Advancing Modeling Tools for Assessment of Long-Term Energy/Water Risks for Hydropower

Draft User Needs Assessment

June, 2017

Project Background

Pacific Northwest National Laboratory (PNNL), with funding from the Department of Energy's Water Power Technologies Office, aims to develop advanced analysis techniques and demonstrate new capabilities that can be used to assess and manage potential future water quality and temperature impacts to watershed-river-reservoir systems by modeling streamflow, hydropower generation, thermoelectric power, water temperature regimes, and water quality indicators (e.g., dissolved oxygen, which may be more important in other regions) under current and altered climates.

The DOE Report on the Energy-Water Nexus: "Challenges and Opportunities"[1], highlights the need to explore questions regarding future risks to complex energy, water and land system interactions. Of specific interest is the relationship between potential future risks regarding: changing water temperature regimes in rivers; electric power generation from hydropower, thermoelectric plant cooling and discharge; and water-quality and habitat needs for sensitive species.

To better evaluate and address the future risks facing hydropower, this project will provide a scalable, fine-resolution, physics-based modeling framework to evaluate different potential hydropower investment and operational decisions in the face of changing conditions. Specifically, the modeling framework will be able to quantify risk, at the plant and system levels; impacts of altered hydrology on hydropower and thermoelectric production; water temperature; and ecosystem resources. The project aims to provide decision makers with the capability to model the potential future likelihood and severity of instream flow changes and water-temperature events (and additional water quality and habitat quality parameters in the future) under a range of possible future climate scenarios and evaluate alternative operations and infrastructure investments to address such events.

Findings

To help inform development of the modeling framework, PNNL, with support from Kearns & West, conducted interviews with hydropower decision makers such as plant and system operators, regulatory agencies, and non-governmental organizations (NGOs) to assure the framework will meet stakeholder needs and be useful to the hydropower community.

Findings from these interviews are presented below, categorized first by stakeholder group and then by general topic area.

[1] https://www.energy.gov/under-secretary-science-and-energy/downloads/water-energy-nexus-challenges-and-opportunities

Findings are pulled from interviews with the following entities:

Organization	Name	Stakeholder Group
AMP Hydro	Phil Meier	Hydropower Operator
Bonneville Power Administration (BPA)	Alisa Kaseweter, Erik Pytlak, Kim Johnson, Julie Doumbia	Hydropower Operator
Brookfield Renewable	Steve Murphy	Hydropower Operator
California State Water Resources Control Board (CA SWRCB)	Jeff Wetzel	Regulatory Agency
Duke Energy	Mark Oakley, Keith Finley, Alan Stuart, Ed Bruce	Hydropower Operator
Eagle Creek Renewable Energy	Dave Youlen	Hydropower Operator
EPRI	Paul Jacobson	Hydropower Operator
Federal Energy Regulatory Commission (FERC)	Matt Cutlip	Regulatory Agency
Grant County PUD	Andrew Munro	Hydropower Operator
National Marine Fisheries Service (NMFS)	Steve Edmondson	Regulatory Agency
Pacific Gas and Electric (PG&E)	Jim Gill	Hydropower Operator
Snohomish County PUD	Keith Binkley	Hydropower Operator
Southern Company	Herbie Johnson and Ken Odom	Hydropower Operator
Tennessee Valley Authority (TVA)	James Everett, Lana Bean, Jeff Ogden, Colleen Montgomery	Hydropower Operator
U.S. Army Corps of Engineers (USACE)	Jeff Arnold, Peter Dickerson, Steve Barton, Julie Ammann	Hydropower Operator
U.S. Bureau of Reclamation (BOR)	Ken Nowak and Clark Bishop	Hydropower Operator
Washington State Department of Ecology	Chad Brown	Regulatory Agency

1. General (Hydropower Operators and Regulatory Agencies)

Overview: Comments below encompass general feedback regarding hydropower operators' and regulatory agencies' operations and responsibilities. These comments help offer insight on areas in which PNNL's model framework will be most valuable.

- Challenges exist around different water uses (e.g., habitat, electricity generation, recreation, drinking water, etc.). It can be challenging to get all the different stakeholders to agree on ways to address these.
- In many cases, because of cold water fisheries hydro projects, the operation of the facility to maintain a below the dam fishery has been important for both regulatory agencies and licensees.
- For many, water quality tends to be a fishery and/or habitat issue (e.g., achieving parameters for cold water fisheries downstream or warm water fisheries in the lake).

- To address varying hydrologic conditions, there may be value in managing for temperature; this could be an important activity because the issue would become more about temperature and less about flow. In that case, PNNL's framework would be valuable. However, it is important to note that currently the primary action taken to address downstream temperature is largely flow releases.
- Some felt that larger scale assessments of basins would be helpful, as operators do not always have the resources to study this (e.g., where to place temperature sensors to optimize their performance, and using models to optimize network design).
- Hydro operators would appreciate an opportunity to have a proactive approach to correcting water quality issues. If this model framework assists in pro-active planning it will be helpful.
- For some operators, storage capacity is decreasing due to sedimentation. Managing downstream temperature is just one piece of that puzzle. If sedimentation blocks some of the lower or deep release points, temperature will be affected. In that case the only options are surface spill or passing water through turbines.
- For projects focused on storage or smaller rivers' Total Dissolved Gas (TDG) is not a prevalent concern.

2. Regional Needs (Hydropower Operators and Regulatory Agencies)

Overview: In the Pacific Northwest (PNW) and California (CA) the major water quality issue is primarily habitat and temperature for downstream fisheries. TDG in the PNW, and Dissolved Oxygen (DO) particularly in the Southeast (SE), East, and Mid-West are more significant water quality issues, with temperature as a contributing factor.

- Different regions deal with different issues. For example, water issues in the West are far more dynamic with widely varied conditions from extreme drought/dry years to extreme wet years. Hydrologic conditions have a big impact on the ability to predict water volumes.
- In the PNW, DO and TDG can be easier to address than instream flows and water temperature.
- Temperature is a big consideration in decision making in the Pacific Northwest.
- In the Southeast, DO is closely tied to other water quality factors, such as temperature and TDG. For some, releases are generally from a deep reservoir, so temperature is not a direct problem, but does have an effect on the DO saturation level. DO is a strong driver behind operations.
- Typically, in the East and Southeast, dams are lower head, which slows the river or mechanical aeration and reduces DO. This also tends to warm the water, which then leads to a reduced ability to hold DO.
- On the West Coast, dams generally have higher heads, so DO is less of a concern.
- In the Southwest (CA), temperature is more of a concern.
- The Midwest, New England, and Southeast regions do not focus on water temperature as much as they do on other water quality issues such as DO, but DO does generally go hand-in-hand with temperature.
- Southeastern entities use models to work together to conserve water across the whole system.
- With low head dams operated in the Ohio River, there seems to be little fluctuation on temperature; monitoring in this region focuses on water quality generally, but not on temperature.
- In the PNW, spill increases total dissolved gas.

- When NOAA considers water quality around a dam, it considers DO or dissolved gasses, impacts on temperature, nutrient delivery, nutrient cycling, and impacts on energy cycling. These linkages between the ocean and fresh water environments are important ecologically.

3. Dissolved Oxygen (Hydropower Operators and Regulatory Agencies)

Overview: Dissolved oxygen is a driving force in the operation of many hydropower systems, particularly in the Southeast, but also in the Northeast and Mid-West, and is an important water quality parameter for PNNL to consider in the development of its framework.

- Requirements for adjusting DO don't always come with requirements to monitor temperature.
- Sometimes requirements for adjusting DO are prescribed based on seasonality (times of the year when DO is likely in need of adjustment).
- Aeration technology (air injection systems) is used to inject air in the water and increase DO when it is low.
- Spilling to adjust DO affects water availability for hydropower.

4. Hydropower Operators Feedback

Policy for Federal Hydropower Operators and Licensees

Overview: Water quality and temperature for fisheries downstream are established in licensing for non-federal hydropower operators. For federal hydropower operators these parameters are set in consultation with the hydro operators, federal and state agencies, and tribes. The primary action is setting flow conditions for different hydrologic conditions (wet, dry, normal), and monitoring.

- To address temperature the primary action taken is flow releases, or, for those with large reservoirs, flow releases from deeper lake elevations.
- In extremely dry conditions, in some cases there are limits on the ability for flows to fully address downstream temperature needs.
- Balancing power generation with the fishery resource can be difficult. However, balancing multiple uses for this renewable energy source is important.
- Flows have to be managed carefully in order to keep species within their temperature bounds.
- Permitting agencies (NMFS, State fishery agencies, and for non-federal operators, the state 401 agency) determine the water temperature that needs to be achieved, and prescribe actions that need to be taken to achieve it.
- The typical regulatory purpose for water flows is to meet temperature requirements and fish habitat requirements. Another regulatory approach to address fishery needs is to require fish passage. For example, there is required spill at many federal PNW projects to aid fish passage.
- Some operators consider water quality's and salinity's effect on infrastructure; constant flows of saline water can rust and deteriorate bridge (and other structures) foundations in the water.
- Operators monitor for instream flows and temperature; in California they report if they exceed requirements but do not necessarily take any actions if temperature conditions are not met.
- For some operators, a change in temperature over time results in more provisions for minimum flow scenarios, as drought and flood scenarios vary.
- A few noted that adding increased storage increases the capacity for flows during dry conditions, as well as increasing storage during wet/high flow times.

- Some operators have the ability to release water from different levels of a reservoir which can address downstream water temperatures.

Compliance/Monitoring (Non-Federal Operators)

Overview: With license terms set, monitoring to report on instream flows and temperature are the primary ways water quality and temperature are addressed in compliance. Similarly, other water quality attributes such as salinity or DO are also monitored. Water availability (especially in dry conditions) and species concerns, along with meeting license requirements, tend to be the drivers in compliance. While some licenses (very few to date,) have license re-openers that FERC would exercise if license terms are not met, FERC rarely takes this action.

- For some operators, water temperature is not a daily driver but water quality is part of licensing. Species concerns, water availability, and maintaining licensing requirements are key drivers for compliance/operations.
- Most non-federal operators in the PNW and Southwest do real-time monitoring for flows and temperature.
- In most recent licenses, implementation is centered on the ability to meet flow requirements, not temperature requirements.
- Water temperature is assessed primarily through licensing; some operators have ongoing work groups for license implementation. For federal hydro operators, the work groups are part of ongoing operations.
- System upgrades for some licensees tend to be driven by requirements in the license such as equipment condition requirements to increase the ability to address low flow conditions.
- Smaller, run of river projects have less impact on temperature because of a small impoundments.
- In the Southeast, during the summer, some federal hydro operators provide daily forecasts to coal and nuclear plants so that these plants can comply with water temperature limits.
- For some licensees, water temperature requirements are primarily driven through the 401 certification process, as well as the ESA/sensitive species federal and state agencies.
- Water flow criteria is developed to meet water temperature and fish passage criteria.
- Some operators may take readings as frequently as one-minute intervals. This may not be put into a model, but the data is input into a graph, which helps the operator look at DO data received from the field sensor and how it fluctuates.
- Field sensors provide a consistent measurement of water temperature, quality, etc.
- Some operators and regulators would appreciate information that can inform recommendations on the placement of monitors in the river, to better understand reverse flows and how water flows between points (e.g., circulation patterns that occur from dam releases). Higher-resolution models can inform monitoring system design (locations, etc.) and also discrete field test design.
- EPRI has done work recently with drones and thermal mapping of surface waters.

Federal Hydropower Systems (Hydropower Operators)

Overview: Federal hydropower operators acknowledged that changing climate hydrology will have a fundamental effect on operations in the future and that it is important for PNNL's framework to complement existing frameworks and tools.

- Many operators have a continuum of operations: short-term, long-term, and 50 years out.
- Many operators plan around low water years.
- While short-term modeling doesn't account for long-term hydrologic conditions, many agree that this is something operators will have to contend with.
- Seasonal variability (temperature and rainfall) makes managing the water difficult. One federal hydropower operator models its tributaries and main stem; this provides them with a good idea of cold water. They also take information about the temperature profile in deep storage reservoirs.
- Operators sometimes have limited management actions they can take (i.e., hydro operations/flow releases cannot fully address the issue) to address temperature issues (e.g., on the lower Snake River).
- Some operators use historical data as a guide for future projections, both for industrial needs and future water demands.
- USACE plans days and months in advance, for all system purposes (flood management, navigation, fish, etc.), routinely taking National Weather Service data to input into their models.
- PNNL should understand USACE's CWMS (Corps Water Management System) and how their modeling framework would interact with what PNNL is developing.
- Some federal operators do day-ahead planning.
- Release schedules can be altered to meet hydrothermal requirements and to ensure steady flows do not disrupt temperature stratification at nuclear plants, etc.

Systems Upgrades (Hydropower Operators)

Overview: Upgrades at hydropower facilities are driven by a number of factors, primarily the condition of the equipment, and the potential to operate with lower flows, if necessary, during dry conditions. Renewable energy credit pricing can impact a hydro operators economic incentives to upgrade equipment. For non-federal operators, upgrades tend to be considered during licensing.

- Upgrades can be based on the condition of the equipment, water availability, and the potential for an increase in efficiency.
- For non-federal operators, system upgrades are considered largely during relicensing.
- Some upgrades create a more efficient system that can operate with lower flows if necessary, to address recent drought / low flow situations.
- Some operators will upgrade multiple projects at one time, even if they are not due for an upgrade, to make sure there is consistency along the entire river.
- The higher the risk, the more contingency is built in when considering upgrades.
- It is important to consider renewable energy credit pricing, as it has an impact on future upgrades and can change annually.
- Timescales for upgrades tend to be driven by available incentives to build (i.e., funding and economic factors).

Collaboration and Coordination (Hydropower Operators)

Overview: Operators interact with a number of entities during the licensing/relicensing process or as part of ongoing federal project operations, and typically have standing work groups that convene regularly or around specific events (e.g., critical seasons for fisheries).

- Licensees often convene and work with federal (NMFS, USFWS) and state resource agencies, environmental NGOs, and others during the licensing process.
- Many operators have ongoing work groups or committees that include hydro operators, federal or state resource agencies, and NGOs / environmental groups.
- Some operators interact with NGO's in a limited role, when needed, and some try to establish a continuous dialogue with them to build relationships.
- Operators sometimes interact with local landowners and residents who have an interest the project.
- For the Columbia Basin, there is a Columbia River Technical Management Team (TMT) which provides leadership and coordination around water quality and temperature issues.
- The TMT meets most frequently during fish passage season. This group consists of action agencies and others: USACE, BOR, BPA, USGS, NMFS, tribes, and the States of Montana, Idaho, Washington, and Wyoming.
- One challenge operators encounter is communicating with diverse audiences. Some people are very knowledgeable (those who run their own models and can question other models), and others do not have scientific expertise. Communicating results and engaging diverse audiences can be challenging.

Forecasting for Operations (Hydropower Operators)

Overview: Forecasting plays an important role in planning for many hydropower operators and will become more critical as hydrologic conditions change and longer-term forecasting becomes more reliable (if possible).

- Use of historical data on DO helps in forecasting for operations.
- There is a lack of accuracy in longer-term forecasts, especially related to extreme conditions.
- Regionally-focused forecasts are needed, as well as a way to accurately predict long-term weather conditions.
- Some operators send out hydro forecasts daily based on models.
- Modeling and forecasting allows a federal operator to adjust the location of water withdrawals from reservoirs for those with water stratification.

Interactions with Regulatory Agencies (Hydropower Operators)

Overview: In many cases, operators do not interact regularly with regulatory agencies once past the licensing phase. Moving forward, it is important for federal agencies to cooperate and work together in identifying efficiencies in the licensing process. Furthermore, it is important for federal and state agencies to be able to share data with each other for monitoring purposes.

- Some operators interact with regulators on a regular basis (don't have a "licensing only" relationship). They maintain a continuous relationship building opportunity.
- On temperature and water quality once a license is issued, some operators do not interact regularly with regulatory agencies (interactions may only occur during licensing). They provide reports on the temperature and if temperature requirements are exceeded, they are reported to the agencies, but to date, in most cases no additional action is taken.
- Some operators provide data to state agencies for a certain period of time after putting new measures into place.

- Some suggest focusing on interagency cooperation for the best management of river flows for power production and environmental needs is worthwhile.
- If federal hydro operators are unable to meet an abnormal condition, they notify the state and federal agencies.
- Federal hydro operators and federal and state agencies share a lot of data with each other, as environmental monitoring on the rivers and reservoirs is a collaborative effort.
- In some cases, when states work with federal hydro operators, they then also serve an important role interfacing with the public and fishermen.

5. Decision Making Tools and Monitoring (Hydropower Operators and Regulatory Agencies)

Below is a list of models used by various entities.

Models in Use – Examples

- CE-QUAL 2E (TVA, Southern Company)
- CE-QUAL-W2 (http://www.ce.pdx.edu/w2/) (USACE)
- CHEOPS model - allows input of withdrawals, returns, inflows and outflows, etc. It's a very comprehensive water management model. (Duke Energy)
- HEC-ResSim (http://www.hec.usace.army.mil/software/hec-ressim) (USACE)
- HEC-RAS (http://www.hec.usace.army.mil/software/hec-ras) (USACE)
- Riverware (BPA, BOR, USACE, TVA)
- CALSIM (California)
- PLEXOS (WAPA)
- eTherm (EPRI)
- WARMF (EPRI)
- DELFT 3D program (nuclear plants) (TVA)
- Energy modeling (Brookfield Renewable)
- NOAA models (TVA)
- 1D and 2D reservoir models (TVA)
- CA basin planning tool (CA SWRCB)

Modeling Approaches (Hydropower Operators and Regulatory Agencies)

Overview: There are a variety of models used, but no "perfect" model. Many factors help determine which model an operator uses, including regionality and affected species in the area. The more detailed the model, the better for forecasting, but longer-term forecasting is challenging.

- Some agencies use their own modeling and then review licensees' models to determine appropriate terms and conditions.
- Generally, monitoring (and measuring) takes place between April 1 and October 30. In April, temperatures in the reservoir are stratified, and operators draw off the top. As the season progresses, operators draw lower, so in the fall when salmon return, they are releasing cool water.
- Water temperature monitoring data, volume data, flow rate, duration, and stratification are tools used to calculate flows.
- Most operators use a variety of models, mostly for flows, and not always for temperature.
- Model accuracy can vary widely.

- Regulators do not always require a model. Sometimes they do a qualitative analysis because the modeling cost for some smaller projects may not be warranted.
- Tools used for each project are very specific to the types of challenges each project encounters. Each project is unique with its challenges. One size does not fit all.
- Regionality and the severity of the issues and presence of species determines how detailed monitoring efforts are.
- Adaptive Management starts at the minimum allowed effect and makes adjustments to reach an optimal state while maintaining compliance.
- Federal hydropower operators will utilize a model to look at long-term (e.g., 50 years out) alternatives for operating the system.
- For some licensees, regulation does not necessarily limit operational flexibility, but can prove challenging. Projects that were licensed in the 1990s have different flow requirements than they would if relicensed today; with changing conditions, and flows that have significantly decreased.
- A powerful part of some models is the ability to graph and animate conditions inside of the reservoir, in terms of water temperature and DO, over the course of a year or a season (how the cold water layer diminished as the season heated up, how DO adjusted, etc.). This has allowed demonstrations to stakeholders highlighting what the operator proposed to do and whether it had a neutral or positive effect on the species and habitat.
- USACE has 2D modeling and is seeking to do an evaluation of where 2D and 3D models are appropriate.
- Some temperature reduction methods/tools include thermal curtains and temperature reduction devices to achieve cold water for downstream fisheries
- One licensee is only required to monitor DO and temperature, since with low-head dams, they cannot impact these. The monitoring is shared with USACE, who then uses the data, but no further actions are required. (The hydropower dam is at a USACE facility.)
- Some federal operators have a good understanding of cold water because they take information about the temperature profile in deep storage reservoirs, and model the tributaries and main stem of their system.
- In modeling, it's important to consider how fish passage affects the cost of the project. It would be helpful if PNNL's modeling framework incorporated fish passage as a water management strategy in addition to addressing downstream temperature for fisheries.
- Regulatory agencies look at the baseline water temperature information (i.e., a year of water quality monitoring data. If reservoirs are involved, they may also request profiles from the summer when reservoirs are stratified.
- A licensee may develop a model to try and maintain their existing infrastructure to assure stakeholders that there is not a true water quality risk.
- There is a need to address ice formation models (in Alaska). In the winter, different things go on under the ice and developers try to determine how the project would affect ice formation but there are no existing models that can do this.
- Models now are too coarse of scale to look 20-50 years out. Coarser tools put agencies in the position of being very conservative.
- For equipment replacement and risk modeling, one licensee uses a risk informed decision making process; for each decision, it ranks the risk score based on factors (safety – both

employee and public safety; environmental risk, and reliability; etc.) then runs an algorithm that summarizes the overall risk score for the project.

Use of Models in Licensing (Hydropower Operators and Regulatory Agencies)

Overview: Operators utilize different kinds of models depending on which stage of the licensing or long-term planning processes they are in.

- For non-federal operators modeling is typically used during licensing when longer-term planning occurs.
- A common approach for several licensees include models for multiple years over the life of its license. For monitoring for compliance during operations/implementation of the license, they are typically on an annual modeling basis (a 12-month model that is updated every 2-3 months). They'll develop seasonal models to optimize generation throughout the year, and also do a 7-10 day basis to get a real-time estimate (weekly modeling).
- For federal hydropower operators they use models for longer-term forecasting and for day to day operations.

Model Improvement Needs (Hydropower Operators and Regulatory Agencies)

Overview: Operators use many different models but are looking for something that is comprehensive and which can be used in conjunction with existing models. It is important for operators to be able to do longer-term forecasting and they need improved resolution to do so.

- A modeling framework that is region-specific is important because every region has different characteristics (different wet and dry seasons, endangered species, etc.).
- A comprehensive model from PNNL would be helpful. Many existing models are hard-wired because they are trying to optimize for power generation; having an additional framework would help understanding how that optimization would be useful.
- Probabilistic types of models (rather than honing in on a specific answer) would be helpful for longer-term modeling.
- Sometimes operators use proprietary models which makes access to assumptions and understanding by the agencies challenging.
- Some operators would like to be able to look 50 years ahead, with the ability to adjust the model based on environmental factors.
- It is difficult to separate flow and downstream temperature management. This would need to be examined closely. One way to do this is to model flow and then, given flows, run the temperature models to see what the consequences are.
- There is a need to model pristine, untouched rivers, to gain a baseline for measuring impacts; this should also provide data that reflects extreme conditions such as droughts and floods.
- Tools are needed to enhance HEC-RAS models that better align real-time and long-term models.
- Federal hydro operators would like to see expertise around predicted rainfall incorporated more into the models; it could inform assumptions or scenarios.
- More 2D models would help with decision making. 3D models can be challenging in regions like the Columbia River Basin, but are useful on smaller, focused areas like a forebay.
- The Columbia River System is very complicated, and simplified models could and have caused problems. Given the complexity, if a model works in this system, chances are that it will work

anywhere else in the US. Over-simplified or inappropriate models might produce inaccurate results that cause concern.
- If PNNL's framework could be a simple interaction between an applicant operations model and then address various water quality factors that would be helpful.
- There is concern that creating new models will complicate the system of existing models. Operators are looking for PNNL to more clearly define the scope of this project.

6. Regulatory Agency Feedback

Regulatory Responsibilities

Overview: Temperature requirements vary based on the region and regulatory agencies have to balance temperature requirements with other conditions of the license (e.g., fisheries, recreation, etc.)

- Licensing and Compliance
  - The relicensing process can include NGOs, federal and state agencies, and other stakeholders in the process.
  - Often (especially in the West), there is a temperature requirement in the license, but it is bundled and primarily managed with flow release requirements.
  - Some state authorities factor temperature and weather conditions into the licensing process (temperature requirements within the standard).
  - Temperature is a difficult and expensive parameter for which to mitigate (usually involves building a tower because infrastructure is usually set up to pull from a certain depth); the instream flow requirement is easier to meet.
  - The primary fix for water temperature is more flow.
  - With relicensing an existing project, warming water downstream is already part of the environment and can be mitigated for; for original licenses (e.g., building a new project), an area is being made worse than it would have otherwise been, so it may lead to different requirements.
  - Considering fish passage as part of long-term water management is important.
  - When licenses do not have requirements for operators to adjust their temperature, it could be problematic in that no enforcement is taken.
  - Operators need to make sure they are meeting the temperature that was decided on at the time of licensing.
  - NOAA is tasked with managing fish, and, pursuant to hydropower projects, it has a responsibility to review impacts and make recommendations. Dams have a significant effect on water quality.
  - FERC has limitations on how much it can change a license mid-way through its duration. License re-openers are rare.
  - Sometimes temperature exceedances are considered violations and are documented by the State. Enforcement is discretionary in California.
  - There is controversy over inter-related, multipurpose projects for irrigation because the State is limited on what it can do for fishery purposes. The release of water from the reservoir that has generation on it is driven by irrigation demand so it is challenging to determine how to encompass all of these impacts.

- Dams can alter or shift the seasonal water temperature regime, which can negatively affect fish.
- It is important to consider the impacts of water temperature on fish disease; this can be caused by crowding and elevated temperatures. Both are a result of low flow releases from dams.
- Some licenses issued by FERC include license conditions to reopen the license due to changed hydrologic conditions, but FERC rarely takes this action.

- Monitoring /Compliance
  - State regulators use real-time monitoring and rain forecast projections to help balance their management of a project.
  - In all cases, FERC requires baseline water temperature information (at a minimum, a year of water quality monitoring data). The severity of a potential impact (e.g., are there ESA-listed species, existing warming problems, etc.) could cause FERC to ask for more data.
  - PNNL will not evaluate temperature model results in terms of State water quality standards. PNNL will only use indicators such as temperature thresholds (e.g., days above 20 degrees Celsius, etc.).

Interactions with Hydro Operators

Overview: Providing an overarching framework can help guide operators in the operations and management of their dam.

- Federal and State resource agencies are sometimes brought in during the settlement agreement process to address challenges before the applicant files its license application.
- Licensees need a framework/guidance on what questions they should ask contractors before hiring them. Inexperienced utilities do not always know what to look for in hiring a contractor. If this modeling effort could provide a framework and inform licensees, it could be helpful.

Appendices

- Appendix A: Survey Topics for Operators
- Appendix B: Survey Topics for Regulatory Agencies
- Appendix C: Survey Topics for NGOs

Appendix A: Survey Topics for Operators

Hydropower investment, operations and potential regulatory decision making related to water temperature

1) Please provide an overview of how you prioritize system upgrades, and operational decisions and whether water temperature (or if not water temperature, then water quality generally) is considered in your decision making today.
    a. Please share an overview below.
    b. If you do not consider water temperature in your operational and system upgrade decisions, please explain, why not?

Planning

1) Please list the most important aspects of, or factors for, water management that impact your planning (e.g. water availability, extreme events, water quality, water temperature, etc.).
    a. Please list the factors below, with the most important listed first, and the least important listed last.
    b. What are the timescales you plan for when considering each of these elements? Please list below.
    c. What physical scales do you plan for each factor (e.g. electric grid resolution, river segment length, etc.)? Please list below.
        i. Do you plan only for your system or do you coordinate with other entities to take a broader look (e.g. single/multiple plants within your system, or a broader look across a basin/region)? Please describe below.
    d. What level of risk is acceptable for each? How do you calculate risk?
    e. Which of these elements poses the biggest challenge? Why?
        i. For example, what are common tradeoffs you are confronted with and what metrics do you use to resolve them?
2) Are you planning for water temperature? If so, where does it rank on your list of planning priorities and what metric(s) do you evaluate? (If not already addressed above). If not, why not?
3) Have you experienced any historical extreme temperature conditions that were unexpected? If so, how did these conditions impact operations, meeting regulatory requirements, or planning?

Decision Making Tools and Monitoring

1) What decision making and modeling tools are you currently using for water temperature planning (or if not temperature, water quality more generally)?
    a. What inputs do these tools require?
    b. What information is available, but is not currently used by these tools?
    c. Are these tools used for real-time operational decisions, for longer-term planning, or for regulatory compliance?
    d. What are the advantages and disadvantages of these tools?
    e. What would you change about these tools? What functions do you wish worked better?
2) Can you describe your water temperature monitoring efforts? Or water quality monitoring efforts?
    a. How do you use the data? (for operations, regulatory compliance, planning)?
3) What features do you prioritize when selecting a tool?
    a. What scales are appropriate in a tool?
    b. What confidence intervals are acceptable in a tool?
    c. How can uncertainty around results best be represented?
    d. What data resolution is preferred in a tool?
4) Are there region-specific needs that your current tools do not account for?
5) Do you explicitly consider hydrologic change in your monitoring and operational decisions?
6) Do you explicitly consider extreme heat wave conditions in your planning?
7) If not already described above, what factors do you monitor for operational decision making or tracking regulatory compliance? Please describe.
8) What regulatory requirements most often limit operational flexibility?

Interactions with Regulatory Agencies

1) Please describe in general your relationships with local/state agencies and federal agencies as they relate to water temperature requirements or other water quality criteria.
    a. How do these relationships relate to meeting water quality criteria (401 water quality entity, or others?)?
2) Please explain if you have water temperature licensing and permitting requirements (protect, mitigate, and enhancement licensing requirements/permit conditions).
    b. Please explain how you meet these requirements and how these connect to your operational upgrades and operational decisions and tools.

3) How often do you interact with regulatory agencies outside of licensing/relicensing or permitting?

4) What information, if any, do you seek from regulatory agencies and are they able to provide it, as it relates to water temperature and potential impacts on species or the environment (during relicensing/permitting and during operations)?

    a. How do you receive this information?

5) What organizations do you interact with in addition to regulatory agencies associated with water temperature and associated resource/water quality topics (environmental NGOs, others)?

    a. Describe the nature of these interactions: when/how you communicate with them, how much is involved on water temperature resource impacts, etc. (during relicensing/permitting and during operations/implementation of the license/permit).

    b. Do your interactions include sharing decision tool results or alternatives?

Other

1) When you consider achieving water temperature objectives and your hydropower investments or upgrades, operations and regulatory requirements, are there other important topics or thoughts that you'd like to share?

2) Similarly, when you consider decision making tools to support operations, upgrades or investment decisions and achieving regulatory requirements, are there additional thoughts on the tools you have that are most valuable, or the features or tools that would be most helpful to you?

3) Any additional thoughts or suggestions for models/decision support tools to enhance water temperature and water quality decisions for operations, meeting regulatory requirements or upgrades in your hydropower projects?

Appendix B: Survey Topics for Regulatory Agencies

Regulatory Responsibilities

1) Could you please describe your agency's regulatory mission related to water resource management and the desired objectives/outcomes of their activities? How does your agency address water temperature?
    a. Is it considered as an attribute of water quality?
    b. If you address water temperature, what are the resource objectives you are targeting that are impacted by water temperature (e.g., ESA fishery goals, other).
    c. Please describe your responsibilities/role during licensing of hydropower projects or other activities related to hydropower operations (compliance).
2) What other water quality issues does your agency address and for what reason? (e.g., riparian habitat, sediment, etc.)
3) What are some of the challenges you've encountered during the licensing process, if any, associated with water quality and water temperature topics?
4) Please describe your interactions during implementation of the license/permit process to ensure that compliance mitigation measures are/will be met.
    a. What information is provided and is it provided by the applicant or licensee?
    b. What other types of information are used?
5) Is modeling used as part of compliance and ongoing operations?
    a. If so, what are the most important attributes of those models? Does the applicant provide these models? How are the models and related data sets validated/qualified?
6) What other federal or state agencies play an active role in licensing and compliance that need water quality and water temperature information?

Interactions with Hydropower Operators

1) Please describe in general your interactions with hydropower operators or licensees as they relate to water temperature requirements or other water quality criteria (quality of the relationship; when/how do you interact with them; frequency; typically around what objectives/purposes?).
    a. If not addressed above, please describe how these interactions relate to meeting water quality criteria (401 water quality entity, or other regulatory requirements that connect to water quality topics?)?
    b. If not addressed above, please describe how you interact on water temperature topics with the hydropower operator? (i.e., is water temperature as part of water quality addressed? For what purposes? When/how is it addressed typically?)

2) How often do you interact with hydropower applicants or operators during licensing/relicensing or permitting? (i.e., calls, meetings, written exchanges, frequency, over how many years, etc.)
3) How often do you interact with the hydropower operator after licensing/permitting?
4) Information Needs
    a. What information is most useful to you in meeting your water quality and water temperature needs for regulatory purposes?
    b. What types of information does the applicant/hydro operator provide? Is it what you need?
    c. Have you used modeling information related to water quality and water temperature? If so, please describe. What features or attributes of the modeling information is most useful for informing you water quality and water temperature decisions for protection, mitigation and enhancement measures or for compliance?
    b. How do you share this information internally, or with other agencies?

Other

1) In your role as a regulator, are there other important topics or thoughts that you'd like to share regarding the licensing process?
2) Any additional thoughts or suggestions for models/decision support tools to enhance water temperature and water quality decisions for operations, meeting regulatory requirements or upgrades for hydropower projects?

Appendix C: Survey Topics for NGOs

Interactions with Regulatory Agencies & Hydropower Operators

1) How and when does your organization get involved in the licensing/relicensing or permitting process?

2) Please describe your relationships with local/state agencies and federal agencies as they relate to water temperature requirements or other water quality criteria.

3) Please describe in general your interactions with hydropower operators or licensees as they relate to water temperature requirements or other water quality criteria (quality of the relationship; when/how do you interact with them; frequency; typically around what objectives/purposes?)
    a. Do you participate in adaptive management groups for any projects?

4) What type of issues is your organization specifically interested in, as they relate to water temperature (e.g., flow requirements, mitigation)?

5) Modeling Information
    a. Do federal or state agencies independently develop their own modeling tools related to water quality and water temperature? If so, please describe.
    b. Do applicants independently develop their own modeling tools related to water quality and water temperature? If so, please describe.
    c. Does your organization use its own models or does it use models developed by another entity?
        i. If so, whose models do you use? What are the most important attributes of those models?
6) Has your organization considered future issues related to water quality or water temperature that may have an impact on hydropower compliance and investment?

Role and Information Sharing

1) How does your organization address water temperature?

2) What other type of resource issues does your organization address and for what reason (e.g., fishery health)?

3) Do you share information around the monitoring that applicants do?
    a. If so, how do you share this information and with whom do you share it?

Other

1) Any additional thoughts or suggestions for models/decision support tools to enhance water temperature and water quality decisions for operations, meeting regulatory requirements or upgrades for hydropower projects.