartner, R. M., & Rathbun, P. R. (1987). Glen Canyon Dam releases and downstream recreation: An analysis of user preferences and economic values. (Glen Canyon Environ. Stud. Rep. GCES/27/87). Springfield, VA: Huberlein-Baumgartner Research Service.

Neher, C., Duffield, J., Bair, L., Patterson, D., & Neher, K. (2017). Testing the limits of temporal stability: willingness to pay values among grand canyon whitewater boaters across decades. Water Resources Research, 53, 10,108–10,120. https://doi.org/10.1002/2017WR020729.

Mueller, E.R., and Grams, P.E., 2021, A Morphodynamic Model to Evaluate Long-Term Sandbar Rebuilding Using Controlled Floods in the Grand Canyon: Geophysical Research Letters, v. 48, p. 1–10, doi:10.1029/2021GL093007.

III. Project C: Riparian Vegetation Monitoring and Research

A. Overview, Project goals and objectives and Link to LTEMP

1. The project relates to natural processes and recreational experience LTEMP resource goals. The project is delineated into four elements that link to monitoring changes to riparian vegetation using field and digital data (C.1. and C.2.), developing predictive vegetation composition models related to hydrologic regime (C.3), and integrated science products into decision support tools (C.4)

B. C.1. Ground-based vegetation monitoring

1. Vegetation monitoring for composition and cover, with emphasis on nonnative species appears to provide robust data that can be used for status and trend analysis, including statistical analysis (i.e., illustrated by figure 1 p26).

C. C.2. Imagery-based riparian vegetation monitoring at the landscape scale

1. This project quantified long term changes in total riparian vegetation related to dam release patterns and climate for reaches of the CRe.
2. It was unclear how the long-term changes were evaluated and on what metric. Additionally, the effect of dam operations on riparian vegetation was unclear, although this topic was addressed in C.3.

D. C.3. Vegetation responses to LTEMP flow scenarios

1. The objective of this project was to develop better predictive models of how LTEMP flows will alter vegetation.
2. How well did the models of riparian vegetation perform (p11)? Was a sensitivity analysis performed to evaluate where additional study or flow experiments might be prioritized?

E. C.4. Vegetation management decision support

1. The specific objectives of this project element were unclear. How was decision support provided? What potential management actions came from information provided by this project element? In other words, was information used to evaluate trade-offs in plantings of specific strains of cottonwoods and willows?

F. Review specific questions

1. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon ecosystem and ensuring progress in defining and conducting adaptive management experiments."*

Assessing the report and recorded presentations the monitoring appears to satisfy these questions. Clarifications on metrics and how they are estimated would be helpful and how those metrics fit with the LTEMP resource goals.

Project C GCMRC PI Response

C.2. Long term changes in riparian vegetation are evaluated by changes in the areal coverage of total riparian vegetation and plant species in the riparian zone. Effects of dam operations are evaluated by relating those vegetation changes to hydrologic variables such as inundation duration. Please see our latest paper (Durning and others 2021 in the journal Ecohydrology) for a detailed example of this work. We will be clearer in how we communicate the results of this science in the Annual Report for FY21.

C.3. Please see the response to general comments, and the forthcoming Status and Trends USGS Open File Report, regarding model performance. An explicit sensitivity analysis was not performed; however, the overall results implicated an effect of daily fluctuating flows and seasonally inverted baseflows relative to pre-dam patterns as mechanisms for further investigation. These are prioritized in our current work and will be explicitly addressed in the FY 2021 Annual Report.

C.4. The conclusions of this work are that translocating plants for restoration within river segments defined by closely related populations are likely to result in maintenance of genetic integrity and application of locally adapted materials that may have higher rates of success than plants from elsewhere. Critically, these genetically-defined regions are generally much larger than those defined by the NPS for translocation. These results have been communicated to the NPS vegetation management team, and we are

working closely with them to help translate this research into decisions related to plant materials use and translocation.

Review Specific Questions: Please see response to general comments (Section 3 Project C above) regarding specific metrics. They are based on the LTEMP and are enumerated further in the forthcoming Status and Trends OFR.

IV. Project D: Geomorphic Effects of Dam Operations and Vegetation Management for Archaeological Sites

A. Overview, Project goals and objectives and Link to LTEMP

1. This project links to the LTEMP goal of preserving cultural resources and that preservation in place will be enhanced by implementing the preferred alternative specified in the LTEMP. The high flow experiments (HFE) specified in alternative D may conflict with preservation, eroding terraces containing archeological sites and depositing sand on aeolian dune fields thereby providing protection in the Marble and Grand Canyon.
2. The goal of the project is to quantify geomorphic effects of dam operations and riparian vegetation management with emphasis on HFEs on sediment supply to terraces and culture sites. The project should allow for the evaluation of how flow and non-flow actions affect cultural resources, preservation of resources, vegetation, and sediment dynamics.

B. D.1. Geomorphic effects of dam operations and vegetation management

1. The potential effects of dam operation and vegetation management were monitored with Lidar, weather, and time lapse camera.
2. Can the monitoring objectives be clarified?
3. Appears to be a good census of archeological sites and features in the monitoring portfolio. Can this monitoring be used to inform a risk model?

C. D.2. Cultural resources synthesis to inform historic preservation plan and repeat photography to inform project element D.1.

1. No specific comments

D. Review specific questions

1. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam*

operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon ecosystem and ensuring progress in defining and conducting adaptive management experiments."

Assessing the report and recorded presentations the monitoring appears to satisfy these questions. Clarifications on metrics, how they are estimated, and how those metrics fit with the LTEMP resource goals and overall monitoring objectives would be helpful. Lastly, clarification is needed on how weather data is used to achieve monitoring objectives.

Project D GCMRC PI Response

In 2016, we developed a long-term monitoring plan that includes specific metrics for evaluating changes in the condition of archaeological sites that are tied to sediment dynamics, stability, and geomorphic change. The monitoring plan calls for condition evaluations using these metrics to be completed once every 4-10 years (depending on the specific metric); therefore, they are not reported on an annual basis.

V. Project E: Nutrients And Temperature as Ecosystem Drivers: Understanding Patterns, Establishing Links and Developing Predictive Tools for an Uncertain Future

A. Overview, Project goals and objectives and Link to LTEMP

1. This project examines patterns in nutrients and temperature in reaches of the CRe. The metrics monitored may not directly relate to LTEMP resource goals but are a necessary precondition to achieving LTEMP resource goals related to biota (humpback chub, rainbow trout, other native fish).

B. E.1. Temperature and nutrients in the CRe

1. What are the biologically important levels for the water nutrients monitored in the CRe?

Project E GCMRC PI Response

At the low end (0.001 mg/L P), the concentrations of soluble reactive phosphorus exiting Lake Powell are extremely limiting to ecosystem production. At the higher end (0.01 mg/L P), the concentrations seem to support a healthier more productive food web. It would likely take a great deal more P than that measured at the outflows to risk eutrophication. For comparison, total phosphorus concentrations at the GCD outflow

are generally well below the 25th percentile of EPA found data from the Xeric west ecoregion (0.022 mg/L P).

2. Is DO measured at the sediment water interface (p60)? Periods of anoxia can mobilize P that is otherwise sequestered in benthic sediments, might be negligible in reaches of the CRe (Mortimer 1942).

Project E GCMRC PI Response

We do not currently measure DO at the sediment water interface, but we did conduct some sediment incubations this summer where we explored the role of sediment anoxia. We compared treatments with low dissolved oxygen to those with higher dissolved oxygen and low pH to try to disentangle potential effects of dissolved oxygen and pH on P release (e.g., via iron-mediated vs. calcite-mediated dynamics).

3. Have nutrient budgets/dynamic models been developed to guide monitoring?

Project E GCMRC PI Response

We are working to construct a P budget for the Colorado River through Grand Canyon as part of this work plan.

4. With the GPP models developed there is some indication that weekend bug flows influence system level GPP? Is there feedback on dam operations? For example, to modify flows for maximum GPP, or something of that nature?

Project E GCMRC PI Response

Yes, given the food-limited status of the river, managing the dam for springtime steady-low flow may improve the condition of the food web by boosting rates of riverine GPP.

C. E.2. Linking temperature and nutrients to metabolism and higher trophic levels

1. The project elements seem to build on and address important questions needed to evaluate dam operations and environmental conditions on GPP, which is primarily driven by nutrients and temperature.

D. Review specific questions

2. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon*

ecosystem and ensuring progress in defining and conducting adaptive management experiments."

Assessing the report and recorded presentations, the monitoring appears to satisfy these questions. The utility of monitoring temperature and the extensive modeling of temperature directly applies to dam operations and tributary and solar inputs. The linkage to the LTEMP, specifically through defined metrics and thresholds, was unclear.

Project E GCMRC PI Response

We will include additional information like linkages to LTEMP and defined metrics and thresholds in future reports, if we report on this model again.

VI. Project F: Aquatic Invertebrate Ecology

A. Goals and objectives

1. The project informs natural resource goals of LTEMP. Specifically, the monitoring efforts are being used to evaluate effects of bug flows from Glen Canyon Dam on aquatic invertebrate production and emergence timing. The project illustrates good interaction with other projects to support inference and provides auxiliary information that might be needed to explain among year differences in higher trophic levels, like native fish and trout.

B. Monitoring of aquatic invertebrates

1. The bases appear to be covered in terms of monitoring instream drifting and emerging aquatic invertebrates. Within the constraints of the project, is the monitoring sufficient to evaluate bug flows (i.e., is sampling sufficient to detect changes in invertebrate production resulting from the flows)?
2. The use of bat echo recordings is an interesting idea and would seem to be another potentially useful source of information indexing aquatic invertebrate production.
3. Monitoring appears to rely on catch rates and emergence. Is it possible and useful to also look at invertebrate biomass production? For example, production rates might provide an additional component, integrating demographics and growth that can be linked to dam operations, albeit the temporal resolution needed might be insufficient for this large of a system.

Project F GCMRC PI Response

We appreciate these supportive comments. Estimates of invertebrate biomass production were done at six sites across three years (2006-2009). These efforts showed that invertebrate production and species diversity in the Colorado River in Grand Canyon were low compared to other rivers. However, making these estimates was extremely labor intensive and in my opinion the ability to detect change in response to dam operations using benthic sampling is limited, particularly in Grand Canyon where sites can only be accessed through river trips. These limitations of invertebrate biomass production estimates were a primary motivation for the development of community science approaches to monitoring that had greater temporal and spatial resolution. Drift monitoring was also adopted because it is a useful proxy for benthic monitoring (drift concentrations increase proportional to benthic density; Kennedy and others 2014) and can be done across a wide range of flows. Hydropeaking tides also greatly complicate collection of benthic samples; sampling at a given site must correspond to low tide, and the timing of low tide varies throughout the canyon. Near the Little Colorado River at River Mile 61, for example, low tide arrives after dark (~10pm) which creates significant safety and data quality issues. During a recent experimental low flow of 4,000 cfs for 5 days in March 2021, we collected benthic samples from a large segment of the river (RM140-225). Low and stable flows like this greatly facilitate collection of benthic samples. If there is interest in having benthic sampling incorporated into invertebrate monitoring efforts, we would be interested in exploring whether special flows could be released from the dam, such as stable low flows, to facilitate safe and accurate sampling of benthic invertebrates.

VII. Project G: Humpback Chub Population Dynamics Throughout the Colorado River Ecosystem

A. Overview, Project goals and objectives and Link to LTEMP

1. This project focused on estimation of abundance and demographic rates of humpback chub in the CRe. Its emphasis is on triggers associated with the Biological Opinion and the potential use of models fit to monitoring data to examine alternative management actions. This project informs humpback chub and native fish LTEMP resource goals.

B. G.1. Humpback chub population modeling

1. The project provides advanced approaches to estimate population dynamics.
2. In Figure 2 (p85), the reduction in uncertainty associated with antennas was not large relative to estimates without antennas. Is the benefit in increased precision worth the associated effort to maintain antenna arrays? Is the use of

antennas something that is expected to further increase precision of humpback chub estimates over time?

3. Will translocation decisions be informed by monitoring, such that the effort associated with the translocations will occur when the expected number of adults produced from the effort is maximized?

C. G.2. Annual spring/fall humpback chub abundance estimates in the lower 13.6 km of the LCR

1. From the estimates illustrated in the figure on p87, the population appears to be increasing. With goal of the effort to monitor status and trend, how is trend evaluated?

D. G.3. Juvenile humpback chub monitoring near the LCR confluence

1. No specific comments

E. G.4 Remote PIT-tag array monitoring in the LCR

1. No specific comments

F. G.5. Monitoring humpback chub aggregation relative abundance and distribution

1. With the associated closed mark-recapture estimators, will relationships of CPUE and abundance estimates be considered to evaluate the relationship of catch, effort, and abundance (C/f=q*B)? Specifically, will evaluating if catchability is constant, or may be exhibiting hyperstability or hyperdepletion (i.e., q^x where x <>1), result in a functional response which may influence the application of capture probability to catch data being used to estimate humpback chub in the Western Grand Canyon?

G. G.6. Juvenile humpback chub monitoring – West

1. No specific comments

H. G.7. Chute Falls translocation

1. See comment above regarding translocations

I. G.9. Backwater seining

1. Will backwater seining be useful to evaluate dam operations? For example, is it expected that these efforts will index age-0 fish production, and in turn be associated with HFEs or other flows? If so, is the sampling effort sufficient to detect potential responses?

J. Review specific questions

1. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon ecosystem and ensuring progress in defining and conducting adaptive management experiments."*

   The project appears to be monitoring many aspects of native fish, with emphasis on humpback chub, life history, demographics, and dynamics. Many applications have direct ability to inform decisions (e.g., translocations) and are informing humpback chub status with population models.

Project G GCMRC PI Response

G1, Q2: This is a good point - the relative cost/benefit of antennas is an important question that should be revisited every few years. Note that in Figure 2, antennas were only deployed in 3 years (2016, 2018, and 2019) and the reduction in the credible intervals are relatively large in these years. The additional costs of maintaining the submersible antennas is low compared to the cost of running an entire sampling trip, so there are relatively good gains in precision for the modest extra costs associated with running antennas. The improvement in precision will increase as a higher proportion of fish are marked (see citation below), but since relatively intensive humpback chub monitoring has been occurring for many years (i.e., >10 years), it is likely that the proportion of marked humpback chub has reached equilibrium.

Dzul, M.C., Yackulic, C.B., Kendall, W.L., Winkelman, D.L., Conner, M.M., & Yard, M.D., 2021, Incorporating antenna detections into abundance estimates of fish: Canadian Journal of Fisheries and Aquatic Sciences, https://doi.org/10.1139/cjfas-2021-0003.

G1, Q3: We will continue to evaluate the best number of fish to translocate in a given year. The summer LCR trip produces a population estimate for age-0 fish, and this age-0 population estimate will help biologists determine the number to translocate in fall or spring. The current thinking is that the benefit of translocations is greater when age-0 densities are high in fall, because it is relatively easy to catch fish for translocation when densities are high and because translocating fish would counter-act the negative effects of density-dependence.

G2, Q1: We cannot infer increases/decreases to the population based solely on USFWS LCR monitoring efforts, because humpback chub regularly move between the LCR and

the Colorado River and thus abundance in the LCR is only part of the story. Accordingly, population trend will be inferred from combining fall abundance estimates from the LCR and the Colorado River (i.e., the multistate model presented in G1). For example, there was a decrease in the number of adults in the LCR in spring of 2015 and 2016, but the multistate model found no decrease during this time and suggested that CR to LCR movement was lower in spring 2015 and spring 2016. Additionally, from antenna data, there seems to be yearly variability in movement timing for fish moving from the Colorado River into the LCR in spring (see citation below) and this may influence the availability of adults during LCR spring monitoring.

Dzul, M.C., Kendall, W.L., Yackulic, C.B., Winkelman, D.L., Van Haverbeke, D.R., & Yard, M.D., 2021, Partial migration and spawning movements of humpback chub in the Little Colorado River are better understood using data from autonomous PIT tag antennas: Canadian Journal of Fisheries and Aquatic Sciences, https://doi.org/10.1139/cjfas-2020-0291.

G5, Q1: For our initial efforts, we are assuming catchability is constant across all densities. From a mark-recapture perspective, we always conjecture about behavioral effects and individual heterogeneity in capture probabilities. These are important questions, but currently we do not have the data to look into this – particularly since capture probabilities are often low.

G9, Q1: The seining project was sadly cut from the budget. The seining trip was a useful index of age-0 abundances in western Grand Canyon, but it was difficult to scale up from CPUE to abundance from these data.

VIII. Project H: Salmonid Research and Monitoring

A. Overview, Project goals and objectives and Link to LTEMP

1. This project relates to the rainbow trout fishery resource goal of the LTEMP as well as a possible predator or humpback chub. Dam operations include experimental 'trout flows' hypothesized to limit rainbow trout recruitment and dispersal. Recent increases in brown trout may pose a challenge to native fish conservation but provide recreational fishing opportunities.

B. H.1. Experimental flow assessment and trout recruitment

1. Is the level of sampling sufficient to evaluate the objectives of Project H.1?
2. Is it possible to clarify the proposed analytical procedures to evaluate H1.1-4 and the associated timeframe for sufficient learning to inform dam operations?

Project H GCMRC PI Response

Please see responses to comments in the SUMMARY OF RESPONSES section above.

C. H.2. Rainbow and brown trout recruitment and outmigration model

1. The coupled brown trout, rainbow trout, and humpback chub models used to evaluate management scenarios sounds like an interesting application.

D. H.3. Using early life history and physiological growth data from otoliths to inform management of rainbow and brown trout in Glen Canyon

1. No specific comments

E. H.4. Rainbow trout monitoring in Glen Canyon

1. Was the creel survey, a roving or access creel?

AZGFD Response

Both. We use an access point creel to survey boat anglers at the ramp, and a roving creel to survey walk in anglers (walk to the main accessible walk-in access areas to interview anglers and use binoculars to count anglers that are fishing at more distant locations). Our methodology has creel technicians move between the ramp and walk-in areas and is designed so they are at the ramp at the times of day when most boats return.

F. Item 2 Review specific questions

3. *"1) whether the best information is being provided to meet these needs of the Glen Canyon dam operations and its potential effects, including whether the investigations focus on the right questions for which the GCDAMP needs answers to carry out its mission; and 2) resources affected by Glen Canyon Dam operations and the effects of those operations, options for managing these effects, coordination and balancing among resource programs, and the combined effectiveness of these programs in advancing understanding of the Grand Canyon ecosystem and ensuring progress in defining and conducting adaptive management experiments."*

The salmonid research and monitoring project, like aquatic invertebrate production, is unique in that there are experimental dam operations associated with meeting LTEMP resource objectives directly associated with salmonids. The monitoring of salmonids builds on long term datasets and an overall question that emerges is how will monitoring data be used to evaluate experimental flows?

Project H GCMRC PI Response

Please see responses to comments in the SUMMARY OF RESPONSES section above.

IX. Project I: Warm-Water Native and Nonnative Fish Research and Monitoring

A. Overview, Project goals and objectives and Link to LTEMP

1. This report section summarizes efforts to monitor warm water nonnative fish and research associated with nonnative fish. A snapshot of results for the 2020 sampling efforts by AGFD (2 mainstem sampling trips). Previous reports indicate that nonnative species have decreased. The project also includes a research component associated with the early detection of warm-water nonnative species and predation of native species by nonnative species.
2. It was not explicit what goal of the LTEMP these efforts support but fall under "Goal 10. Nonnative invasive species. Minimize or reduce the presence and expansion of aquatic nonnative invasive species" and helps inform the "mechanical removal of nonnative fish near the Little Colorado River confluence" management action listed in the preferred alternative D of the LTEMP.

B. Goals and objectives

1. The stated goal included trends in abundance and distribution of native and nonnative fish in the Grand Canyon. However, it is unclear from the report section how trend is calculated from monitoring data. Evaluating trend is likely important for informing adaptive operations of Glen Canyon dam and whether operations can achieve management objectives.
2. It is unclear why Asian tapeworm monitoring is important and how it supports GCDAMP and LTEMP. Is there mortality associated with infestations in humpback chubs?

C. Improving early detection of warm-water invasive fish

1. Targeting areas where rare non-natives have been caught as well as warm water areas seems reasonable to the detection process. It is unclear how this sampling a) can inform the sampling efforts needed at a larger scale to detect warm-water invasive fish (i.e., power to detect given presence at low levels) and b) if warm-water invasives are expanding in range.
2. The use of eDNA is a potentially powerful method for monitoring the presence of warm-water invasive fish DNA. However, given stream flows, eDNA detected at a site could be DNA material that has washed downstream. Is there any

information on the downstream persistence of DNA in systems like the CRe? Similarly, what concentration of DNA is needed to reliably detect warm-water invasive fish? In other words, is eDNA in this application sensitive enough to provide an early detection system for warm-water invasive fish in the system?

Project I GCMRC PI Response

Please see response in SUMMARY OF RESPONSES section above pertaining to the topic of eDNA persistence and detection in the CRe.

B. Warm water nonnative fish risks to native fish

1. Some details for the field component of this study would be helpful. Was this effort to provide estimates of diet composition which could be further used to inform relative risk?

Project I GCMRC PI Response

Please see response in SUMMARY OF RESPONSES section above.

X. Project J: Socioeconomic Research in the Colorado River Ecosystem

A. Integration with GCDAMP and LTEMP

1. Integration with GCDAMP and LTEMP. This project appears to be integrating science outputs into management actions. A table or bulleted list that explicitly defines the links to the LTEMP and specifically management actions articulated in preferred alternative D.

B. Integration with existing projects

1. The applied decision and scenario analysis described in the report represents interesting applications of dynamic programming to evaluate and identify optimal management actions with a utility that presumably links back to socioeconomic values. Given the use of dynamic programming and value of information referenced in this section, it is exciting to see it applied to real world problems and whether it is important or not to reduce uncertainty in humpback chub survival and rainbow trout abundance.
2. It is clear from this section that there is much integration with native fish monitoring and management efforts (i.e., translocation of humpback chubs). Additionally, there appears to be integration with the preferred alternative D and monitoring efforts, specifically using dynamic programming to assess trout flows.

C. Use of tribal survey information in AM and decision making

1. It was unclear how the survey information for tribal perspectives will be used to inform decision making and adaptive management. For example, will the outcomes of the survey be used to develop functions representing preference for varying outcomes of management actions? Will the survey instruments inform any weighting of multi-attribute utilities that might be in optimization routines evaluating alternative management actions?

Project J GCMRC PI Response

Thank you for the comments about the dynamic programming modeling. We will include a more detailed table or bulleted list that explicitly defines the links to the LTEMP and specifically management actions articulated in preferred alternative D. The tribal surveys will be used to: 1) collect information to recognize Tribal values for downstream resources and support the prioritization of management goals, 2) identify Tribal preferences for experimental flows specified in the LTEMP EIS, and 3) evaluate trade-offs from a Tribal perspective. These are all important elements in adaptive management and value of information assessment. To be specific, I think the Tribal preferences for experimental flows (and other management actions) are potential proxies for relational values. This information may not be useful in trade-off analysis, but very informative in the prioritization of monitoring and research related to reducing critical uncertainties. This information will become increasingly important with the potential impacts of climate change and the evaluation of the suite of management actions that may be necessary to meet the humpback chub goal, for example. The challenge is explicitly working this information into a formal adaptive management decision framework.

XI. Project K: Geospatial Science and Technology

A. General overview

1. The investment into managing the experimental and monitoring data generated as part of a program of this size is very important. Impressions from the summary provided in the report is that this project is well positioned to provide the support needed by the science projects and to curate the data.
2. Like most large-scale science and monitoring programs, this effort is shifting to the use of near real time summaries of monitoring data in the form of dashboards which, in turn, can be used to support the GCDAMP and LTEMP.
3. The project demonstrates clear integration and support of other science projects (e.g., Project B, C, E, G, H, G, I) in the text.

4. It was uncertain what the needs of the GCDAMP and LTEMP are for geospatial science and data technology. For example, does the GCDAMP need feedback from information systems to support decision making? Are there monitoring thresholds or triggers identified from the LTEMP that are reported and critical to system operations?

B. Science tools developed

1. The project appears to have developed an impressive set of tools to support the GCDAMP and LTEMP, for example, the lake level and water quality tool for Lake Powell.
2. Of particular interest was the use of interest of things (IoT) to migrate data from field sensors to a single field location, potentially increasing the efficiency of offloading sensor data and minimizing personnel effort.
3. Source control. The project development and integration of source version through GIT represents some of the best practices for reproducible analyses - an important component of a program of this size.
4. The project appears to be making the best efforts to provide information to stakeholders and supporting the science associated with the GCDAMP and LTEMP.

Project K GCMRC PI Response

Please see responses in SUMMARY OF RESPONSES section above.

XII. Project L: Overflight Remote Sensing in Support of GCDAMP And LTEMP

A. Link to GCDAMP

1. It was unclear from the summary exactly what the outcomes of this effort will be beyond imaging from the river corridor and how the outcomes of these efforts will support the GCDAMP. Specifically, how will remote sensing be used to evaluate the effect of Glen Canyon Dam operations? For example, can this technology be used to evaluate vegetation encroachment on sandbars?
2. Potentially add a table or narrative that lists expected products from remote sensing and potential integration with monitoring the effects of dam operations and potential role in decision making.

B. Support and integration with LTEMP

1. It was unclear from the report summary how this effort will integrate with the LTEMP. From the summary the effort appears to be a singular effort to occur in

2021. How this effort will support the long-term component of the monitoring plan is uncertain.

2. Potentially add a table that lists expected products from remote sensing and potential application and integration with long-term monitoring efforts.

C. Clarify link of this effort to other science projects

1. It seems reasonable that remote sensing would be of use to other projects in the portfolio of science efforts. It is unclear how this effort might support those projects and what outputs might be used once the effort is undertaken in 2021.
2. Potentially add a table that lists expected products from remote sensing and potential application to ongoing science projects.

Project L GCMRC PI Response

Please see response in SUMMARY OF RESPONSES section above.

XIII. Project M: Administration

1. No specific comments

XIV. Project N: Hydropower Monitoring and Research

1. No specific comments

XV. Appendix 1: Lake Powell Water Quality Monitoring

1. No specific comments, section was a summary of data collected and monitored to support understanding of flows downstream.

Mortimer, C.H., 1942, The exchange of dissolved substances between mud and water in lakes. II. J. Ecol. 30, 147–201.

XVI. Appendix 2: Deliverables (Products) FY 2018-2020

A. Program productivity

1. The program appears to be highly productive with a great number of peer reviewed articles produced, presentations given, reports and datasets generated.
2. The development of varying web-based resources to serve, process and summarize data is an asset.

XVII. Appendix 3: Budgets, All Projects

1. No specific comments

Peer Reviewer 2

AGENCY:	US Bureau of Reclamation, Glen Canyon Dam Adaptive Management Program (GCDAMP)
MATERIAL(S) REVIEWED:	2020 Grand Canyon Monitoring and Research Center (GCMRC) Annual Report
REVIEWED BY:	Stefanie A Kroll, PhD, Drexel University
DATE:	August 20, 2021

I. Project A: Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem & Project B: Sandbar and Sediment Storage Monitoring and Research

A. Sediment transport need vs turbidity impacts on biota

1. The modeling and monitoring effort is well designed. The research is well supported by an article in press.
2. I am noting a tension here between the goal of supplying sufficient sediment to maintain sandy banks and sand bars for recreational and tribal activities, competing with the problems that turbidity is causing for biota. While I cannot suggest any solutions to this tension, perhaps the managers of this aspect of flow regulation and the researchers are already working to balance the sediment transport needs and the mechanism for it with the advantages to the biota when turbidity is low.
3. I do not know if the hypothesis that sand can be managed to achieve all goals of the GCMRC can hold true for this topic. It's very ambitious and I appreciate that it is your goal. From the study on the Hualapai Tribe's opinions, there seem to be mixed feelings about the priorities of each activity.
4. It is possible that I don't have enough information, as I see that the report notes that riparian vegetation encroachment and decreased sand from tributaries is responsible for the dynamics of sand erosion/deposition. There may still be some need to connect to the turbidity of Glen Canyon Dam releases for this item. I see that High Flow Experiments (HFEs) are being deployed to this end and note that increasing the number of these events should be monitored in terms of the objectives of Projects E, F and others. The previous study on the 2008 HFEs (Rosi Marshall et al. 2010) showed declines in *Potamopyrgus antipodarum* and *Gammarus*, which may be desired results if a reduction in the

nonnative snail is desired. However, HFEs may put the objective of improving Ephemeroptera, Plecoptera, and Trichoptera (EPT) communities at risk. It appears that these HFEs improve sand deposition, but that the effects are short-term, if I am understanding properly.

Project A GCMRC PI Response

Given that turbidity is mainly maintained by silt and clay concentrations, and to a lesser degree by sand concentrations, there is not necessarily a conflict with maintaining larger amounts of sand in the Colorado River while also maintaining periods of lower turbidity. Also, given that the animals that evolved in the Colorado River evolved in a highly turbid system, there may be no large conflict anyway.

Project B GCMRC PI Response

- Sandbars are dynamic features of the Colorado River system. Long-term persistence of sandbars is not expected without regular high-flow experiments to deposit new sand. Thus, the HFE protocol was designed to trigger HFEs frequently. The combined results of the sandbar monitoring and modeling show that sandbars are on average larger during the recent period with frequent HFEs than in earlier periods with no HFEs or infrequent HFEs.
- The relation between turbidity, HFEs, and effects on biota requires further study. Although some linkages between HFEs and turbidity have been suggested, those linkages may be very weak. Because HFEs occur for only a short (< 1 week) period in November and turbidity is driven primarily by silt and clay inputs from tributaries, it is unlikely that fall HFEs substantially affect turbidity the following late winter and spring.

II. Project E: Nutrients And Temperature as Ecosystem Drivers: Understanding Patterns, Establishing Links and Developing Predictive Tools for an Uncertain Future

B. TP-SRP budgets

1. The approach to monitoring and studying phosphorus (P) dynamics is well designed—it appears that the researchers will continue to work to parse out the soluble reactive phosphorus (SRP) fraction and total phosphorus (TP), and perhaps what other fractions of TP may be biologically available, which should better inform algal dynamics and therefore the food web interactions.

2. Development of a P budget is certainly a priority for understanding how P patterns interact with flow, temperature, turbidity and exert bottom-up controls on the biological communities.
3. The studies before and after fire are also sound, and the shift to studying gross primary production (GPP) is a good step toward characterizing the dynamics of nutrients in the system, especially regarding the food web. In addition, the high variation during storms is an interesting and pertinent research topic.
4. I agree that understanding other forms and amount of bioavailable P is needed as per the experiment notes in E.1.2.

C. Seeding P

1. From the question during the presentation about adding P to the system, I agree with the researcher's response that the potential effects are unknown, and that this action may have unwanted results in terms of supporting nonnative fishes, or other effects. This caution seems particularly important given the management actions to reduce brown trout populations in favor of humpback chub and rainbow trout and removing rainbow trout in certain areas to favor humpback chub. Was P historically limited or higher in this area, or how do levels compare with inputs into reservoirs? From the studies presented, the turbidity seems to be a greater limitation to algal growth and macroinvertebrate success (along with hydropeaking flows, of course), than bioavailable P into the system. While I do not have enough information to say this is the case, it would be better to continue the Bug Flows experiment and the analysis of available P forms before considering taking actions to change P dynamics by seeding P.

Project E GCMRC PI Response

About 95-99% of P entering Lake Powell never makes it below Glen Canyon Dam. This retention is much more dramatic for P than for other potentially limiting nutrients (N and Si) so the river is more P limited than it was historically. P and turbidity interact to determine gross primary production.

A. Whole system food web dynamics

1. In the presentation by Yackulic, he noted a desire to better analyze and model food web dynamics. I agree that this research is needed to better understand the bottom-up controls of P concentrations, turbidity, and flows through the food web and in connection to the dynamics of the fish communities. Food web research would be a high priority for the next steps if I were involved in this program. I support the next steps proposed in E.2.1 to better understand the drivers of variation in GPP.

2. To bring together all the elements regarding energy flows, including metabolism, nutrient dynamics, algal, macroinvertebrate and fish communities, the results of propose sub-element E.2.4 seems like an ideal next step that has a clear and interesting foundation already published.

D. Algal community dynamics as food for macroinvertebrates

1. Relative to Projects E and F, macroinvertebrate diets could be analyzed using DNA metabarcoding of their whole abdomens to understand which diatoms and prey are most dominant in diets, to complement the gut analyses of fish that have been done in previous studies, which I assume would be part of any food web study.

Project E GCMRC PI Response

We agree that eDNA metabarcoding could be a useful tool to identify diatom and prey species in fish diet. If resources allow in the future, we may explore this option for the Colorado River in Grand Canyon.

2. The laboratory study in E.2.3. is interesting for *P. antipodarum*. It would be interesting to know, either through field or laboratory studies, if a more diverse set of grazers (including desired EPT and Diptera other than tolerant Chironomids) will respond to changes in upright vs. adnate diatoms. I do not think an additional lab/ artificial stream study on response of invertebrates other than *P. antipodarum* is a high priority, as gut analysis of macroinvertebrates could be cost- and labor effective. But as the researchers note the varying palatability of *P. antipodarum* to the different fish taxa, the suitability of diatoms as food for higher quality invertebrates could provide interesting information on what may be needed for their successful colonization during bug flow experiments and how that moves through the food web to support more diverse invertebrates. Ideally, native snails and other grazers can eventually reduce the prevalence of the nonnative *P. antipodarum*, but I would consider that a less urgent management issue than increasing macroinvertebrate diversity, abundance, and biomass overall.

Project E GCMRC PI Response

Thank you for your comment. We agree additional information on invertebrate taxa other than mud snails would add to this body of research. As noted, subsequent studies would be costly, so we instead will focus on analyzing the data we have from the mesocosm study funded in FY18-20. There are no additional funds to do this type of work.

E. Temperature

1. The development of high-resolution temperature models is important in watersheds, especially with flow regulation interacting with climate change. This model and approach are well-designed. I am familiar with the modeling approach because some of my colleagues are working on the same topic. I appreciate the user-friendly version being developed for use by stakeholders as well.
2. It is encouraging to see that projected temperature increases due to climate change may benefit humpback chub, even though there is a risk of expansion of largemouth bass or other nonnative fishes. This topic certainly deserves to continue to be monitored for temperature increases and effects throughout the ecosystem.

Project E GCMRC PI Response

Thank you for your comment. We hope the water temperature model is a useful tool in predicting the response of water temperatures to changes in flows, release temperatures, and air temperatures.

III. Project F: Aquatic Invertebrate Ecology

A. Experimental design, community science ("Bug Flows")

1. Weekend "breaks" are an excellent idea for egg survival and other possible mechanisms for macroinvertebrate success, and therefore for increasing diversity as well. Once this experiment is complete, will there be another study on how weekend flows can be best designed as ecological flows for macroinvertebrates? I do not see details on how they were determined, but perhaps this aspect has been modeled and assessed previously to set the flows. I am not an expert on ecological flows, so I am not requesting data on the specific flows, but the methodology would be interesting, to know if it's fully developed or another part of the experiment.
2. Sampling of aquatic insects is comprehensive, including sampling in the substrate, drift and adult emergence, and is well-aligned with the goals of the monitoring to inform this objective (i.e., successful growth and reproduction, as food for fishes, overall indicators of ecosystem health).
3. I love the community science involved in this project! I don't know what interactions you have with them after data collection and analysis, but I am sure you know it's important to show them what their work accomplishes and make the results available to them in some form so they can share with their stakeholders and communities.

4. Are there opportunities for Tribal groups and other local communities and stakeholders to take part in the community science programs, including, but not limited to, those run by rafting trips? In this case, access to rafting trips may limit the participation of a diverse audience who 1) are not tourists and therefore may not consider participating in such a trip; 2) are financially limited and may not be able to afford such a trip; or 3) have been historically excluded from such activities. Could this group invest in recruiting stakeholders from diverse groups and funding their participation in this work (even if the recruitment is done by a different office or stakeholder group)? It seems that with so many trips happening in a typical year, a small budget allocation could make a big difference in connecting local stakeholders to the research.
5. At the same time, sparking interest in these community science trips for a diverse audience may help build a more robust and diverse community of recreation guides, scientists, etc., which, as you know, is direly needed in the white dominated environmental research and recreation sectors. Increasing diversity and inclusion have not been explicitly incorporated into many actions by environmental agencies and research groups and may seem out of place in my review of the scientific merit of this program. However, we must start incorporating Diversity Equity and Inclusion (DEI) into all our activities, and this seems like an ideal opportunity to add DEI work, with potential for mentoring diverse young people into existing community science activities.

Project F GCMRC PI Response

We appreciate these supportive comments. We have scheduled workshops on October 28 and November 4 to identify potential next steps in ecological flow experiments for natural processes and macroinvertebrate assemblages. To improve opportunities for Tribal members and diverse audiences to participate in the community science project, GCMRC has partnered with Grand Canyon Youth to launch Partners in Science river trips for more than 20 years. In 2021, three Partners trips were launched, and all collected light trap samples of aquatic insects and several other data collection activities. Each of these Partners in Science trips engage approximately 30 high school age students and in 2021 one of these trips was comprised entirely of Tribal youth participants (see https://www.youtube.com/watch?v=2TxLWlrw7y4 and https://www.youtube.com/watch?v=dhBGWV8yQw4 for short 7 min videos about these Partners in Science river trips.) These trips are a powerful tool for training the next generation of scientists in the scientific process and educating participants about the role that science plays in management of the Colorado River and Grand Canyon. Moving forward, we are exploring how to involve tribes in all Partners in Science trips to facilitate monitoring of tribal resources and to describe the role that traditional

ecological knowledge and tribal values plays in management of the Colorado River and Grand Canyon.

B. Hypothesized effects of bug flows

1. Overall, this experiment seems to be showing success, and I support its continuation to compensate for loss of data in 2020 and gather more data to better understand the patterns of macroinvertebrate response. The presentation by Jeff Muehlbauer was clear and well laid out, as was the report. The 2016 paper by Kennedy et al. was also very helpful in understanding the framework. This represents an important compromise for hydropower to better support aquatic life, and could be applied at many other reservoirs, and I respect and appreciate the objectives and methods.

2. I don't have a problem with the egg desiccation hypothesis as the driver of Bug Flows (in reference to a comment after the presentation) in light of the other findings and the published paper on the topic (Kennedy et al 2016). Hypotheses are meant to be tested, and when they are not supported, lead to other, valid conclusions and hypotheses, so it is always acceptable for a hypothesis to not hold. Jeff Muehlbauer notes that it may or may not be a hypothesis supported by the data, that there are many effects of "bug flows," and he also indicates uncertainty on the mechanism for the increases in EPT abundance and biomass in 2018 and 2020. For example, possible other mechanisms for higher 2018 emergence despite no 2017 bug flows: 1) if there are several cohorts of Hydropsychids per year and bug flows support emergence of adults, not just egg moisture, and 2) if a small number of eggs is able to persist during drying, or if some egg deposits occur at low flows, which are low again at the time of emergence. I appreciate the experiment on this topic and can also appreciate that the researchers understand that bug flows have multiple effects on invertebrate life histories, not just avoiding egg drying. I am not suggesting the researchers try to find out if other mechanisms are responsible, but I am noting that it is entirely possible that the 2018 emergence at the start of bug flows could occur through several different mechanisms. I think if the approach works, a definitive causal analysis may not be needed. The analyses of ecological linkages from P up the food web seems more important than a specific causal analysis of the success of bug flows.

Project F GCMRC PI Response

We agree with the reviewer that Bug Flows appears to improve conditions for aquatic insect populations through several mechanisms. We also agree that because the Bug Flow experiment appears to be effective at improving natural processes and aquatic insect populations, it may not be relevant to management to quantify the marginal role

of improved egg laying vs. other mechanisms in driving these increases. This causal analysis would require additional Bug Flow experimentation in summer months when egg laying activity is high combined with much larger research budgets. Yet, recent discussions and comments from stakeholders have emphasized the desire to reduce impacts to the hydropower resource as a primary objective for future Bug Flow experimentation, which might require eliminating summer months from the experiment or reducing it to just one weekend day instead of two. We agree with the reviewer that reducing uncertainty concerning the role of P in driving food web dynamics is more relevant to management decisions than a causal analysis of individual Bug Flow effects. Research concerning the role of P in structuring food web dynamics is ongoing as part of Project E. In our professional opinion, Bug Flows had ecologically meaningful benefits to natural processes and the experiment appears to be a useful tool for achieving LTEMP resource goals. If DOI decides to test Bug Flows or other types of stable flows again in the future, we will focus study designs and research dollars on food web analysis to quantify fish population response to improved natural processes rather than a causal analysis of mechanisms underlying insect response.

3. As I noted above, it would be of interest to know how flows could be best structured to support macroinvertebrates. Maybe the current form is the best one—I don't have enough information to be sure.

Project F GCMRC PI Response

As evidenced by questions and comments at the October 28 Bug Flow workshop, minimizing impacts of the Bug Flow experiment to the hydropower resource will be an important factor in determining the 'best' flow strategy for supporting healthier macroinvertebrate assemblages. As ecologists, we could design a naturally patterned flows regime that would support healthy assemblages of macroinvertebrates and fish, but the ecological benefits are hard to quantify compared to the certain financial impacts this flow would have on hydropower revenue. Thus, identifying the best flow regime to support macroinvertebrates requires analysis of tradeoffs and a willingness to experiment and adapt as new information becomes available. It is our hope that the Bug Flow workshop will provide a useful venue for discussing these tradeoffs and identifying cost-effective strategies for improving natural processes and macroinvertebrate assemblages.

4. Research on bug flows is a great start for restoring and increasing insect biomass and aiming to increase insect diversity. As I note above (in Project E), the assessment of the food web (adding to fish diet studies) would be helpful—if possible, an analysis of insect diets with DNA barcoding (perhaps combined with Stable Isotope to understand the proportions of food types) could help understand diatom, organic matter, and plant dynamics leading to insect success. In the previous analyses, the group has used stable isotope analysis of

fish guts which were informative regarding algal- or insect-dominance in fish diets. However, genus or species-level resolution of fish and insect gut contents may contribute significantly to this work by showing small changes over time and improvement of the macroinvertebrate community or variation among years. As the research over the years done by your group has shown in this area, there are changes longitudinally as well as at low flows, which may also be better understood with greater taxonomic resolution of macroinvertebrates.

Project F GCMRC PI Response

Project F includes a one-year native fish diet study element that will quantify feeding habits of native fish. This was originally planned for 2021 but was deferred to 2022 because of the possibility that Bug Flows might be tested. Conducting these native fish diet studies in the context of a Bug Flow experiment would allow us to investigate whether these flows improve foraging conditions and energy intake for native fish, similar to what was documented in Glen Canyon relative to rainbow trout. If Bug Flows is implemented in 2022, we will consider adding invertebrate diet studies and DNA barcoding to the study design. We will also consider adding these tools to study designs during the next triennial workshop for FY24-26, irrespective of whether Bug Flows is occurring.

5. Related to above, in terms of identifying the genera of macroinvertebrates in samples and in fish diets: one difficulty in designing such restoration practices/ experiments is that we do not always have a clear sense of what recovery will look like or the expected time scale (or longitudinal reach of the effects, depending on the type of restoration). While the initial results are encouraging and the experiment is ongoing, it may be helpful to examine genus-level data in macroinvertebrate samples as well as fish diets to look for early signs of ecosystem recovery. Chironomidae may have a variety of pollution and temperature tolerances, so I would invite examination of the genera to see if any shift within the midge taxa may be an early indicator of improvement, while EPT may lag but are still increasing. You have a lot of samples, so even focusing on certain taxa would be informative.

Project F GCMRC PI Response

We will consider reallocating lab effort towards greater taxonomic resolution of macroinvertebrate samples. Tracking changes in species richness or diversity of Chironomidae in response to Bug Flows would be a logical place to start given the prevalence of Chironomidae in samples. Unfortunately, the sample set with the greatest temporal and spatial coverage is light traps of adults, and chironomidae adults are extremely difficult and time consuming to identify to genera compared to larvae samples. Although it can become cost-prohibitive, we are considering DNA barcoding of

a limited number of adult Chironomidae samples as a means to address this diversity question. In fact, in many cases keys are not even available to identify adult Chironomidae to genus. Nonetheless, if Bug Flows is tested again in the future we will consider approaches for detecting species richness changes of common taxa including Chironomidae, and we will consider reprocessing prior light trap samples to investigate whether changes in richness of Chironomidae occurred in response to 2018-2020 Bug Flow experiments.

6. I also support the statement by Kennedy et al. (2016) and in the presentation that macroinvertebrate function should be included in the analyses. Viewing macroinvertebrates and fishes through the lens of functional traits is likely to be important to understanding not only food web dynamics, but ecosystem functions contributed by the biota and changes due to variations in the prominent environmental drivers. In my work using multiple indicators relative to restoration, I have found that using the functional lens along with the structure lens allows me to better understand the biotic communities' relationships with stressors. Using functional traits also allows for target-setting of reasonable, desired increases in % EPT, % disturbance-tolerant or disturbance-sensitive taxa, etc., and can be combined with setting taxon-specific goals as the researchers have for Hydropsychidae and Hydroptilidae. Thus, if a function remains similar but the taxa who perform it change, it may be an indicator of ecosystem resilience, where if we only consider them from a taxonomic viewpoint, we may see only the loss of diversity. It goes without saying that it would not be ideal for different fish species to replace your target management fishes, but for macroinvertebrates, the changes among taxa may be okay if functions are supported.

Project F GCMRC PI Response

We appreciate these comments and suggestions about additional approaches for analyzing macroinvertebrate data in relation to management goals. We will consider incorporating these function- and trait-based approaches into future publications and annual reports.

7. In terms of flattening the sine wave of longitudinal changes in abundance—I understand the researchers would like to see a less patchy distribution. At the same time, the data show that caddisfly biomass/abundance is higher where RBT and HBC are prevalent. Is this because other aspects of habitat are better for both the macroinvertebrate and fish communities in these areas, or is it driven by the changes in base flow levels? It would be interesting to know if less patchiness of bugs makes more areas suitable for these fishes, or if there are other habitat and water quality constraints in those areas. Perhaps I have missed the connection in the report and talks. If a more homogenized

distribution of bugs leads to the same for the fish communities, I can see the great value of "flattening the sine curve." Right now, I am inclined (with limited data) to understand that the same habitat is supporting the fishes and caddisflies.

Project F GCMRC PI Response

These are excellent points. We will still evaluate whether the sine wave has changed because of Bug Flows, because this provides insights into mechanisms underlying insect population response, but we will not emphasize potential benefits of flattening the curve to fish populations in future presentations or reports because any benefits are speculative and highly uncertain.

8. While Palmer et al. (2005) encourage us to set goals for ecosystems based on more natural systems, few researchers and restoration practitioners do so because there is a lack of data on recovery of systems, and we do not quite know where to start. This becomes a vicious cycle of not knowing not setting targets not being able to provide data for others to use to set targets (back to not knowing). I think it is a good idea to set targets for acceptable/desired amounts of improvement. As above, if the hypothesis is wrong, so be it—it can be updated. But target-setting allows us to really focus on the specific goals of experiments in restoration and to refine the goal-setting process so it can be more commonly adopted by others doing similar work. During early analyses of how close we got to our goals, we may choose not to share them externally for the uncertainty of being held to them. But nonetheless, I think it's an important exercise to undergo, at least internally, within the research group. This approach may not always be possible and may be one of my pet topics, admittedly, but I like to raise it in restoration/management research, in this case improving flows for biota.

Project F GCMRC PI Response

We wholeheartedly agree that goal setting is an important part of ecosystem and adaptive management. Ongoing work to develop metrics for each LTEMP goal will provide a framework and venue for having these interactive discussions about goals between scientists and managers. However, as scientists that conduct research in support of the adaptive management program, it is not our role to set goals. Rather, our job is to inform management decisions about goals by describing, for example, what goals are attainable, what goals are lofty, and what goals are unattainable, and what kind of management decisions are likely to support these different goals.

C. Bug Flows and the food web, especially diatoms

1. The 1992 study by Hardwick et al indicates changes in diatom communities, which have implications in terms of macroinvertebrate diet. However, turbidity

and continuing to experiment with ecological flows seem like the best approaches to understanding how macroinvertebrate communities can improve to better contribute to the food web and shift from midge-dominated to [larger and more nutritious] EPT and Diptera taxa (and for diatom communities to improve as well, as they also seem denser at shallower depths and lower turbidity). Diatom diversity may be less important than the quality of biofilms and habitat suitability in terms of supplying macroinvertebrates with palatable taxa, but macroinvertebrate diets could be analyzed through DNA metabarcoding of macroinvertebrate abdomens for gut contents. The objective in Project E above to analyze other available forms of P would complement this work and may make it unnecessary to have taxonomic data on diatoms in the macroinvertebrate diets. But I'm sure you know that just as certain macroinvertebrate taxa provide better nutrition to fish, the same is true for diatoms and other algae as food for macroinvertebrates. Thus, any information on the nutrition of biofilms and diatoms in the P experiments can be informative to the macroinvertebrate analyses.

Project F GCMRC PI Response

We appreciate these comments about the potential role of food quality (i.e., diatom species richness or nutrient ratios) in driving invertebrate populations. We also appreciated the comment and reference from Science Advisor reviewer Albert Ruhi during the Bug Flow workshop on October 28 mentioning studies that have shown hydropeaking flows lower quality of algae food resources. We will consider incorporating these approaches and insights into study designs if Bug Flows is tested in 2022 and during development of the next triennial workplan but note that these efforts would require larger budgets or reducing effort of existing monitoring.

D. Emergence timing and spring "mud"

1. This topic seems to reinforce the negative effects of turbidity over longer time scales on macroinvertebrate communities. In the report, late emergence appears to be interpreted as a negative outcome in relation to spring mud; but in the presentation, Jeff Muehlbauer notes that later emerging insects may be larger and therefore provide a better food source. It will be interesting to see how this pattern evolves with more data collection.

Project F GCMRC PI Response

We now have data showing that later caddisfly emergence in 2019 was associated with smaller sized adults, another indication that abundant mud slowed growth of caddisflies. Additionally, carbon stable isotope analysis of adult caddisflies shows lower use of high-quality algae-based resources by caddisflies in 2019 compared to other years

(data will be shown at 2022 ARM meeting). Thus, the combination of high suspended sediment and low algae production in 2019 slowed growth of caddisfly larvae, reducing both the size and abundance of adult caddisflies that emerged in 2019. Tributary inputs of fine sediment played a large role in increasing turbidity in fall 2018-spring 2019, but as noted above hydropeaking operations are also an important driver of fine sediment dynamics and contributed to this chronically high turbidity and sand transport. Bug Flows improved growing conditions for larvae by temporarily decreasing turbidity and sediment transport on weekends. Thus, the abundance and size of caddisflies that emerged in 2019 would likely have been lower if Bug Flows had not been occurring.

2. Have degree days been related to this later emergence as well in the case that the annual water temperature pattern is also related?
3. The pattern with the fall "mud" does seem to suggest that turbidity affects macroinvertebrates differently at different life stages, with a higher emergence at low turbidity, which would align with general understanding that turbidity negatively affects macroinvertebrates through various mechanisms (food sources, breathing structures, etc.).
4. I understand this topic is still being researched, and it does seem like an important link to turbidity and sediment transport, and thus food web connections. I will be curious to know how this variable compares with flow, light, GPP, etc. in its strength of relationship with measures of the macroinvertebrate community (diversity, biomass, emergence, etc.).

Project F GCMRC PI Response

We appreciate these supportive comments and suggestions for continued research into the interactive role of flow and turbidity in affecting food web dynamics.

IV. Project J: Socioeconomic Research in the Colorado River Ecosystem

A. Modes of outreach with tribes

1. I am glad to see that the project team met with tribes and worked to develop communication in ways that tribal leaders preferred and offered them a stipend for participation.
2. In terms of the survey, no reason was given in the report for why the three tribes declined to participate. Is there a member of any of the tribes who is working on your team to design the survey, assist with outreach, and overall be a highly involved member of the team? Are there opportunities for tribal members to be paid more than for surveys, as a part of research and

management teams? I assume you are continuing to work on these relationships, that it may take time, and, especially now, may require good timing and specific opportunities to connect with them. I appreciate this objective of your work and see a need for opportunities to expand it.

3. While it is right to request their input and information, when collaborating for research, it is also important to treat the community as a full partner. What are the concerns and research questions of the Tribes in terms of management of the Grand Canyon and Glen Canyon Dam? To what extent do individuals or leaders from the Tribes want to be involved and informed about your work? In my work in collaboration with community groups, including some Tribal leaders, some decisions need to be bottom-up, from their perspectives, rather than top down, from your research teams and the government agencies they represent. It is a good time to seek ways to allocate funding for deeper involvement of these groups. For example, when we write grant proposals with a community member, they are co-PI of the project. You may have already considered these questions— it was difficult for me to tell from the materials.

4. One survey item, willingness to pay, seems inappropriate for Tribes. It is known nationally that the Navajo Tribe requires greater economic support and access to resources than they currently have, and thus they and other Tribes should not be asked to contribute financially to management of the Grand and Glen Canyon resources. This survey item may be appropriate for non-tribal communities using the water resources, but due to the history of Europeans taking Native American resources and the current topics including the landback movement and reparations it appears inappropriate with respect to Tribes.

5. The results working with the Hualapai Tribe are encouraging in terms of understanding their priorities and perspectives. I think the item “anyone should have access to these areas at any time” deserves special attention. As it is unlikely this area would be given back to Tribal governments, setting aside times and areas for their activities may be appreciated, if that is what is meant in the response to that survey item.

B. Deliverables related to Tribes

1. I am pleased to see some deliverables related to the use of USGS science by Tribal communities, along with the standard academic and data-driven deliverables I see in the report. Have Tribal collaborators weighed in on what they might like to see come as a result of the variety of work going on and their involvement? There may be books, materials, or other items that Tribes are interested in to inform their and other communities of their involvement and practices, to promote their culture and well-being, etc. that should be

considered alongside the formal, scientific outputs. I see workshops that appear to be mainly with Tribes-where else should this collaboration with them be shared to highlight the cultural aspects and their areas of interest? How could such outreach and deliverables directly support them with funding and resources?

C. Inclusion of other stakeholders, Willingness to Pay

1. I am sure you meet with other regional stakeholders such as watershed associations, the Riverkeeper, etc. I know that it can complicate the work to hear from stakeholders with different objectives and different perspectives on how much their opinions should be considered. I think it would be helpful to include more information in the reports, more explicit lists, etc., of meetings held and groups to whom outreach has been done. Have the non-Tribal towns nearby been surveyed about Willingness to Pay? I do think it is an important topic in natural resource conservation and management for non-Tribal users. Are the other stakeholders (governments, recreation groups, watershed associations, etc.) involved in any Water Fund/Willingness to Pay research? I understand that your group may or may not be the convener of large stakeholder meetings, but it would help to know more about participation without having to glean it from workshops and presentations in the Deliverables section.

Project J GCMRC PI Response

Thank you for the comments. The Hopi Tribe, Pueblo of Zuni, and Southern Paiute Consortium declined to participate for various reasons, some that were not explicit. We did interact with the Hopi Tribe and Pueblo of Zuni at length in the initial phases of the project. The decisions to not participate were complex, but in my opinion resulted from the limited relationship with the Tribes and longstanding issues with the Federal government. We worked alongside Tribal representatives to the GCDAMP AMWG and TWG during the entire project.

You are correct to point out that there are many avenues for engagement. COVID-19 caused significant delay with interacting with Tribal members to present results of the survey. The plan moving forward is to present these results of the survey to tribal members, publish the research (including detailed information about engagement), and continue to engage with and identify opportunities for Tribal involvement in the program. I think that this will allow for a dialogue about Tribal interests and also how this information is delivered to Tribal members now and in the future. Co-management of resources and funding is a bigger question than Project J. I think the next big step in Project J is to improve the implementation of an adaptive management decision framework in the program and identify space within that framework for meaningful

consideration of cultural benefits knowledge. I am engaging with Tribal representatives to the GCDAMP and academic and government practitioners to do this.

There is other 'willingness to pay' research. This research includes recreational (angling and whitewater) surveys (Bishop et al. 1987, Bair et al. 2016, Neher et al. 2017, Neher et al. 2019) that have been funded by this program and a public survey related to resource in the Grand Canyon (Welsh et al. 1995, U.S. Bureau of Reclamation 2016), the later funded by the National park Service. The 'willingness to pay' question in the Tribal surveys does not tie management to specific resource outcomes. This was based on early discussion with the Pueblo of Zuni. The question format is similar to a referendum, and results are interpreted as such. The question format worked as designed, and we did provide respondents who voted '$0' an opportunity to voice a reason why (i.e., identify protest votes).

Peer Reviewer 3

AGENCY:	US Bureau of Reclamation, Glen Canyon Dam Adaptive Management Program (GCDAMP)
MATERIAL(S) REVIEWED:	2020 Grand Canyon Monitoring and Research Center (GCMRC) Annual Report
REVIEWED BY:	Ben Livneh, PhD, University of Colorado - Boulder
DATE:	July 29, 2021

I. Project A: Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem

Commentary

This project is focused on making and interpreting basic measurements of streamflow, water quality, and sediment budgeting, with relevance for management. Impacts of dam operations on sand budgets have implications for nearly all of the LTEMP goals. Overall, progress has been made in terms of collating, analyzing, and modeling the Colorado River ecosystem (CRe) to identify drivers of sand and to articulate limitations in historical monitoring. A large number of data products, reports, and presentations indicate good progress, generally sound methods, and potential applications for further high flow analysis.

Sustainability of sand resources

The authors report reductions in sand concentrations in the river, i.e., those needed to maintain sand bars. This appears to be both a robust and an important result, which raises the question of the sustainability of sand resources within the system. In their companion manuscript (Topping et al. 2021), the authors contend that sand concentrations need to be measured continuously in order to effectively monitor sand availability, given the episodic nature of sand loading in relation to high flows. For example, sand loads in different reaches are largely uncorrelated based on the available data, which is due to irregular sampling relative to high and low flows. Normal flows appear to result in losses in sand, i.e., erosion, such that only high flow events can contribute net gains to the sand budget.

Recommendations for this project element include:

i. Continue monitoring and evaluation of sand resources to support the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) sediment goal. If feasible to implement and maintain, the continuous monitoring of sand

will support greater understanding of the sustainability of current and future sand resources and critical connections between sand concentrations and high flows and other concomitant factors such as changes to the channel bed and flood deposits.

ii. To mitigate the continued loss of sand, the timing of HFEs need to be coordinated during periods of high availability of fine sand, as a way to support a net contribution of sand and minimize erosion of sand.

Reconstruction of flood flows

The authors indicate that flood peaks in the Little Colorado River Basin have decreased through time, citing Dean and Topping (2019). This assertion is based partially on the authors reconstruction of flood flows using linear regression methods between different stream gage data sources. This method inherently contains uncertainty. It would be valuable if the authors could estimate the magnitude of this uncertainty either as a function of the mean flows or the flood flows in question, so that a clearer interpretability of the potential impact of the uncertainty could be made. The flood peak attenuation associated with within-channel vegetation (e.g., tamarisk) has the potential to minimize the benefit of upstream large flood peaks to propagate into the Little Colorado River.

Recommendations for this project element include:

i. Explicitly report uncertainties in the reconstruction.
ii. Where long-term precipitation gage data exist, consider incorporating these into the regressions, and/or expanding stream gaging to improve understanding of within-basin variability, inter-gauge relationships and reduction of uncertainty.
iii. Given the high interannual variability in sand mass (i.e., reported in the table for years 2018-2020), it would be useful if the authors can report long-term rates of change and their uncertainties for overall planning, as well as to put individual years into clearer context.
iv. Ensure all tables include a descriptive caption.
v. Consider management options of riparian vegetation to minimize increased roughness and flood-peak attenuation associated with vegetation encroachment.

Project A GCMRC PI Response

Recommendations 1 and 2 are addressed in Dean and Topping (2019). Recommendations 3-4 are addressed in Topping and others (2021) and Griffiths and Topping (USGS-OFR, to be submitted for review by Dec. 1, 2021). Recommendation 5 comes directly from Dean and Topping (2019). We are currently trying to gain support for a tamarisk removal demonstration project in the Little Colorado River.

II. Project B: Sandbar and Sediment Storage Monitoring and Research

Commentary

This project seeks to connect high flow experiments and dam operations with impacts on sandbar dynamics, with relevance for management. Predictive tools for sand transport and behavior are contributed, as well as analysis of campsite areas together with citizen science. This project addresses the LTEMP sediment goal. Numerous data products, publications, and presentations indicate good progress, generally sound methods, and potential applications linking high-flow events with sand and camping impacts. Monitoring and data sharing are important continued activities from this project.

B.1. Sandbar Monitoring Using Topographic Surveys and Remote Cameras

The authors report that while some significant fraction (greater than or equal to 25%) of the sand comes from pre-dam sources, High Flow Experiments (HFEs) contribute to new sand deposition. This new sand is eroded in many places, but it does persist in other places. In the context of campsite areas, vegetation encroachment is an ongoing problem which is largely independent of HFE activity. The authors, as well as Chapman et al. (2020) clearly show that even the largest controlled floods from the past 20 years are much smaller than the pre-dam peak annual flows. In addition, the volume released by HFEs is small enough not to affect the annual water volumes released, such that HFEs can continue to occur without impacting the needs of the large number of reliant stakeholders

Recommendations for this project element include:

i. The importance of Paria River inputs for sand budgets is underscored by the authors analyses. Given that trends in the Paria River sediment delivery and flood frequency are affected primarily by climatic changes rather than by human development activities (as noted by Chapman et al. 2020), it is therefore recommended that the authors expand their future work to diagnose the roles of historical temperature and precipitation more directly within their sand analysis. In this way, in the future it may be possible to more clearly understand the implications of projected temperature and precipitation on the long-term sustainability of sand resources within the domains of interest.

ii. The authors have the capability to report uncertainties in the sand attribution analysis using their mixing model approach. It would therefore be helpful if they can present their relative confidence in magnitudes of the sources of sand as a way to put the current knowledge base into context. For example, to

understand the likelihood that the erosion of pre-dam sand presents an existential crisis for the system.

iii. The viability of replanting native vegetation or manual removal of specific vegetation (e.g., tamarisk) should be analyzed as part of future analyses to understand the cost-benefit analysis of such an activity.

iv. Remote camera images provide invaluable information on the status of sandbars within the system and their continued deployment is recommended. However, it would be of potentially greater impact to explore the use of existing high-resolution (<10 m) spaceborne visible satellite imagery as a way to complement and extend the knowledge base gained from existing satellite imagery.

v. The public sandbar data base is a positive and important development. Consideration should be given as to whether MySQL is the appropriate database tool in the event that data volume becomes an issue.

vi. It would be helpful to see a map of the points in the figure to understand their position within the system.

B.2. Bathymetric and Topographic Mapping for Monitoring Long-Term Trends in Sediment Storage

Recommendations for this project element include:

i. Repeated mapping of the riverbed in LMC should be continued, given the demonstrated value of this effort in determining the sand budget and high signal to noise ratio.

ii. Further exploration is warranted into potential applications of the Bayesian framework (e.g., Ashley et al. 2019) as a tool for quantifying reach-scale sediment deficits and surplus relevant for future studies.

B.3. Control Network and Survey Support

Recommendations for this project element include:

i. The FY2020 expansion into un-surveyed reaches represents an important development that could offer new insights into mapping the system and key fluxes within it.

ii. Regional geodetic improvements may serve a longer-term benefit of connecting local imagery with spaceborne remote sensing capabilities.

iii. Mapping of the riverbed in LMC should be continued, given the demonstrated value of this activity.

Project B GCMRC PI Response

- The reviewer is correct that the future sediment budget for the Colorado River depends heavily on the activity of tributaries like the Paria River, which are very likely to be impacted by temperature and precipitation changes associated with climate change. We appreciate the reminder of this importance. Although such research is outside the scope of current AMP projects, we will look for ways to develop partnerships to pursue this research direction.
- We thank the reviewer for the suggestion to apply estimates of uncertainty in sand sources to our analyses of the overall sand budget. We will consider this and attempt to apply this idea where possible. Although we also note that any estimate of the degree to which sand erosion represents an "existential crisis" for the system will depend heavily on poorly known future sand inputs (which the reviewer also recognized as an important issue).
- Vegetation management is currently being undertaken by the National Park Service in cooperation with this and other GCMRC projects.
- We have informally evaluated the potential use of "free", high-frequency satellite imagery, such as the products available through Planet Imagery. Products with ~ 3 m resolution can be used to estimate changes in sand area, although shadows on the images present difficulties in many parts of the canyon. One of the main problems with using "off-the-shelf" imagery is the variable discharge regime of the Colorado River downstream from Glen Canyon Dam. Accurate measurements of feature area can only be made when the discharge is relatively low and the features are fully exposed. However, as data collection platforms continue to collect images at greater frequency it may become possible to find images collected under the right conditions.
- The open-source MySQL platform was recommended to us at the time we developed the sandbar database. Currently, the database is still relatively small (~170 MB) and we don't expect database volume to become an issue.
- A map of the study sites is available on the sandbar website (www.gcmrc.gov/sandbar), but we can also add a map showing study site locations to future reports.
- Although we have used some Bayesian methods for some specific analyses, we have used more mechanistic and process-based models for most sediment budget applications. We will consider whether there is opportunity for advances or improvements by applying other statistical methods such as Bayesian inference.

- We agree that repeat riverbed maps will be useful for monitoring and interpreting the sand budget.

III. Project C: Riparian Vegetation Monitoring and Research

The authors have compiled a useful set of monitoring data and methods that connect vegetation with flow, environmental variables, and management.

C.1. Ground-based Vegetation Monitoring

Recommendations for this project element include:

i. It would be helpful to report what criteria are included in the 'error checking' of the ground-based monitoring data and to consider including stakeholders in the ideation process, so as to ensure that important criteria are not being screened or missed.

ii. The percent cover reported in Figure 1 appears to be very small, i.e., less than 1.2% of the area, such that a clearer explanation for why such a small coverage is of significance is needed.

iii. The website is very nice and provides good overview information. The authors should consider posting data directly to the webpage.

C.2. Imagery-based Riparian Vegetation Monitoring at the Landscape Scale

Recommendations for this project element include:

i. It would be helpful to report the fraction of woody riparian vegetation as a function of total vegetation and as a function of total riparian area. Further, understanding changes in woody vegetation through time will be an important reference point in terms of data management strategies. It looks like some of this is covered in Kasprak et al. (2020).

ii. Given the imperfect land-cover classification process (e.g., described by Bedford et al. 2018), it would be helpful for the authors to report the uncertainty in their estimates of various species composition, fractional coverage, etc., so as to more clearly articulate the state-of-the-knowledge of riparian vegetation species composition.

iii. Given the recent advances in high-resolution spaceborne remote sensing, the authors should consider incorporating this technology as part of future work, at a minimum comparing their results with viewable scenes from satellite remote sensing.

C.3. Vegetation Responses to LTEMP Flow Scenarios

Recommendations for this project element include:

i. The analysis relating climate variables with vegetation patterns (Butterfield et al. 2018) is interesting and should continue to be pursued. For example, considering the diurnal temperature range, i.e., the difference between maximum daily temperature (T_{max}) and minimum daily temperature (T_{min}) for two reasons. First, the diurnal temperature range has been shown to be closely related to the daily downwelling shortwave radiation which is an important predictor variable for vegetation, and second the maximum and minimum temperatures are widely reported and are much simpler to observe than radiation.

ii. The climate analysis in conjunction with the HFEs highlights an interesting avenue to pursue for future vegetation control with warming affecting inundation tolerance.

C.4. Vegetation Management Decision Support

Recommendations for this project element include:

i. Given the challenges brought about by riparian vegetation for campsites and other uses, it would be helpful for the authors to report the typical depth of roots for each of the species, as well as the density of the roots at different depths, since these will be valuable in determining management strategies and to inform decision making regarding long-term treatment options of replanting, removal, etc.

Project C GCMRC PI Response

C1. We will include information on the error checking process in the FY 2021 annual report where appropriate. Regarding the cover values in Figure 1, they are for a particular group of plants. Monitoring includes a broad array of habitat types, many of which are not suitable for any one species.

C2. We have the ability to (and do in other reports and publications) report the fraction of woody riparian vegetation as a function of total vegetation and as a function of total riparian area. We also agree that understanding changes in woody vegetation through time will be an important reference point in terms of data management strategies. So, we appreciate these comments and suggestions.

Please see our latest publication (Durning and others, 2021 in the journal Ecohydrology) in which we characterize the uncertainty and effects of classification errors on the species classification from the overflight remote sensing data.

Please see our recent paper (Bransky and others, 2021 in the journal Remote Sensing) which is an example of work we do incorporating high-resolution spaceborne remote sensing (in that case from the Worldview satellite) with the high-resolution airborne imagery from the manned airplane overflights.

C3. Agreed, we are including vapor pressure deficit, which is tightly correlated to diurnal temperature range, into our modeling moving forward.

C4. We have not collected these data within the CRe given the effort and disturbance necessary. However, data are available for many of our species from Stromberg, 2013, Journal of Arid Environments.

IV. Project D: Geomorphic Effects of Dam Operations and Vegetation Management for Archaeological Sites

Recommendations for this project element include:

i. The meteorological monitoring and data collection described by Caster et al. (2018) is extremely valuable and its continuation should be prioritized. The potential linkages between climate and riparian and riverine conditions offer unique insights into monitoring and management.

ii. There appears to be a grammatical issue on Page 41 of the report, under the third-to-last sub-bullet of FY 2019.

iii. Consideration should be given to exploring the use of high-resolution spaceborne remote sensing to complement existing aerial (e.g., LiDar methods) given the semi-continuous availability of spaceborne datasets, which would supply a valuable time-evolution of variables of interest.

Project D GCMRC PI Response

Please see our responses related to these comments about Project D above in the SUMMARY OF RESPONSES section of this document.

V. Project E: Nutrients And Temperature as Ecosystem Drivers: Understanding Patterns, Establishing Links and Developing Predictive Tools for an Uncertain Future

Recommendations for this project element include:

i. The authors report improvements in their predictive model on the basis of including solar radiation as a predictor. Details of the radiation data were

entirely missing, such that it is not possible to evaluate the utility and appropriateness of the observations. However, effort should be made to utilize radiation observations reflective of conditions *in situ*, rather than relying upon radiation observations from distant locations, i.e., from gridded datasets. Further, where radiation is not readily observed—acknowledging the challenges in widespread radiation observations—the authors should consider using the diurnal air temperature range as a proxy for solar radiation in their model.

Project E GCMRC PI Response

Thank you for your comment. Solar radiation data were obtained from the closest NSRDB location ID relative to each dam that contained data from years matching the other physically-based data in the water temperature model. Details on solar radiation data are included in the main response section.

ii. Many of the figures in Project E are low-resolution, making their evaluation challenging. This may simply be a typesetting issue.

Project E GCMRC PI Response

We apologize for the low-resolution quality of the Project E figures and will make an effort to improve the resolution of figures in the next annual report.

iii. Clearer justification of the water temperatures chosen, i.e., 10C, 15C, 20C, should be provided in the context of existing pool temperatures and temperatures relevant for other project components.

Project E GCMRC PI Response

In the artificial streams experiment, we chose 10, 15, and 20C to approximate release temperatures associated with three reservoir elevation scenarios. Ten degrees represents very cold temperatures that occur when Lake Powell is completely full, and the penstocks draw from deep within the hypolimnion. Fifteen degrees represents release temperatures from the mid-2000s when reservoir elevations dropped, and warming water temperatures in Grand Canyon propagated downstream. Twenty degrees represents a potential future scenario where reservoir elevations continue to drop closer toward minimum power pool—under this scenario water would be drawn through the penstocks that comes from the metalimnion or even lower part of the epilimnion.

iv. Overall, establishing connections between water temperature and taxa and species of interest is a viable area of investigation that should be continued going forward.

Project E GCMRC PI Response

We thank the reviewer for the suggestions.

VI. Project J: Socioeconomic Research in the Colorado River Ecosystem

This integrative project plays in important role in connecting physical science with stakeholder needs, incorporating tribal perspectives within the context of dam operations.

Recommendations for this project element include:

i. Overall, this project is an important component of the CRe, GCMRC, and GCDAMP, because it allows for a broad assessment of the connections of ongoing activities with needs and economics downstream. Therefore, it is recommended to continue prioritizing this area of analysis.

ii. The proposal to evaluate nonstationary climate impacts using the Donovan et al. (2019) model appears to be an important idea and its prioritization is recommended. However, the authors need to be careful that such a modeling approach is implemented with realistic constraints dictated by the physical system, since there appears to be a chain of models proposed which can lead to solutions that are not realistic or feasible. For example, connections between the biogeomorphic (Dean and Topping 2019) and humpback chub recruitment (Van Haverbeke et al. 2013) conditions need to be mapped at the outset to identify linkages, constraints and outcomes of interest to stakeholders, while also ensuring that physically infeasible solutions are eliminated.

Project J GCMRC PI Response

Thank you for the comments.

VII. Project K: Geospatial Science and Technology

Recommendations for this project element include:

i. The migration of datasets away from traditional ‘flat-files’ into databases and within cloud computing resources (USGS Cloud Hosting Services and Amazon Web Services) is an important cross-cutting innovation that will continue to payoff throughout and beyond the life of the project. It is therefore recommended to be prioritized going forward.

ii. The GIS toolkits provided by ESRI Desktop ArcGIS are effective and generally comprehensive for small processing and analysis jobs, but can become

overwhelmed with larger, multi-site analyses. Therefore, it is recommended that consideration be given to more powerful and efficient tools capable of handling larger datasets and analyses (e.g., Python-based tools), in the event that data sizes and ArcGIS-latency become an issue. The reliance upon ArcGIS may be suitable for the short-term, but as data volume and analysis-scope grows, there may be a need to expand towards more big-data-capable tools. There may be transition-relevant tools like ArcPy that could serve as a bridge. There appears to already be some project work being done on the project in Python; for example, the geoprocessing done for the lake elevations (Figure 1).

iii. Tableau is a sleek visualization software that is generally easy to use and has a good community and forum. However, drawbacks of Tableau are its high-cost, security issues, and limited product support. Therefore, consideration should be given to the cost-benefit of this product in the context of other comparable visualization products.

iv. Consideration should be given to whether the streamlining of multiple desktop applications (ArcGIS, ArcMap, GGIS) would improve workflows.

v. It is important that migration continues for software development to follow version control protocols. For example, those provided by GitHub.

vi. The transition towards IoT sensors will have numerous benefits. However, consideration should be given to security issues surrounding such a transition.

Project K GCMRC PI Response

Thank you for the comments. Responses provided for items here:

i. This Project has been the lead for GCMRC adopting the AWS cloud, however, we will continue to balance the cost-benefit of utilizing cloud resources versus on-premise data resources – or other options – as each GCMRC science project has unique data needs as well as capacity for project staff to work with cloud components. We have been and will continue to address cloud adoption on a project-by-project basis for the foreseeable future.

ii. This Project has been successful at developing batch processing methods using Python (both native and ArcPy, as well as other libraries) to support geospatial processing and analysis for science projects. Again, the needs between projects vary greatly given the different nature of data being collected (e.g., discreet fish sampling locations, with hundreds of thousands of tabular records versus continuous imagery and elevation data sets that have relatively simple data structure, but high resolutions and very large file sizes). The migration of GCMRC's backend databases from Oracle to Postgres will begin to allow for the

use of native Python, and other programming options such as R, to query and analyze project-specific data sets more freely.

iii. The PI for Project K has worked closely with the USGS Cloud Hosting Solutions group to gain Creator, Editor and Viewer level licenses of Tableau Desktop software. We continue to use this software through that nationally-funded USGS entity and have not had to spend GCDAMP funds for those licenses. It is noted that this software would otherwise present a higher than budgeted expense.

iv. Project K will continue to determine the feasibility of other, open-source GIS software, such as QGIS, for meeting the objectives of individual projects and the Center as a whole. QGIS can do many of the same functions that ArcGIS Desktop applications can, however, the power of ArcGIS is in the ability to author and share GIS resources more readily through ArcGIS Server and the larger ArcGIS Enterprise platform.

v. Agreed. Project K has led GCMRC into a more consistent era of source control for project development by leveraging both the USGS-approved internal GitLab space for code and software development and the related Cloud Hosting Solutions GitLab space for development occurring within Amazon Web Services.

vi. Project K staff work closely with the Cloud Hosting Solutions, Cloud Processing Framework Team as well as with a newly-formed Information Technology Advisory Council for the USGS' Ecosystem Mission Area (EMA ITAC) that has determined the growth of IoT and connect sensors in the USGS as one of its Top Five Themes to track. Security, specifically for IoT devices, is commonly discussed and we strive to follow the guidance from these two entities.

VIII. Project L: Overflight Remote Sensing in Support of GCDAMP And LTEMP

Recommendations for this project element include:

i. Although the details of the overflight are not clearly articulated, the value of additional remote sensing seems high and worthwhile. One recommendation would be to evaluate opportunities for integrating remote sensing imagery with publicly available spaceborne imagery as a way to potentially extend the investment.

Project L GCMRC PI Response

Please see our response to these suggestions for Project L in the SUMMARY OF RESPONSES section of this document above.

IX. Project M: Administration

No major comments. However, one minor comment is that the citizen science programs, e.g., Adopt-a-Beach, seem like an excellent way to extend budgets, while also elevating the awareness of visitors to issues within the region.

Project M GCMRC PI Response

Please see our response to these suggestions for Project M in the SUMMARY OF RESPONSES section of this document above.

X. Project N: Hydropower Monitoring and Research

Recommendations for this project element include:

i. Continue to coordinate with partners to identify opportunities to improve hydropower and energy resources. For example, the impact of HFEs on total outflows, the sensitivity of GHG emissions to reservoir levels, etc.

Project N GCMRC PI Response

Please see our response to these suggestions for Project N in the SUMMARY OF RESPONSES section of this document above.

XI. Appendix 1: Lake Powell Water Quality Monitoring

Recommendations for this project element include:

i. The collaboration with EPA to support floating chamber-based measurements of carbon dioxide and methane should continue to be prioritized to advance understanding of GHG emissions from Lake Powell.

Appendix 1 GCMRC PI Response

The collaboration with EPA for work on Lake Powell has ended. PI Deemer has funding from EPA for surveying reservoir GHG emissions from desert Southwest reservoirs more broadly, but Lake Powell was not randomly selected to be included in that study.

Peer Reviewer 4

AGENCY:	US Bureau of Reclamation, Glen Canyon Dam Adaptive Management Program (GCDAMP)
MATERIAL(S) REVIEWED:	2020 Grand Canyon Monitoring and Research Center (GCMRC) Annual Report
REVIEWED BY:	Lynne Lewis, Elmer W. Campbell Professor of Economics
DATE:	September 15, 2021

Introduction

I have reviewed the report *U.S. Geological Survey Grand Canyon Monitoring and Research Center Fiscal Year 2020 Annual Project Report to the Glen Canyon Dam Adaptive Management Program.*

I also viewed the video presentations in or related to my area of expertise, listed in in order of the agenda list:

- Introduction to Modeling Tools for Adaptive Management – Mike Runge
- Sediment in the Grand Canyon – Paul Grams
- Recreational use in Glen and Grand Canyons – Lucas Bair
- Hydropower – Clayton Palmer
- Panel Discussion Modeling Tools for Management
- Lees Ferry Fishery Monitoring – Jan Boyer

I focused particularly on those presentations that address in whole or in part, hydropower and energy, recreation and endangered species as well as those that were more indirectly related, including the rainbow trout materials. I have also reviewed the tribal resources slides (no audio accompanied those).

I have reviewed the following documents that appeared in the references that relate to socioeconomic values including recreational fishing and hydropower and some that were located elsewhere.

Lucas S. Bair, David L. Rogowski & Chris Neher. 2016. Economic Value of Angling on the Colorado River at Lees Ferry: Using Secondary Data to Estimate the Influence of Seasonality, *North American Journal of Fisheries Management*, 36(6): 1229-1239, DOI: 10.1080/02755947.2016.1204388

Pierce Donovan, Lucas S. Bair, Charles B. Yackulic and Michael R. Springborn. 2019. Safety in Numbers: Cost-Effective Endangered Species Management for Viable Populations.

Neher, Chris, John Duffield, Lucas Bair, David Patterson, and Katherine Neher. 2017. Testing the limits of temporal stability: willingness to pay values among Grand Canyon whitewater boaters across decades. *Water Resources Research* 53, no. 12: 10108-10120.

Duffield, Neher and Patterson (2016) Economics Analysis of Glen Canyon Angler and Grand Canyon Whitewater Visitor Surveys. Prepared for USGS, https://gcdamp.com/images_gcdamp_com/e/e0/Whitewater_Angler_FINAL_REPORT.pdf

I also looked at some of the survey instruments.

Based on the report structure, my main objective was to review LTEMP Goals on Recreational Experience and hydropower which appear in Projects, B, C, H, J and N as well as in the presentations. Project J is focused exclusively on Socio Economics, (Project J: Socio-economic Research in the Colorado River Ecosystem); however, socio-economic values and priorities permeate many of the other projects including Projects, B, C, H and N.

I will make some general comments and then more specific comments below:

General Comments

The report that I was asked to review was extremely difficult to review. The LTEMP goals, listed at the beginning of the project report, do not map directly to the projects themselves. Table 2 is a useful mapping of where those goals appear in the projects, but there is no overall assessment or connection across the related items as far as I could tell. Additionally, the presentations do not map onto particular projects or goals directly either. Many of them covered parts of several projects, but there were no direct articulations of the connections. As such it is not at all clear how a decision-maker might use this information. There are many disparate studies and a clearer delineation and/or compilation with summaries and recommendations would be enormously helpful for any reader to know how they tie together.

Each project area clearly reports their goals and objectives, but many of the results sections are very difficult to follow and some seemed cobbled together. There are some general results, but finding specific details is very challenging. A reader should not have to look up each reference in the hopes of finding the methods or data for a particular study. Prior recommendations should be bulleted with specifics on whether or not those goals were met. Links to survey instruments, data and methods of analysis need to be more clear. Without proper context, it is very difficult to review some of the sections. Since socio-economics permeates several of the projects, the authors might want to discuss how to incorporate a summary of the socio-economics in each project?

That said, the video presentations were excellent. Each presentation started with the goals, followed by the metrics used to measure performance and then what the impact topics are.

Mike Runge, in the first presentation, articulated that decision makers need this monitoring information in order to make predictions and the critical uncertainty is reduced by confronting

predictions with data from monitoring. He also said that the decision framework is developed by US Fish and Wildlife and their role is to determine what predictive models they need to help them make those decisions. The example he used was the mallard population. The mallard population is a function of habitat and hunting regulations. In that case the hunting regulation is the decision metric. They can then choose the best performing alternative for this metric using a consequence table. As I understand it, consequence tables he mentioned show which alternative performs best in which scenario. In this case, there are seven scenarios including the status quo. My question then is where is this table? There is no summary table anywhere that I could find, and the report does not offer information a decision-maker needs at their fingertips. I had to search through a lot of documents to find the information and am still left with many questions.

Thinking more broadly, how does climate change impact any of the scenarios? What about the current renegotiation of the Colorado River Compact? How is future uncertainty included in these studies? I do not see any specific mention of climate change in the report. I understand the report is primarily monitoring the current situation, but if these are used to form predictions, I wonder if the probabilities of extremely low flow futures are considered.

In my comments below I focus on the report *U.S. Geological Survey Grand Canyon Monitoring and Research Center Fiscal Year 2020 Annual Project Report to the Glen Canyon Dam Adaptive Management Program and* intersperse what I took from the presentations and references that perhaps could be used in a revision of the report.

General comments on Socio-economics

My area of expertise is economics. There is one chapter in the report labeled socio-economic research, Project J. This section outlines two very different modeling efforts – Tribal surveys and bio-economic modeling. Project J refers to tribal surveys without results or survey instruments to refer to or references. Then it moves on to bio-economic modeling and some results but does not connect the two or have a general summary on those resulting values. Additionally, socioeconomic results are scattered throughout the entire document related to recreational fisheries, endangered species and hydropower. The recreational fisheries values are presented in a different project as far as I could tell. Hydropower economic values are discussed, but not presented in Project N. As a reviewer it is very hard to understand the bigger picture for each of the management scenarios. What were each of the recommendations in conflict with and what is the total value? In fact, one of the LTEMP goals is the recreational experience, which is mentioned, but not summarized in any of the projects. For each flow experiment, what are the management recommendations? Which flow regime maximizes economic value or recreational experience and is that outweighed by another priority or not? Answers to such questions and many others are not obvious.

I recommend moving from the use of “citizen science” to the more inclusive term “community science.” Many organizations have already made this change to their language referencing

public participation in data collection, so it would be appropriate to consider doing the same. The term "citizen science" appears in a number of projects.

Specific Project Comments and Questions

I. Project B: Sandbar and Sediment Storage Monitoring and Research

A. Campsites

1. This project chapter reports that high flow experiments benefit campsites by causing temporary increases in campsite area. At the same time, vegetation encroachment causes campsite declines. While the primary goal of this project is to monitor sediment and sandbars (as I understand it), "this project also contributes to the goals for recreational experience."
2. I do not see campsites mentioned anywhere else. Is there a recommendation or conclusion? Do larger campsites allow for more visitors or larger individual campsites? How does this effect the economic value of the recreational experience?
3. What are the recommendations as they relate to recreational experience? This is missing from the entire report, not just in project B.

B. Citizen Science

1. See above on moving to the more inclusive term "Community Science."

Project B GCMRC PI Response

- Campsites are considered by AMP stakeholders as an important aspect of the recreational experience. Although visitation numbers are regulated by Grand Canyon National Park and are not tied to variations in campsite size, the size of campsites does affect the recreational experience.
- The conclusions expressed in the report are that HFEs result in sandbar deposition and increases in sandbar volume and increases in campsite area. Based on AMP goals and objectives and previous studies (Bishop and others, 1987; Kearsley and others, 1994; Neher and others, 2017), these changes are relevant to the recreational experience. We hope to conduct future work to more explicitly connect sandbars, campsites, and the economic value of the recreational experience. We did not intend to make recommendations regarding recreational experience in this report.
- We note that the reviewer recommends using the term "community science" instead of "citizen science."

Bishop, R. C., Boyle, K. J., Welsh, M. P., Baumgartner, R. M., & Rathbun, P. R. (1987). Glen Canyon Dam releases and downstream recreation: An analysis of user preferences and economic values. (Glen Canyon Environ. Stud. Rep. GCES/27/87). Springfield, VA: Huberlein-Baumgartner Research Service.

Kearsley, L.H., Schmidt, J.C., and Warren, K.D., 1994, Effects of Glen Canyon Dam on Colorado River sand deposits used as campsites in Grand Canyon National Park, USA: Regulated Rivers: Research & Management, v. 9, p. 137–149, doi:10.1002/rrr.3450090302.

Neher, C., Duffield, J., Bair, L., Patterson, D., & Neher, K. (2017). Testing the limits of temporal stability: willingness to pay values among grand canyon whitewater boaters across decades. Water Resources Research, 53, 10,108–10,120. https://doi.org/10.1002/2017WR020729.

II. Project C: Riparian Vegetation Monitoring and Research

A. Campsites

1. Goals and Objectives are missing. There is a section, but it does not list the goals and objectives, only the list of accomplishments.
2. This project aims to monitor changes to riparian vegetation which can reduce camping area (negative in economic value), add beauty to the landscape (positive) and create shades and windbreaks (positive). All of these things affect the socioeconomics. Is there a summary or recommendations as related to Project J?

Project C GCMRC PI Response

We will incorporate these suggestions into the FY21 Annual Report as appropriate and relevant.

III. Project H: Salmonid Research and Monitoring

There is significant overlap in topic, if not work, with this project and Project J.

A. Recreational Fishery

This project focuses on protection of the endangered humpback chub and maintaining a healthy recreational rainbow trout fisheries. The goal is to maintain a balance between the sport fishery and the downstream humpback chub. Experimental flows proposed in the LTEMP were designed for this purpose. Simultaneously, there is an effort to slow the increase in brown trout populations. According to the report “The primary objective of

this Project Element is to assess the effectiveness of GCDAMP policy actions that influence abundance, survival, recruitment, and movement for two distinctly different trout species."

1. There is reference to an angler survey, but it appears this is a different angler survey than the one used to measure economic value? The economic value (contingent valuation survey) looks to be from 2016. Was there any attempt to collect additional socio-economic data via the survey that was conducted in 2020? Has the data that was collected in terms of numbers of anglers and catch rates compared to the 2016 survey?

AZGFD Response

Our angler surveys are designed to collect data on angler use with the intent of using that data to understand angler use, assess whether fishery management goals are being met, and manage the fishery. They are not designed to measure economic impact or collect socioeconomic data. Estimates of angler use and catch rates by year can be found on page 27 (figures 11, 12) of the AZGFD 2020 Annual Report. Surveys to assess economic impact are typically separate studies conducted by GCMRC or partners. I know that surveys associated with the incentivized harvest program (NPS and GCMRC) included questions about annual income.

2. I assume the recreational fishery is extremely valuable, but there is no reference to the economics or which flow regime could improve the recreational experience (value).

AZGFD Response

We do address this when we have opportunities to do so. For example, our presentations and reports in 2019 included graphs and information on how bug flows affected angler catch.

3. Jan Boyer's presentation also covered catch rates and angler satisfaction. Catch rates and satisfaction both went down this year. The significant drop in 2020 is curious. Does this drop have to do with covid-related travel conditions? Or is it simply that different people are fishing this year? There was certainly increased visitation at all federal recreational areas and national parks in 2020 and 2021. Since the number of anglers did indeed go up, is there a way to connect or examine the differences in demographics? Does congestion play a role with increased visitation?[1] [1]

[1] Jan Boyer's presentation covered items that overlap Projects H and J.

AZGFD Response

These are interesting questions, but I'm not sure we have the data to answer them well. We suspect low satisfaction has to do with lower catch, although it is odd that satisfaction dropped so much in 2020, but similarly low catches in 2016 did not lead to a similar decrease in satisfaction. I think the most I can say here is that angler satisfaction is an imperfect and opinion-based metric – even though we tell anglers we are interested in their satisfaction with the fishery specifically – their responses end up including other factors: the scenery was amazing, they liked their guide, it was too hot, they saw 5 bighorn sheep, there were too many kayakers, etc. We did look at angler numbers related to covid travel conditions. We saw a drop in April when the initial lockdowns went in place, but then angler use increased to expected levels for the rest of the year. For annual use, boat angler days were similar to the last 5 years, but walk-in angler use increased in 2020. Note that walk-in angling is far more affordable and accessible, and easier for new anglers to start with. Regarding examining demographics, we collect data on ZIP code and age (youth, adult, retired prior to 2020, started asking age in 2020) but not much else. The metric we have that would be best for looking at shifts in demographics would be walk-in vs. boat anglers, or ZIP code to see how far people are travelling. Congestion decreasing satisfaction is something we have anecdotal evidence for (i.e., guides saying they don't even like to fish on weekends now with so many kayaks), but not something we have data to look at (presumably crowding could influence the satisfaction data, but we do not specifically ask anglers if crowding affects their experience).

B. Incentive program

1. There is brief mention of an incentive program put together by the National Park Service and the Arizona Department of Fish and Game aimed at reducing brown trout populations. The goal is to incentivize anglers (through payments) to harvest brown trout. This is the only time I saw this program mentioned, though it was mentioned in one of the video presentations. From a socio-economic perspective, incentives can be very powerful tools. Is it working? Is there any data on participation? What is the recommendation?
2. This incentive program was discussed in more detail in Jan Boyer's presentation. From my notes from that presentation, apparently 58% of survey respondents said they would participate in an incentivized harvest of brown trout. The survey also asked about the amount of money that would incentivize the respondent to participate. It sounds like this incentive program was started in November? With a $25? Incentive? This was followed by a survey asking anglers if they were aware of this program. This seems to be extremely important information, but it is missing from the report.

Project H GCMRC PI Response

We will include additional information in the FY21 annual report on the incentivized harvest program, angler participation, incentives, and other details. The program had just started when the FY20 annual report was written.

C. Citizen Science

1. I recommend moving from "Citizen Science" to the more inclusive "Community Science."

Project H GCMRC PI Response

This suggestion will be relayed to AZGFD as well as other project PIs for their consideration.

IV. Project J: Socioeconomic Research in the Colorado River Ecosystem

This project addresses the Tribal Resources, Humpback Chub (*Gila cypha*), Hydropower and Energy, and Rainbow Trout Fishery Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement resource goals by addressing the LTEMP Record Of Decision (U.S. Department of Interior 2016a, 2016b) objective to respect the "interests and perspectives of American Indian Tribes" and "determine the appropriate experimental framework that allows for a range of programs and actions, including ongoing and necessary research, monitoring, studies, and management actions in keeping with the adaptive management process." These studies also attempt to "maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term stability of downstream resources."

Summarizing the socio-economics is tricky since pieces are covered or mentioned in several other projects. This project only reports on two of the resource goals. Since socio-economics permeates several of the projects, the authors might want to discuss how to incorporate a summary of the socio-economics in each project?

A. Tribal Resources

1. Tribal Values: I have read Project J on Tribal values and reviewed the slides that were presented. This section is difficult to review since the reports are currently confidential as I understand it and the audio that accompanied the slides was not released. Within my area of expertise, both the report and the slides mention a tribal survey that included a contingent valuation question. I was

interested in learning more about this since in my experience, many indigenous groups have balked at the idea of monetizing cultural resources.

Project J GCMRC PI Response

I provided the Bureau of Reclamation the draft Navajo Nation and Hualapai Tribal reports for this review. It is disappointing that you were unable to review the reports.

1. After a series of questions about preferences for environmental and management outcomes, the contingent valuation question reads:

   > "What is the most you would be willing to pay per month in order to have the river management tools you approve of used to manage the Colorado River ecosystem? Please keep in mind your financial situation and the fact that you may prefer to use the money for other purposes including alternative environmental conservation programs." (Incorporating Tribal Knowledge and Preferences slides, January 9, 2021)

   I have two concerns with the phrasing of this question. The first is about *what* is being valued. Contingent valuation results suffer from biased responses when respondents are not clear on what is being valued, but also when different respondents are valuing different things. In this case, the respondent needs to presumably remember what management tools they said they preferred, but also might be making a payment choice based on something entirely different from another respondent. My preferred management goal might be different from yours; in which case, we cannot compare or average our individual willingness to pay (WTP) since we are "bidding" on different goods. What are they valuing? If each respondent is simply valuing their own choices, these data cannot be used to measure the economic value and I urge extreme caution with use of these responses, unless they are grouped by management tool.

Project J GCMRC PI Response

This is a very good question. We purposely did not include a quantitative outcome related to what is being valued. Even in this system, this question format is common (Jones et al. 2017, Neher et al. 2017 [replicating Bishop et al. 1987]) but the analyst must be cognizant that the question format prevents an estimate of economic value related to what is being valued. We make this explicit in the report and past presentations. The question format was chosen based on initial focus groups and pre-tests with the Pueblo of Zuni (ultimately the Pueblo of Zuni did not participate in the community survey). The result of this question format is similar to a referendum. In this decision context we feel this information is relevant.

Second, the last phrase seems like it could easily induce bias. "Please keep in mind your financial situation and the fact that you may prefer to use the money for other purposes including alternative environmental conservation programs." This reads a bit like a caution that perhaps I should say no to the willingness to pay question? Did this language come from focus groups or survey pre-testing?

Project J GCMRC PI Response

Thank you for the comment. In our opinion the reminder about "budget constraints" and possible alternative uses of funds is a standard best practice in CV question design. The question format is also in response to stakeholder concerns about question format. The inclusion of these reminders is consistent with guidance from Arrow et al. (NOAA Panel) which stated:

> "Respondents must be reminded that their willingness to pay for the environmental program in question would reduce their expenditures for private goods or other public goods. This reminder should be more than perfunctory, but less than overwhelming. The goal is to induce respondents to keep in mind other likely expenditures, including those on other environmental goods, when evaluating the main scenario."

Again, without more context and information, I can only make these general comments and cautions.

Finally, the slide that shows the responses to the WTP question does indeed show a larger percentage of $0s. The data on why respondents chose "no" or $0 could be very informative on whether they protest the scenario, cannot afford it, prefer the opt out given in the question, or something else. Best practice suggests protest bids should be removed.

The simple average of willingness to pay is okay, but a rather crude measure when using this payment card method.

Project J GCMRC PI Response

This is a very good question. We purposely did not include a quantitative outcome related to what is being valued. Therefore, the result of this question format is similar to a referendum and a simple average in this case is a relevant statistic. Including $0 votes is therefore also relevant and we did include a question to capture protest votes or other reasons for a $0 response.

B. Recreational Use

1. There is no mention in Project J about the economic value of the recreational fishery.

2. Lucas Bair's presentation, however, presented two performance metrics: recreation and visitor use and experience as it relates to fishing, boating and camping. The impact topics include recreational use values and employment and income.

Glen Canyon rafting metrics were presented, including the statistic that 50,000 people participate in day use rafting. The presentation also examined whether or not high flow scenarios impacted the number of visitors. They also examined inundation of recreation sites.

C. Whitewater rafting (a subset of B above)

1. Whitewater rafting was also not mentioned in Project J although rafting plays a large role in socio-economic value. The presentation did cover whitewater rafting extensively comparing the more recent data with the original Bishop study. In high demand months, the economic value is significant. I did review the two published papers by this team on the value of the whitewater rafting. Those studies are based on a contingent valuation survey that was then compared to the original 1995 Bishop survey.

2. The decision about which model to apply to WTP data is not neutral, which is why sensitivity analysis is so important. The parametric approaches are fairly straightforward and deliver good estimates with good statistical properties provided the specification of the distribution is correct. If the proposed distribution family is incorrect, however, the estimated mean WTP can have a systematic upward or downward bias. Non-parametric techniques are appealing, in part, because they do not rely on an assumption about the underlying distribution of WTP values. Since we do not know what this distribution looks like, a linear or logistic function may or may not be appropriate. In fact, the authors state that the pooled model suggests possible differences in the underlying WTP distribution functions between the two studies suggesting a non-parametric approach would be most appropriate for comparison. It would be interesting to use some of the more commonly used approaches such as the non-parametric Turnbull with this data. The Turnbull is easy to calculate by hand and the data from Table 3 in the Neher et al (2017) article would allow for a comparison using a non-parametric technique. Another appeal for using the Turnbull with this particular data is that the Turnbull does not rely on covariates which clearly are changing over time for demographics. As such I recommend including sensitivity analysis of WTP estimates including the use of non-parametric models for the next iteration with this data. It would certainly be an interesting test of whether these values are stable over time using a different technique.

3. Using a price index more representative of recreation is recommended (rather than the CPI for all urban consumers).

Neher, C., Duffield, J., Bair, L., Patterson, D., & Neher, K. (2017). Testing the limits of temporal stability: willingness to pay values among Grand Canyon whitewater boaters across decades. *Water Resources Research*, *53*(12): 10108-10120.

Project J GCMRC PI Response

Recreation economics research is not funded every fiscal year, thus not included in the FY20 Annual Report. There have been past studies that use revealed and stated preference methods to estimate the economic value of the fishery and whitewater boating (Bair et al. 2016, Neher at el. 2017, Neher et al. 2019) and how specific attributes (e.g., flow, catch) influence that economic value. There are also ongoing efforts to refine willingness-to-pay estimates with existing data. For example, as part of Project O (FY21) a choice experiment was conducted to complement past economic assessments of the recreational fishery (Neher et al. 2016, white paper). The AZGFD creel could be used to update the revealed preference economic value estimates (Bair et al. 2016). I also agree that it would be interesting to use the non-parametric Turnbull with the recreation data. As you point out, the published analysis was intended to replicate the Bishop et al. 1987 analyses. This along with other analysis of existing data is always a consideration. However, funding is limited and does not occur in every three-year workplan.

D. Humpback Chub and Rainbow Trout

1. "Donovan and others (2019) published an updated bioeconomic model to estimate the most cost-effective approach to managing rainbow trout removal at the confluence of the LCR and the Colorado River to meet long-term adult humpback chub survival goals." The report gives a relatively short description of the bioeconomic dynamic programming model that evaluates that tradeoffs between protecting humpback chub and rainbow trout abundance.
2. Where is a summary of the findings? Who are the decision-makers?
3. Both of these species have considerably large economic value I presume, so how are the tradeoffs measured? Endangered species and other non-use values can be quite large. Has the economic value of the humpback chub been estimated?

Project J GCMRC PI Response

The detailed summary of the findings of the bioeconomic model is found in Donovan et al. 2019. The objective of the Annual Report is to brief stakeholders on the recent outcome of research. In the 2020 Fiscal Year Annual Report the focus of Project J was on

the utility of the bioeconomic model in identifying the cost-effectiveness of humpback chub translocations (Yackulic et al. 2021). The decision makers are stakeholders in the GCDAMP, specifically the U.S. Fish and Wildlife Service. For example, as part of the review of conservation triggers for humpback chub the results of the bioeconomic model were used to evaluate the current triggers.

Tradeoffs are measured using a cost-effectiveness analysis in the bioeconomic models (Bair et al. 2018, Donovan et al. 2019). The National Park Service has updated a stated preference survey that estimates the value of resources in the Grand Canyon (Welsh et al. 1995, Neher at al., Unpublished Park Service Report). The estimates of economic value related to native fish are high. The marginal value of native fish in this context is not helpful in decision making. We use a cost-effectiveness approach because there are also other non-economic reasons to recover endangered fish. This decision framing shifts focus from the ends to the means (Sagoff 2009) and is useful for adaptive management and facilitates the incorporation of relational values into the framework (e.g., Tribal values, ongoing work). I made sure there were a few sentences in each manuscript (Bair et al. 2018, Donovan et al. 2019) discussing this and there is a lengthier discussion in the Donovan et al. (2019) manuscript referencing these points in relation to the NPS study.

E. Rainbow Trout Fishery

1. Recreational fishing is covered above, but the rainbow trout fishery is also discussed in several of the other projects. There needs to be some summary material in this report that weaves these similar topics together. I am still not clear on the economic value of this fishery although it is extremely valuable.
2. How have the change in numbers and types of recreational fishers influenced these values?
3. Has the incentivized catch program for brown trout impacted satisfaction and economic value of the rainbow trout fishery?
4. 2016 report on the economic value of the recreational fishery. Is this survey going to be repeated to get a more current assessment of recreational fishing that can be used with the 2020 fish and angler counts?

Project J GCMRC PI Response

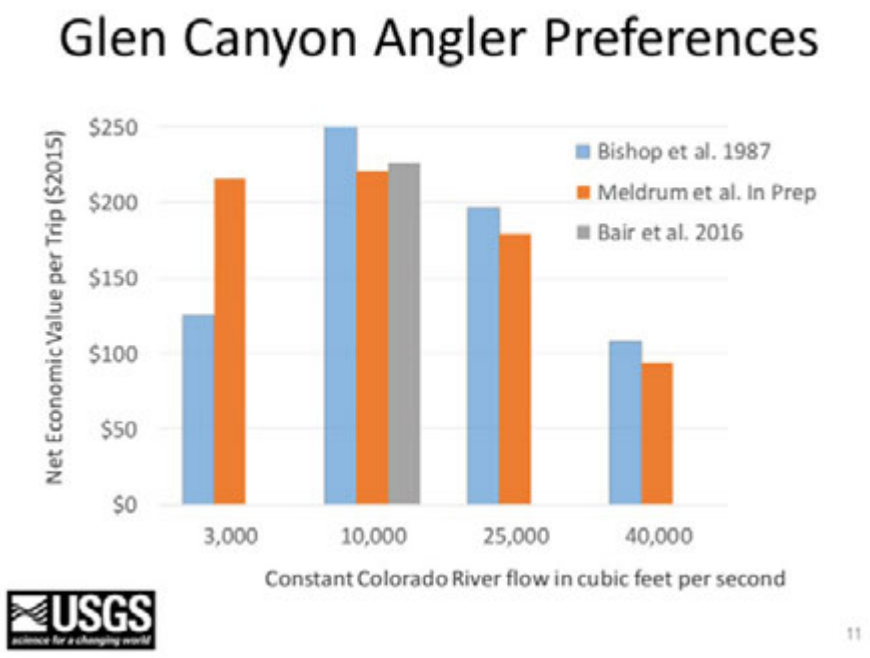
Recent use of survey methods to estimate the economic value of the fishery was published in 2016 (Bair et al. 2016). This utilized data from an AZGFD on-site intercept survey. This information could be updated with the ongoing collection of data by AZGFD. The second recent effort was made to survey anglers and update the Bishop et al. 1987 research using stated preference survey methods. This information is available in a white paper and there are ongoing efforts to refine and publish this work (Meldrum

et al. In Prep). A choice experiment was implemented this calendar year to identify how low flows impact angler value (Project O). This will be made available in a white paper the intent is to publish this work. Comparisons have been made between the various efforts.

You can see from the below figure that we do have robust estimates of the economic value of angling at different flows. This could be used in a simulation model to estimate the annual value of angling under different flow regimes. This was something that was proposed but not funded in the GCDAMP FY21-23 Workplan.

Ongoing estimates of recreation economics will occur as possible.

The brown trout incentivized harvest started in November 2020 (FY21). We have increased the on-site intercept survey (AZGFD 6 per month and GCMRC 12 per month, Project J) and are working with NPS on incentive design. We are also designing a choice experiment to further our understanding of the program that will be mailed to anglers in 2022. Preliminary results of the brown trout incentivized harvest will be presented at the FY21 Annual Reporting Meeting.



F. Hydropower and Energy

1. Why is there no summary of the socioeconomics of hydropower?

Project J GCMRC PI Response

Hydropower and Energy is not an explicit project element in Project J. The Annual Report is not intended to summarize the socioeconomics of hydropower. Again, I don't object to this, but it's not the direction provided.

G. Climate Change

1. There is no mention of the on-going severe drought or climate change. Will new low flow scenarios be tested? Are there recommendations going forward related to climate change? And how does the renegotiation of the Colorado River Compact impact this report.
2. The report does include: "The Donovan and others (2019) model will also allow research into the impact of nonstationary climate impacts (e.g., changes in flood frequency) on humpback chub recruitment in the Little Colorado River and how that may inform effective and efficient management and research." This will be important for continued inclusion.

Project J GCMRC PI Response

I agree that climate change is important. Robust decision making is a method that could be implemented, using the bioeconomic and other modeling tools available. This will be considered in future proposal submitted for funding. As noted, there is mention of climate change and resource dynamics in reference to humpback chub modeling and this work is in development.

V. Project N: Hydropower Monitoring and Research

A. Lack of detail

1. Goals and objectives could be clearer.
2. One of the goals is "The operation of [Glen Canyon Dam] GCD to meet hydropower and energy resource objectives, as the integration of renewables and a greater recognition of the social cost associated with power system emissions occurs, is an important consideration when attempting to maintain and improve resources downstream of GCD."
3. There is no detailed report on the economic value of hydropower outside of the slides, and it isn't clearly laid out in the Annual Report. What is the total value of hydropower? The report states "The total value of hydropower generated at

GCD includes costs associated with energy generation, greenhouse gas emissions, human health, and other regional impacts. These impacts are dependent on the price of fuel (e.g., natural gas) and the integration of additional generation, including renewable energy, into the electricity sector. Scenarios incorporating these factors were used to assess total economic costs associated with a proxy experimental flow at GCD." Where are these results?

4. "We demonstrated the change in production and emissions costs in the Western Interconnect by reoperation of GCD has the potential to be significant and could potentially result in offsetting costs." (p 156). A table with numbers and results from different scenarios would be extremely helpful. I would like to see what these external social costs are. I agree that they are very important, but having some details or a summary table is necessary.
5. There is a link in the document "for more detail and preliminary results…" but that link simply takes me to a PowerPoint presentation from February 2020. There are 3 slides on hydropower (slides 30-32), but those have very little detail without knowing what the speaker said. I do not know how the various scenarios were calculated. For example, how are emissions costs measured? Which experimental flow scenario results in which costs? What are the recommendations?
6. Project N needs more detail.
7. From the presentations I learned that the value of hydropower generation is $millions/year was estimated over 20 years discounted at 3.375% and the value of hydropower capacity was calculated by finding the 90% exceedance value for daily minimum generation in August. A table of these results would be extremely helpful. Was any sensitivity analysis performed? Is the choice of a 3.375% discount rate mandated or chosen by analysts? From the presentations I understand they estimated capacity and energy for various flow? scenarios which can then be used to estimate economic value and changes in rates for rate payers. Then they look at how this impacts emissions. This seems really important? Are the results posted anywhere?

Project N GCMRC PI Response

The funding for hydropower and energy research (Project N) is limited (0.3% of total budget). The goal is to coordinate with ongoing projects to advance research with respect to the Hydropower and Energy resource goal in the LTEMP EIS. As mentioned above, the objective of the Annual Report is to update stakeholders on FY20 projects in a concise document. References to documents or presentations in past fiscal years is standard (it sounds like you were pointed to a summary of the Project N presentation for FY19 and not the complete presentation). It also sounds like you were reviewing

Western Area Power Presentations (Question 7) or information from the LTEMP (e.g., capacity expansion, rate payer impacts). The LTEMP EIS information is part of the final environmental documentation (Appendix K). Historically, annual reports, including the FY20 annual report, have not been a place to summarize fundamental concepts like the economic value of hydropower, past results, detailed FY20 results, or modeling that took place in environmental compliance documents or by other stakeholders. However, your points are all productive. I will attempt to summarize information, past and present hydropower modeling undertaken by all stakeholders, in future annual reports.

Other Comments

How do the references on total economic value tie in with the other items in socio economics (The Bair/Duffield/Neher references)

Covid-19 impacted data collection in 2020. It also significantly impacted the numbers and types of visitors. How are these changes influencing the monitoring efforts and decision-making?

Finally, there is no mention of the on-going severe drought or climate change. Will new low flow scenarios be tested? Are there recommendations going forward related to climate change? And how does the renegotiation of the Colorado River Compact impact this report?

Project N GCMRC PI Response

These are all good comments. Model integration and understanding more about shocks to direct use values (e.g., COVID-19) and the dynamics of climate change would be interesting. The socioeconomic program is limited (2% of annual budget), we continue to work on the variety of issues, and we appreciate the thoughts about opportunities for research.

Appendix B: Reviewer's Curricula Vitae

The reviewer CVs are omitted from this review response document for brevity; please see the review report.